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Weak signals in Science and Technologies 2019

Analysis and recommendations

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

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Contents

Abstract

JRC has developed a quantitative methodology to detect very early signs of emerging technologies, so called "weak signals of technology development". Using text mining and scientometric indicators, 256 of these weak signals have been identified on the basis of scientific literature and have been reported earlier this year in a JRC technical report. The purpose of this follow-up report is to provide a European perspective and to provide recommendations for policy makers. Europe shows vulnerabilities in 179 of these weak signals, further analysed in the present report.

Executive summary

This report presents the results of an analysis performed on 256 weak signals in technology development detected through applying text mining techniques to a dataset of scientific publications. The aim of the present analysis is to identify points of focus for policy-makers, the research community, and stakeholders of technological development.

The main conclusions from the analysis are:

- There is a risk of technology dependency of Europe in 98 of the weak signals.
- There is no or little R&D activities in Europe for ¼ of the weak signals (64).
- Research in Europe should be reinforced for ¼ of the weak signals (66).
- Research ecosystems in Europe are fragmented in more than a third of the weak signals (97).
- Patenting incentives should be put in place for more than half (136) of the weak signals.
- 42 research ecosystems might be impacted by the Brexit.
- There are knowledge monopolies or duopolies in 8 weak signals.

It also appears that Europe is strong in weak signals related to social sciences, health, and environment, but shows some vulnerabilities in Physics & Engineering, Biology, ICT, Viruses, Energy, and Materials. Looking at sub-topics, Europe is strong in weak signals related to biomaterials, microbiology, neurosciences, new medicines, and digital social sciences but vulnerable in weak signals related to the 27 other sub-topics, including perovskite, solar cells, 5G, Internet of Things, 3D printing, Neural Networks, Viruses, new materials (2D materials, nanomaterials, metasurfaces, new catalysts).

Organisations leading R&D are most often from China and the US. Overall, a reasonable proportion of European companies are taking part in research and development efforts in the various weak signals. There are as many small industrial players in Europe than in the other main territories, but fewer large size companies. Organisations from China and the US are the most frequent in the ranking of the top 10 organisations for each weak signals. Except for the weak signals related to Environment, European organisations do not appear often in these top 10.

Finally, Europe suffers from a low capacity of transformation of knowledge into patents compared to the US, China, Japan, or South Korea. This is observed for many weak signals, even when European companies are very active. Chinese organisations are very active in patenting but only a small number of the patents filed in China (6.22%) are extended to another patent jurisdiction. This proportion of patents extended is much higher for South Korea, the US, Japan, and for the EU (up to 80%).

1 Introduction

For an organisation like the Joint Research Centre acting at the interface between science, policy making and society, the early identification of emerging technologies is key to support the design and implementation of European policies, which need to take into account the potential of these new technologies to create opportunities or disruptions. To complement its current foresight capacity, which is mostly based on qualitative technology monitoring and assessment, JRC is developing new analytic techniques based on text mining applied to large datasets.

The present report analyses the 256 weak signals in technology development identified with the new quantitative methodology developed by JRC and presented in the report "Weak signals in Science and Technologies - 2019 Report"[1]. This quantitative methodology relies on text mining algorithms and was conceived to identify early signals of new technological developments, as well as new applications of existing technologies. The weak signals of the 2019 exercise (see figures 1 and 2) were detected by applying this new text mining methodology on a corpus of scientific publications covering the period 01/01/1996 to 31/12/2018.

The 256 weak signals can be examined in detail here:
https://www.timanalytics.eu/TimTechPublic/main.jsp?dataset=s_1231

The aim of the analysis is to better understand the positioning of Europe for each of the weak signals and to make recommendations. The following types of questions are considered: Does Europe produce knowledge? Are European organisations active in innovation and patenting? Is there a risk for future technology dependency? Will Brexit have an impact on the research environment? The weak signals can be sorted in one of the four following categories: 1) Europe is weak in producing knowledge, 2) Europe is weak in patenting, 3) Europe is strong in producing knowledge, and 4) Europe is strong in patenting. In particular, the analysis will focus on the weak signals where Europe is producing little knowledge or patents (categories 1 and 2) and those which could be impacted by Brexit.

In a next step, the results of the present exercise will be submitted to experts in Europe and more widely in other regions of the world. Through an iterative and structured process, the significance and future impacts of the identified weak signals on the European economy and society will be evaluated. The objective is to combine the results of the new JRC quantitative methodology to detect weak signals with expert consultations to reach an assessment of the European positioning and competitiveness in these technologies, their possible widespread development, including needs for further research and investments, and their social and ethical acceptance. The ultimate aim is to identify a set of key policy recommendations and legislative opportunities for European stakeholders and policymakers to act upon.

The detection of weak signals using text mining techniques on large data corpuses will be integrated to existing foresight and anticipation mechanisms in JRC to support services and policy Directorate Generals of the European Commission in designing European policies.

[1] JRC 2019.5552, EUR 29900 EN, ISBN 978-92-76-12386-6, ISSN 1018-5593, doi: 10.2760/858426

2 List of weak signals as identified in JRC report “Weak signals in Science and Technologies – 2019 Report”

Figure 1: wheel of weak signals, per topic.

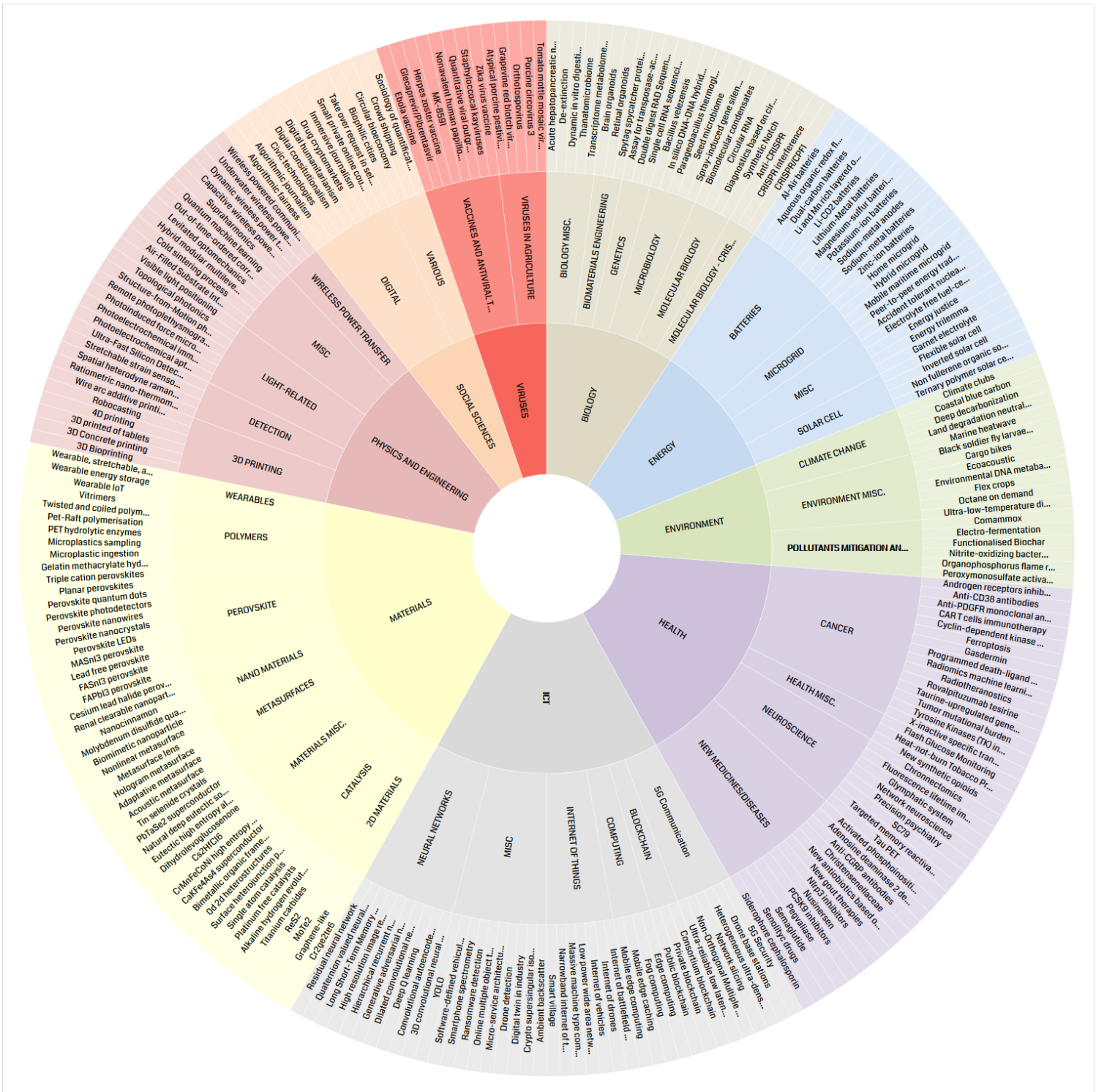


Figure 2: List of weak signals per topic.

BIOLOGY

BIOMATERIALS ENGINEERING
Melt Electrowriting
Brain organoids
Retinal organoids
Spytag spycatcher protein ligase

GENETICS
Assay for transposase-accessible chromatin sequencing
Double digest RAD Sequencing
Single cell RNA sequencing

MICROBIOLOGY
Bacillus velezensis
In silico DNA-DNA hybridization
Parageobacillus thermoglucosidasius
Seed microbiome
Spray-induced gene silencing

MOLECULAR BIOLOGY
Biomolecular condensates
Circular RNA
Diagnostics based on circular RNA
Synthetic Notch

MOLECULAR BIOLOGY - CRISPR
Anti-CRISPR
CRISPR/CPF1
CRISPR interference

BIOLOGY MISC.
Acute hepatopancreatic necrosis disease
De-extinction
Dynamic in vitro digestion
Thanatomicrobiome
Transcriptome metabolome wide association

HEALTH

NEUROSCIENCE
Chronnectomics
Fluorescence lifetime imaging ophthalmoscopy
Glymphatic system
Network neuroscience
Precision psychiatry
SC79
Targeted memory reactivation
Tau PET

NEW MEDICINES/DISEASES
Activated phosphoinositide 3-kinase (PI3K) δ syndrome
Adenosine deaminase 2 deficiency
Anti-CGRP antibodies
Christensenellaceae
New gout therapies
Nlrp3 inhibitors
Nusinersen
Octapeptins
PCSK9 inhibitors
Pegvaliase
Semaglutide
Senolityc drugs
Siderophore cephalosporin

CANCER
Androgen receptors inhibition
Anti-CD38 antibodies
Anti-PDGFR monoclonal antibodies
CAR T cells immunotherapy
Cyclin-dependent kinase (CDK) 4/6 inhibitors
Ferroptosis
Gasdermin
Programmed death-ligand 1 (PD-L1) inhibitors
Radiomics machine learning
Radiotheranostics
Rovalpituzumab tesirine
Tyrosine Kinases (TK) inhibitor
Taurine-upregulated gene 1 (TUG1)
Tumor mutational burden
X-inactive specific transcript (Xist)

HEALTH MISC.
Heat-not-burn Tobacco Product
Flash Glucose Monitoring
New synthetic opioids

MATERIALS

2D MATERIALS
Graphene-like
- Antimonene
- Arsenene
- Bismuthene
- Borophane
- Borophene
- Phagraphene
- Phosphorene
- Stanene

Cr2ge2te6
MoTe2
ReS2
Titanium carbides

WEARABLES
Wearable flexible electronics
Wearable energy storage
Wearable IoT

NANO MATERIALS
Biomimetic nanoparticle
Renal clearable nanoparticles
Nanocinnamon
Molybdenum disulfide quantum dots

CATALYSIS
Alkaline hydrogen evolution reaction
Platinum free catalysts
Single atom catalysis
Surface heterojunction photocatalytics

POLYMERS
Gelatin methacrylate hydrogel
Microplastic ingestion
Microplastics sampling
PET hydrolytic enzymes
Pet-Raft polymerisation
Twisted and coiled polymer muscles
Vitrimers

METASURFACES
Acoustic metasurface
Adaptative metasurface
Hologram metasurface
Metasurface lens
Nonlinear metasurface

PEROVSKITE
Cesium lead halide perovskites
FAPbI3 perovskite
Lead free perovskite
FASnI3 perovskite
MASnI3 perovskite
Triple cation perovskites
Perovskite LEDs
Perovskite quantum dots
Perovskite nanocrystals
Perovskite nanowires
Perovskite photodetectors
Planar perovskites

MATERIALS MISC.
0d 2d heterostructures
Bimetallic organic frameworks
CaKFe4As4 superconductor
CrMnFeCoNi high entropy alloys
Cs2HfCl6
Dihydrolevoglucosenone
Eutectic high entropy alloys
Natural deep eutectic solvents
PbTaSe2 superconductor
Tin selenide crystals

VIRUSES

VIRUSES IN AGRICULTURE
Atypical porcine pestivirus
Grapevine red blotch virus
Orthotospovirus
Porcine circovirus 3
Tomato mottle mosaic virus

VACCINES AND ANTIVIRAL TREATMENT
Ebola vaccine
Glecaprevir/Pibrentasvir
Herpes zoster vaccine
MK-8591
Nonavalent human papillomavirus vaccine
Quantitative viral outgrowth assay for HIV
Staphyloccocal kayviruses
Zika virus vaccine

ICT

5G Communication
5G Security
Drone base stations
Heterogeneous ultra-dense networks
Network slicing
Non-Orthogonal Multiple Access
Ultra-reliable low latency communication

BLOCKCHAIN
Consortium blockchain
Private blockchain
Public blockchain

INTERNET OF THINGS
Internet of battlefield things
Internet of drones
Internet of vehicles
Low power wide area network
Massive machine type communication
Narrowband internet of things
Smart village

NEURAL NETWORKS
3D convolutional neural networks
Convolutional autoencoders
Deep Q learning
Dilated convolutional neural network
Generative adversarial networks
Hierarchical recurrent neural network
High resolution image recognition by NN
Long Short-Term Memory neural network
Quaternion valued neural network
Residual neural network

COMPUTING
Edge computing
Fog computing
Mobile edge caching
Mobile edge computing

MISC
Ambient backscatter
Crypto supersingular isogeny
Digital twin in industry
Drone detection
Micro-service architecture
Online multiple object tracking
Ransomware detection
Smartphone spectrometry
Software-defined vehicular networks
YOLO

PHYSICS AND ENGINEERING

LIGTH-RELATED
Photoelectrochemical aptasensors
Photoelectrochemical immunosensors
Photoinduced force microscopy
Remote photoplethysmography
Structure-from-Motion photogrammetry
Topological photonics
Visible light positioning

DETECTION
Ratiometric nano-thermometers
Spatial heterodyne raman spectrometer
Stretchable strain sensors
Ultra-Fast Silicon Detectors

3D PRINTING
3D Bioprinting
3D Concrete printing
3D printed of tablets
4D printing
Robocasting
Wire arc additive printing

WIRELESS POWER TRANSFER
Capacitive wireless power transfer
Dynamic wireless power transfer
Underwater wireless power transfer
Wireless powered communication networks

MISC
Air-Filled Substrate Integrated Waveguide
Cold sintering process
Hybrid modular multilevel converter
Levitated optomechanics
Out-of-time-ordered correlators
Quantum machine learning
Supraharmonics

ENERGY

MISC
Accident tolerant nuclear fuel
Electrolyte free fuel-cell
Energy justice
Energy trilemma
Garnet electrolyte

SOLAR CELL
Flexible solar cell
Inverted solar cell
Non fullerene organic solar cell
Ternary polymer solar cells

BATTERIES
Al-Air batteries
Aqueous organic redox flow batteries
Dual-carbon batteries
Li and Mn rich layered oxides
Li-CO2 batteries
Lithium-Metal batteries
Magnesium-sulfur batteries
Potassium-ion batteries
Sodium-metal anodes
Sodium-metal batteries
Zinc-ion batteries

MICROGRID
Home microgrid
Hybrid microgrid
Mobile maritime microgrid
Peer-to-peer energy trading

SOCIAL SCIENCES

DIGITAL
Algorithmic fairness
Algorithmic journalism
Civic technologies
Digital consitutionalism
Digital humanitarianism
Drug cryptomarkets
Immersive journalism
Small private online course
Take over request in self driving

VARIOUS
Biophilic cities
Circular bioeconomy
Crowd shipping
Sociology of quantification

ENVIRONMENT

CLIMATE CHANGE
Climate clubs
Coastal blue carbon
Deep decarbonization
Marine heatwave
Land degradation neutrality

POLLUTANTS MITIGATION AND DEGRADATION
Comammox
Electro-fermentation
Functionalised Biochar
Nitrite-oxidizing bacterium suppression
Organophosphorus flame retardant
Peroxymonosulfate activation

ENVIRONMENT MISC.
Black soldier fly larvae biodiesel
Cargo bikes
Ecoacoustic
Environmental DNA metabarcoding
Flex crops
Octane on demand
Ultra-low-temperature district heating

3 Methodology for the analysis

The 256 weak signals detected have been reconstructed in TIM Technology, a technology monitoring system developed and operated by JRC, using semantic searches. As a result, each weak signal in TIM Technology is composed of a group of documents retrieved by the search query in a patent database (Patstat), a scientific literature database (Scopus), and a database containing R&D grants funded by the Framework Programme for Research of the European Commission (Cordis). Bibliometric indicators are then calculated on the basis of the documents retrieved to analyse and classify the weak signals.

3.1 Indicators

The following indicators are used in the analysis of the weak signals:

- Total number of scientific publications worldwide;
- Number of scientific publications by European organisations (including UK);
- Number of publications for organisations in Europe (all Member States except UK);
- Total number of patents families worldwide;
- Number of patent families by organisations in Europe;
- The fragmentation of the research environment in Europe, calculated by dividing the number of organisations from Europe active in research (i.e. publishing scientific publications) by the number of co-publications between these organisations. A fragmented research landscape is a research environment where research organisations do not collaborate together (few or no co-publications), while a collaborative landscape is characterised by a lot of co-publications between the organisations active in research.

It should be noted that the indicators for patents are considering only the number of patent families (a set of patents applied in various countries to protect a single invention) and do not use proxies related to their importance, such as the essential patents or the triadic patents (a series of corresponding patents for the same invention filed at the European Patent Office, the US Patent Office, and the Japan Patent Office).

3.2 Entity disambiguation

A common issue in scientometrics is the disambiguation of entity names i.e. merging all the name variants of an organisation from different documents and/or sources into one unique name. Algorithms that automatically compare the entities names with a list of known organisations are used to ensure a reasonable level of disambiguation of organisation name variants. This process is complemented by manual cleaning when necessary. Although this allows reaching high levels of disambiguation of the data related to organisations, it must be noted that the accuracy of the entity matching process in TIM never reaches 100%.

To estimate the accuracy of the entity matching process, 10 randomized samples of 100 name variants have been extracted from the raw metadata in our system (patents in Patstat, scientific publications in Scopus, EU grants in Cordis), and compared manually to their unique name as resolved by the TIM entity matcher. The average accuracy of the process as measured by this sampling technique reaches 93.8% with a standard deviation of 2.15. Although the disambiguation of entities names is not error-free, the result is accurate enough to allow the observation of trends in science and technologies.

3.3 Categories of weak signals

The focus of the present analysis is made on weak signals that are problematic from a European perspective. The following vulnerabilities have been considered:

- Low knowledge production (Europe representing less than 25% of the scientific publications for the weak signal). The number of publications from European organisations is used as a proxy to knowledge production. There are of course other types of knowledge produced that are not considered in this study (number of PhD thesis, informal knowledge within organisations …). The assumption is: the higher the number of scientific publications for a country/territory, the higher the knowledge production for that country/territory.

- Low transformation of knowledge into innovation (less than 25% of the patents belong to organisations in Europe). The number of patents is used as a proxy to the capacity to innovate. The following assumption is made: the higher the number of patents, the higher the capacity of a country/territory to transform academic knowledge into patents (technological products or services). Innovation is a complex mechanism and patents only reflect the capacity for technological innovations. In addition, patenting strategies can vary from one country to another (some countries have strong incentives in place to promote patenting), from one culture to

another, or from one technological field to another. The number of patents should therefore be taken as an indication of the capacity to innovate, and not as a definitive and accurate measure of innovation.

- A significant proportion of knowledge and/or patents originating from the UK. This is considered as a vulnerability in view of Brexit, which might isolate UK institutions and companies from their counterpart in Europe. It is likely that collaboration at a scientific level will continue, but research environments might be disturbed by the transition towards Brexit. In addition, Brexit could represent a loss of knowledge from the European perspective. We consider here that the weak signals that could be impacted by Brexit are those for which more than 40% of the scientific publications or of the patents from Europe involve at least one organisation from the UK (author or applicant). These vulnerabilities could potentially lead to technology dependency of Europe in various new emerging technological areas.

- In addition, two characteristics of the research ecosystem in Europe are considered as vulnerabilities:
  - A low level of collaboration in knowledge production (i.e. number of co-publications). This level is calculated by the fragmentation of the network graph of publishing organisations. The network is considered as fragmented when the fragmentation indicator is above 1.
  - Imbalances in strength for the different actors in Europe (e.g. monopolistic situation when one organisation dominates)

The analysis is designed to investigate the above mentioned vulnerabilities. In a first step, the indicators described at point 3.1 are calculated for each weak signal, which allows for their classification into the four categories described in figure 3: 1) EU is weak in knowledge production (and in patenting), 2) EU is weak in patenting, 3) EU is strong in knowledge production, 4) EU is strong in knowledge production and in patenting. In a second step, weak signals belonging to the categories "EU weak in KW" and "EU weak in IP" are analysed further in order for recommendations to be made (see chapter 4), while the weak signals of the categories "EU strong in KW" and "EU strong in KW and IP" are only analysed further if a possible impact from Brexit is detected. The report also contains an additional analysis of some of the so-called "persistent" weak signals (for which documents have been retrieved over many different years), which may seem counterintuitive for technologies that are supposed to emerge. In total, 190 weak signals are looked at in this report.

Figure 3: Categories chosen for the analysis of weak signals

Category	Description	Includes weak signals that have			
		% scientific publications from Europe	Number patents worldwide	% patents from Europe	
EU weak in KW	Contains the weak signals for which there is little knowledge production in Europe	< 25 %	< 5	-	Brexit risk only
		< 25 %	> 5	< 25 %	Full Analysis
EU weak in IP	Contains weak signals for which there is knowledge produced but little/no patents from Europe while patents are detected for other countries	> 25 %	> 5	< 25 %	Full Analysis
EU strong in KW	Contains weak signals for which there is little/no patents worldwide and for which EU organisations produce scientific publications	> 25 %	< 5	-	Brexit risk only
EU strong in KW and IP	Contains the weak signals for which there is knowledge and patents in Europe	> 25 %	> 5	> 25 %	Brexit risk only

3.4 Recommendations

The Joint Research Centre acts at the interface between science, policy making and society, and supports the design and implementation of European policies. Within the context of that mission, early identification of emerging technologies is an important step to ensure economic opportunities for Europe or mitigate technological disruptions. Recommendations are therefore made to stakeholders of the European science and innovation ecosystem to support adequate decision-making regarding for example funding of research, support mechanisms to innovative industry, or investment opportunities.

5 types of recommendations have been made for the weak signals for which Europe shows some vulnerabilities:

- Measures should be put in place to **create R&D activities**: For weak signals where Europe lags behind in knowledge production.

- Measure to further **reinforce R&D activities** should be considered for weak signals where there is production of knowledge in Europe but for which there is fierce competition with other countries/territories.

- Measures to **develop the network** of research organisations and increase scientific collaboration should be put in place. For weak signals where actors from European are not collaborating.

- Measures to **foster innovation** and encourage innovation and patenting should be put in place for weak signals where Europe lags behind in patenting. Patenting of innovations developed in Europe are essential if Europe wants to remain technologically independent in strategic technologies.

- Measures to **support** the R&D ecosystem in Europe **during Brexit**: for weak signals for which the research ecosystem in Europe might be disturbed by the departure of UK organisations from the European Union.

In addition, two risks are flagged:
- **Risk of technological dependency** when there is very little knowledge developed in Europe, or very few patents owned by European organisations, or very few organisations from Europe active in R&D compared to other countries.
- Risk related to "**Knowledge imbalance**" when knowledge in Europe is concentrated in one or two organisations.

3.5 Considerations on the patent data

A steep increase in the number of patents from China is observed for many of the weak signals detected. Without negating the reality of Chinese innovation capacity in the various weak signals that have been detected, some particularities related to patent data call for considering the number of patents for the last 24 months with some caution. First, and for most of the patent authorities, a systematic decrease in the number of patents for years 2017 and 2018 can be observed. This is inherent to the patent system and related to the 18 month delay between the first filing of a patent and its publication. An extra delay can be caused by the frequency at which national patent offices send their patent data to the European Patent Office (EPO) for integration in the Patstat database. Figure 4 shows the effect of these two factors on the database of patents used for the analysis.

Figure 4: number of patents families per year and related relative proportions for the 5 biggest territories (EU = patents filed in the 28 Member States).

Countries	Number of patents families					
	2013	2014	2015	2016	2017	2018
China	208159	172242	185757	264384	311289	118162
Japan	141504	144440	178683	190996	78289	4211
United States of America	133964	123297	120846	118149	67973	2238
Republic of Korea	91510	86706	87219	89352	47406	6168
EU	87535	83852	84280	83237	49734	7081
Sum	662672	610537	656785	746118	554691	137860
	Percentage patent families by country per year					
China	31%	28%	28%	35%	56%	86%
Japan	21%	24%	27%	26%	14%	3%
United States of America	20%	20%	18%	16%	12%	2%
Republic of Korea	14%	14%	13%	12%	9%	4%
EU	13%	14%	13%	11%	9%	5%

The higher proportion of patents from China observed for the years 2017 and 2018 is the exception to the above-mentioned decrease. This is confirmed by figures 5 and 6, using data compiled by the EPO[2] for the present report and shown below.

Figure 5: total number of patents applications for the year 2018 contained in PATSTAT Global - 2019 Spring Edition. Figures for the Korean, Japanese, US, Chinese, and European patent offices

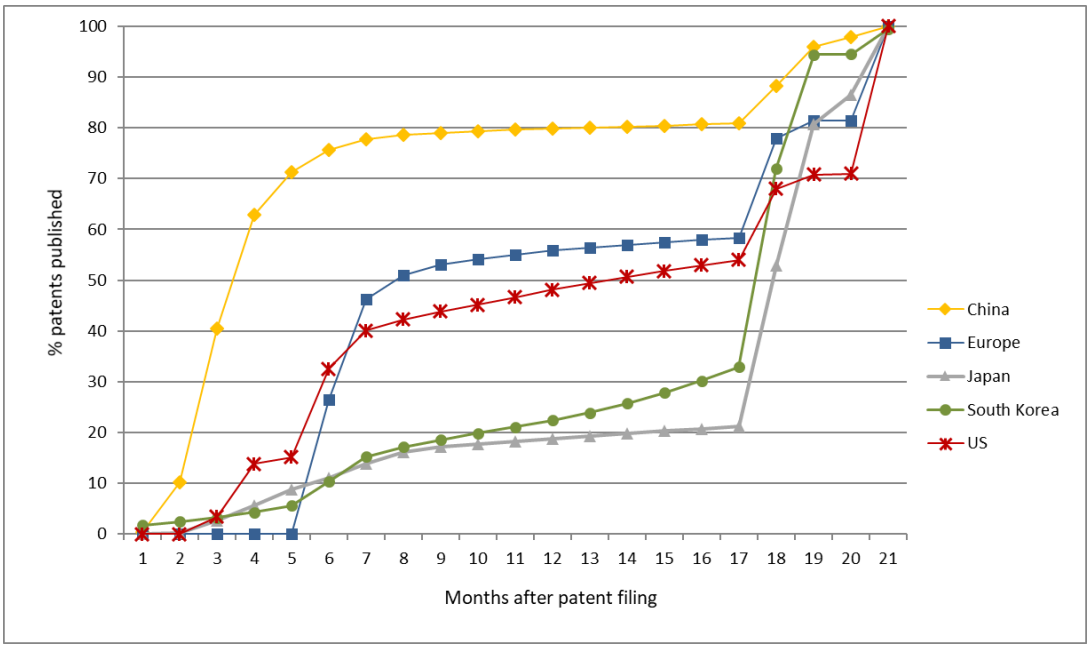
appln_auth	freq
EP	15699
KR	20634
JP	38728
US	127580
CN	1381672

[2] Courtesy of Geert Boedt, European Patent Office.

Figure 5 shows that the numbers of patents filed at the Chinese patent office in 2018 is at least ten times higher than in the four other territories considered here. This might be a direct result of the National Patent Development Strategy of the Chinese National Intellectual Property Administration which has incentives in place to increase the number of patents filed in China[3]. This results in numerous patents being awarded for small design improvements and incremental changes, protected by utility models and design patents. Contrary to patents for inventions, utility models and design patents are delivered faster (less than 1 year) and are not subject to rigorous examination. 77% of the patents filed in China in 2017 are utility models or design patents and about 60% of them are abandoned within five years of their filing[4]. This could partly explain both the increase in patenting observed in China and the skewing of data towards China in 2017-2018 observed in figure 4. This trend to multiply design patents and utility models is not observed in other economies like Japan, the EU, or the US, where patents are still mostly granted for entirely new inventions ("patents for inventions").

Figure 6 clearly shows that China applies an early publication strategy for invention patents as well. Around 80% of invention patents are already published 6 months after their filing at the Chinese patent office. Early publications are also observed for the other territories, but later and to a lesser extent. For example, for patents registered at month 6, while 80% of Chinese patents are already published, only 10% of the patents have been through early publication in Japan and South Korea and around 40% in Europe and the US.

Figure 6: proportion of invention patents published as a function of the number of months after filing for South Korea, Japan, US, China, and Europe (courtesy of the EPO). Data from August 2019, excluding PCT applications.



Considering the three elements explained above, i) incentives in China to patent, ii) design patents and utility models included in the numbers of patent filed, and iii) the trend for Chinese organisation to request early publication of their patent, it is not surprising to observe more Chinese patents over the last years for many of the weak signals detected (see details in annex 1). The steep increase in patenting from Chinese organisations over the last 2-3 years should therefore be nuanced, considering further elements explained below.

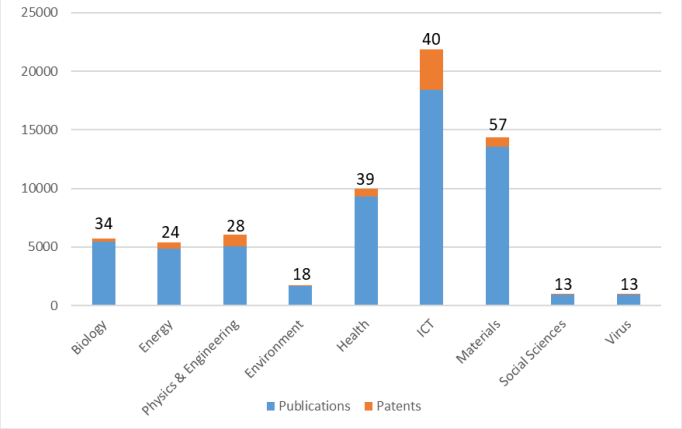
[3] "International Patenting Strategies of Chinese Residents: An Analysis of Foreign-Oriented Patent Families", Mila Kashcheeva, Sacha Wunsch-Vincent, Hao Zhou, Economic Research Working Paper No. 20, WIPO, 2014.
[4] Source: National Intellectual Property Administration of China.

4 Analysis of the weak signals in technology and science

4.1 Overview

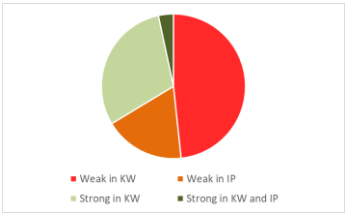
In total, 60193 scientific publications and 6922 patents have been retrieved for the 256 weak signals detected. From the distribution of publications and patents into the 9 topics of weak signals (figure 7), one can see that more than half of the scientific publications have been retrieved for three topics: ICT, Materials, and Health. Half of the patents have been retrieved for the topic ICT.

Figure 7: number of patents and publications per topic of weak signals (number of WS per category on top of each column).



According to the categories of weak signals defined at point 3.2 above, Europe lacks knowledge and patents in 45% (114) of the weak signals detected. This means that European organisations are involved in less than 25% of the publications and of patents worldwide. There are 44 weak signals for which European organisations are strong in producing knowledge but fail to transform this knowledge into patents. For these weak signals, European organisations are involved in more than 25% of the scientific publications worldwide but applied to less than 25% of the patents. In addition, Brexit could impact 10 of these weak signals. Finally, Europe is strong in 80 weak signals (72 EU strong in KW, 8 EU strong in patents). In total, Europe leads in 98 of the weak signals detected but Europe's strength resides in UK organisations for 18 of them (more than 40% of the publications and/or 40% of the patents involve UK organisations). There are therefore only 80 weak signals (72 EU strong in KW, 8 EU strong in patents) out of 256 for which Europe is strong.

Figure 8: proportion of weak signals per categories.



The proportion of weak signals for which Europe is vulnerable or strong varies with the technical topic of the weak signal (figure 9). For example, Europe leads in all the weak signals related to Social Sciences but underperforms for those related to Materials.

Figure 9: proportion of weak signals per categories and by topics.

	EU weak in KW	EU weak in IP	EU strong in KW	EU strong in IP
SOCIAL SCIENCES	0.0%	0.0%	92.3%	7.7%
HEALTH	20.5%	17.9%	56.4%	5.1%
ENVIRONMENT	38.9%	0.0%	61.1%	0.0%
PHYSICS AND ENGINEERING	39.3%	25.0%	32.1%	3.6%
BIOLOGY	41.7%	12.5%	45.8%	0.0%
ICT	45.0%	42.5%	10.0%	2.5%
VIRUSES	53.8%	7.7%	38.5%	0.0%
ENERGY	58.3%	12.5%	25.0%	4.2%
MATERIALS	70.2%	8.8%	15.8%	5.3%

Figure 10 shows the sub-topics of weak signals where:

- Europe leads: European organisations lead in terms of patenting and or scientific publications in a majority of the weak signals (the majority of weak signals in the sub-topics belong to the categories "EU strong in KW" and "EU strong in KW and IP");
- Europe follows: European organisations lead in some weak signals and follows in others (a high proportion of weak signals in the sub-topics belonging to the categories "EU weak in KW" and "EU weak in KW and IP");

- Europe lags behind: European organisations take a leading role in very few or none of the weak signals for the sub-topics (the majority of weak signals in the sub-topics belong to the categories "EU weak in KW" and "EU weak in KW and IP").

Figure 10: Positioning of Europe in sub-topics of weak signals
With [x, y, z] = [#WS in categories "EU strong in KW" and "EU strong in KW and IP", #WS in category "EU weak in IP", #WS in category "EU weak in KW and IP"]

EU leads in	EU follows in		EU lags behind in		
Biomaterials 3, 1, 0	**Genetics** 1, 2, 0	**Light-related WS** 3, 0, 4	**Molecular biology** 1, 0, 4	**Perovskite** 1, 1, 10	**Solar cells** 0, 0, 4
Microbiology 4, 0, 1	**Cancer** 6, 5, 4	**Detection** 2, 0, 2	**CRISPR** 1, 0, 2	**5G** 1, 4, 1	**Microgrids** 1, 2, 1
Neuroscience 7, 0, 1	**Polymers** 4, 0, 3	**Wireless power transfer** 2, 0, 2	**2D materials** 1, 1, 10	**Blockchain** 0, 1, 2	**Viruses** 0, 1, 4
Medicines/diseases 9, 1, 3	**Vaccines&antivirals** 5, 0, 3	**Batteries** 4, 0, 7	**Wearables** 0, 1, 2	**Internet of things** 1, 4, 2	**Catalysis** 1, 0, 3
Digital social sciences 9, 0, 0	**Computing** 1, 3, 0	**Climate change** 3, 0, 2	**Nano materials** 0, 0, 4	**3D printing** 0, 5, 1	**Metasurfaces** 1, 1, 3
		Pollutants 3, 0, 3		**Neural Networks** 1, 1, 8	

Although Europe is strong in 80 of the 256 weak signals detected (31%), it appears clearly from figure 10 that there are only few sub-topics of weak signals where Europe is the leader. While EU is a clear leader in weak signals related to e.g. neurosciences, medicines & diseases, and digital aspects of social sciences, Europe shows vulnerabilities in topics like batteries, perovskite, solar cells, 3D printing, or 2D materials, to name but a few.

4.2 Risk of technology dependency

Based on the analysis presented in the annex, the possibility of a future technology dependency has been identified for 98 weak signals (figure 11). In the present report, we considered a risk of technology dependency when:

- Modest research activities is ongoing in Europe while intense research is being performed elsewhere in the world,
- Little patenting activity is detected in Europe while patents are being filed in the main competing countries.

Figure 11: weak signals presenting a risk of technology dependency for Europe

Risk of technological dependency					
Topic	**Weak signals**	**Topic**	**Weak signals**	**Topic**	**Weak signals**
Env	Peroxymonosulfate activation	Mat	Surface heterojunction photocatalytics	ICT	Software-defined vehicular networks
Env	Functionalised Biochar	Mat	Twisted and coiled polymer muscles	ICT	Hierarchical recurrent neural network
Phy&Eng	Photoelectrochemical aptasensors	Mat	Phagraphene	ICT	Online multiple object tracking
Phy&Eng	Photoelectrochemical immunosensors	Mat	Perovskite photodetectors	ICT	3D convolutional neural networks
Phy&Eng	Photoinduced force microscopy	Mat	Bimetallic organic frameworks	ICT	Private Blockchain
Phy&Eng	Spatial heterodyne raman spectrometer	Mat	Pet-Raft polymerisation	ICT	High res. image recognition by NN
Phy&Eng	Underwater wireless power transfer	Mat	Cr2Ge2Te6	ICT	Generative adversarial networks
Phy&Eng	Stretchable strain sensor	Mat	Renal clearable nanoparticles	ICT	Internet of vehicles
Phy&Eng	Capacitive wireless power transfer	Mat	Borophane	ICT	YOLO
Phy&Eng	Cold sintering process	Mat	Molybdenum disulfide quantum dots	ICT	Consortium Blockchain
Phy&Eng	Wireless powered communication networks	Mat	Perovskite quantum dots	ICT	Micro-service architecture
Phy&Eng	Hybrid modular multilevel converter	Mat	Perovskite nanowires	ICT	Heterogeneous ultra-dense networks
Phy&Eng	4D printing	Mat	Wearable energy storage	ICT	Drone detection
Phy&Eng	3D Bioprinting	Mat	Titanium carbides	ICT	Massive machine type communication
Phy&Eng	Quantum machine learning	Mat	Planar perovskites	ICT	Fog computing
Phy&Eng	Robocasting	Mat	Borophene	ICT	Drone base station
Phy&Eng	Wire arc additive printing	Viruses	Porcine circovirus 3	ICT	Public Blockchain
Phy&Eng	3D Concrete printing	Viruses	Zika virus vaccine	ICT	Narrowband Internet of Things
Phy&Eng	3D printing of tablets	Biology	Diagnostics based on circular RNA	ICT	Ransomware detection
Mat	Phosphorene	Biology	CRISPR/CPF1	ICT	Internet of battlefield things
Mat	Cesium lead halide perovskite	Biology	Bacillus velezensis	Energy	Aqueous organic redox flow batteries
Mat	Antimonene	Biology	Circular RNA	Energy	Dual-carbon batteries
Mat	Perovskite LEDs	Health	Taurine-upregulated gene 1	Energy	Non fullerene organic solar cells
Mat	Perovskite nanocrystals	Health	SC79	Energy	Ternary polymer solar cells
Mat	Lead free perovskite	Health	New gout therapies	Energy	Lithium-Metal batteries
Mat	Metasurface lens	Health	Tyrosine kinases inhibitors	Energy	Garnet electrolyte
Mat	Wearable flexible electronic	Health	Heat-not-burn tobacco product	Energy	Sodium-metal batteries
Mat	Wearable IoT	Health	CAR T cells immunotherapy	Energy	Inverted solar cells
Mat	MoTe2	Health	Tumor mutation burden	Energy	Hybrid microgrids
Mat	FAPbI3 perovskite	Health	Ferroptosis	Energy	Flexible solar cell
Mat	Adaptative metasurface	Health	Programmed death-ligand 1 inhibitors	Energy	Li-CO2 batteries
Mat	Natural deep eutectic solvents	Health	Cyclin-dependent kinase 4/6 inhibitors	Energy	Zinc-ion batteries
		ICT	Residual neural network	Energy	Potassium-ion batteries

4.3 Knowledge and patent imbalances

Figure 12 lists the 8 weak signals that have been flagged for a knowledge or patent imbalance i.e. when research activities or patenting in Europe is mainly due to one or two organisations. R&D ecosystems that are characterised by a monopoly or a duopoly are considered to be more fragile than ecosystems where research and patenting are performed by a large number of actors.

Figure 12: weak signals with a knowledge or patents imbalance

WS with knowldege or patent imbalance					
Topic	**Weak signals**	**Monopole/Duopole**	**Topic**	**Weak signals**	**Monopole/Duopole**
ICT	Digital twin in industry	Siemens	Energy	Electrolyte free fuel-cell	KTH Sweden
ICT	Ultra reliable low latency communication	Nokia / Ericsson	Energy	Mobile maritime microgrids	Aalborg University
ICT	Massive machine type communication	Ericsson	Energy	Energy justice	Aarhus University
ICT	Mobile edge computing	Nokia	Energy	Home microgrids	Aalto and Aalborg Universities

4.4 Creation or reinforcement of research and development activities in Europe

R&D activities were very low in Europe for approximately one quarter of the weak signals detected (64 WS). Figure 13 lists them by topics. Depending on the strategic importance of these technologies, Europe could decide to support the development of these burgeoning research and development activities.

For another quarter of the weak signals (66 WS, listed in figure 14), R&D activities were detected but were at levels below the R&D intensity detected for the main competitors of Europe. Measures to support R&D could be considered for these weak signals, possibly building on the R&D capacity of some identified knowledgeable organisations in Europe.

Figure 13: weak signals with little or no R&D activity in Europe

Weak signals with very little or no R&D activity					
Topic	**Weak signals**	**Topic**	**Weak signals**	**Topic**	**Weak signals**
Env	Coastal blue carbon	Mat	Surface heterojunction photocatalytics	ICT	Smartphone spectrometry
Env	Marine heatwave	Mat	Twisted and coiled polymer muscles	ICT	Hierarchical recurrent neural network
Env	Black soldier fly larvae biodiesel	Mat	Phagraphene	ICT	Ambient backscatter
Env	Peroxymonosulfate activation	Mat	Perovskite photodetectors	ICT	Online multiple object tracking
Energy	Aqueous organic redox flow batteries	Mat	Bimetallic organic frameworks	ICT	Private Blockchain
Energy	Dual-carbon batteries	Mat	Pet-Raft polymerisation	ICT	YOLO
Energy	Non fullerene organic solar cells	Mat	Cr2Ge2Te6	ICT	Consortium Blockchain
Energy	Ternary polymer solar cells	Mat	Renal clearable nanoparticles	ICT	Ransomware detection
Energy	Garnet electrolyte	Mat	Borophane	Phy&Eng	Photoelectrochemical aptasensors
Energy	Sodium-metal batteries	Mat	Bismuthene	Phy&Eng	Photoelectrochemical immunosensors
Energy	Li-CO2 batteries	Mat	Nanocinnamon	Phy&Eng	Photoinduced force microscopy
Energy	Zinc-ion batteries	Mat	PbTaSe2 superconductor	Phy&Eng	Spatial heterodyne raman spectrometer
Energy	Potassium-ion batteries	Mat	Eutectic high entropy alloy	Phy&Eng	Underwater wireless power transfer
Energy	Energy trilemma	Mat	PET hydrolytic enzymes	Phy&Eng	Stretchable strain sensor
Energy	Al-Air batteries	Mat	FASnI3 perovskite	Phy&Eng	Cold sintering process
Biology	Synthetic Notch	Mat	Alkaline hydrogen evolution reaction	Phy&Eng	Hybrid modular multilevel converter
Biology	Transcriptome metabolome wide associat.	Mat	MASnI3 perovskite	Viruses	Orthotospovirus
Biology	De-extinction	Mat	Molybdenum disulfide quantum dots	Viruses	MK-8591
Biology	Anti-CRISPR	Mat	Dihydrolevoglucosenone	Viruses	Grapevine red blotch virus
Biology	Acute hepatopancreatic necrosis disease	Health	Taurine-upregulated gene 1	Viruses	Tomato mottle mosaic virus
Biology	Spray-induced gene silencing	Health	SC79		
		Health	Pegvaliase		
		Health	New gout therapies		

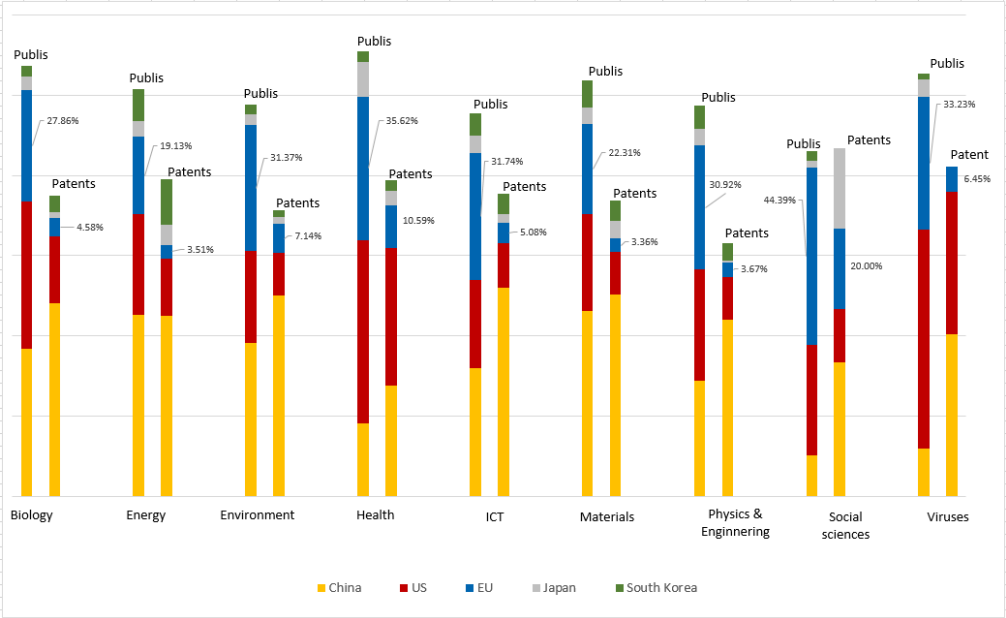
Figure 14: weak signals for which support to existing R&D activities in Europe could be considered

Weak signals for which R&D activity should be reinforced					
Topic	**Weak signals**	**Topic**	**Weak signals**	**Topic**	**Weak signals**
Energy	Accident tolerant nuclear fuels	Mat	0d 2d heterostructures	Health	X-inactive specific transcript
Energy	Lithium-Metal batteries	Mat	Tin selenide crystals	Health	Siderophore cephalosporin
Energy	Inverted solar cells	Mat	Hologram metasurface	Health	Heat-not-burn tobacco product
Energy	Hybrid microgrids	Mat	Acoustic metasurface	Health	Senolityc drugs
Energy	Flexible solar cell	Mat	Stanene	Health	Activated phosphoinositide 3-kin syndrom
Energy	Electrolyte free fuel-cell	Mat	Arsenene	Health	Targeted memory reactivation
Energy	Energy justice	Mat	Biomimetic nanoparticles	Phy&Eng	Capacitive wireless power transfer
Energy	Home microgrids	Mat	Single atom catalysis	Phy&Eng	Visible light positioning
ICT	Smart village	Mat	Perovskite quantum dots	Phy&Eng	Wireless powered communication networks
ICT	Convolutional autoencoders	Mat	Perovskite nanowires	Phy&Eng	4D printing
ICT	Dilated convolutional neural network	Mat	Wearable energy storage	Phy&Eng	Wire arc additive printing
ICT	3D convolutional neural networks	Mat	Titanium carbides	Phy&Eng	3D Concrete printing
ICT	Deep Q learning	Mat	Planar perovskites	Phy&Eng	Levitated optomechanics
ICT	Internet of vehicles	Mat	Borophene	Phy&Eng	3D printing of tablets
ICT	Massive machine type communication	Mat	Antimonene	Phy&Eng	Topological photonics
ICT	Public Blockchain	Mat	Perovskite LEDs	Biology	Double digest RAD Sequencing
ICT	Narrowband Internet of Things	Mat	Metasurface lens	Biology	Thanatomicrobiome
ICT	Internet of battlefield things	Mat	Wearable flexible electronic	Biology	Diagnostics based on circular RNA
ICT	Residual neural network	Mat	Nonlinear metasurface	Biology	CRISPR/CPF1
ICT	Internet of drones	Viruses	Zika virus vaccine	Biology	Bacillus velezensis
Viruses	Quantitative viral outgrowth assay HIV	Viruses	Atypical porcine pestivirus	Biology	Retinal organoids
Viruses	Porcine circovirus 3	Viruses	Herpes zoster vaccine	Env	Functionalised Biochar

4.5 Transformation of academic knowledge into patents

Figure 15 shows, by topics, the percentage of scientific publications and patents to which organisations from Europe, China, South Korea, Japan, and the US are contributing. While European organisations are contributing significantly to scientific publications (EU is in the top 3 contributors for each topic of weak signal with the US and China), it can be observed that the leading role of European organisations in production of knowledge does not translate into a strong position in patenting, as they are indeed significantly less European organisations contributing to patents.

Figure 15: contribution to scientific publications and patents by territory and for each topic of weak signals (percentage of publications and patents to which EU organisations contribute are displayed on the graph).



On figure 16, the ratio #patents/#publications is indicated for each topic and for each of the main territories. This ratio is an indirect indication of the capacity of a country to transform knowledge acquired through research (proxy: # of scientific publications) into innovations (proxy: # of patents). Comparing this ratio for the main territories confirms that Europe is less efficient in transforming knowledge into innovations. China, South Korea, and Japan have the highest ratio patents/publications for the various categories of weak signals. The US are either third or fourth (except for the topic viruses where it is second), and Europe has the lowest patents/publications ratio for every topic. This is confirmed by the graphic shown in figure 17 where one can observe the proportion of companies versus public institutions active in the nine weak signals topics.

Figure 16: Knowledge transformation ratio (#patents/#scientific publications) per territory and WS topic.

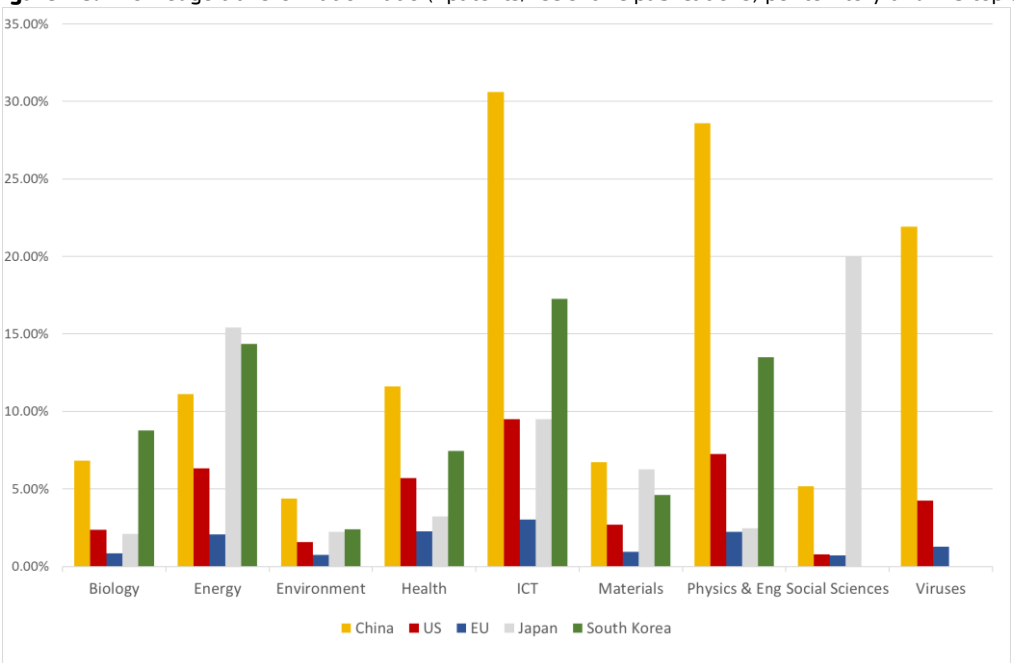
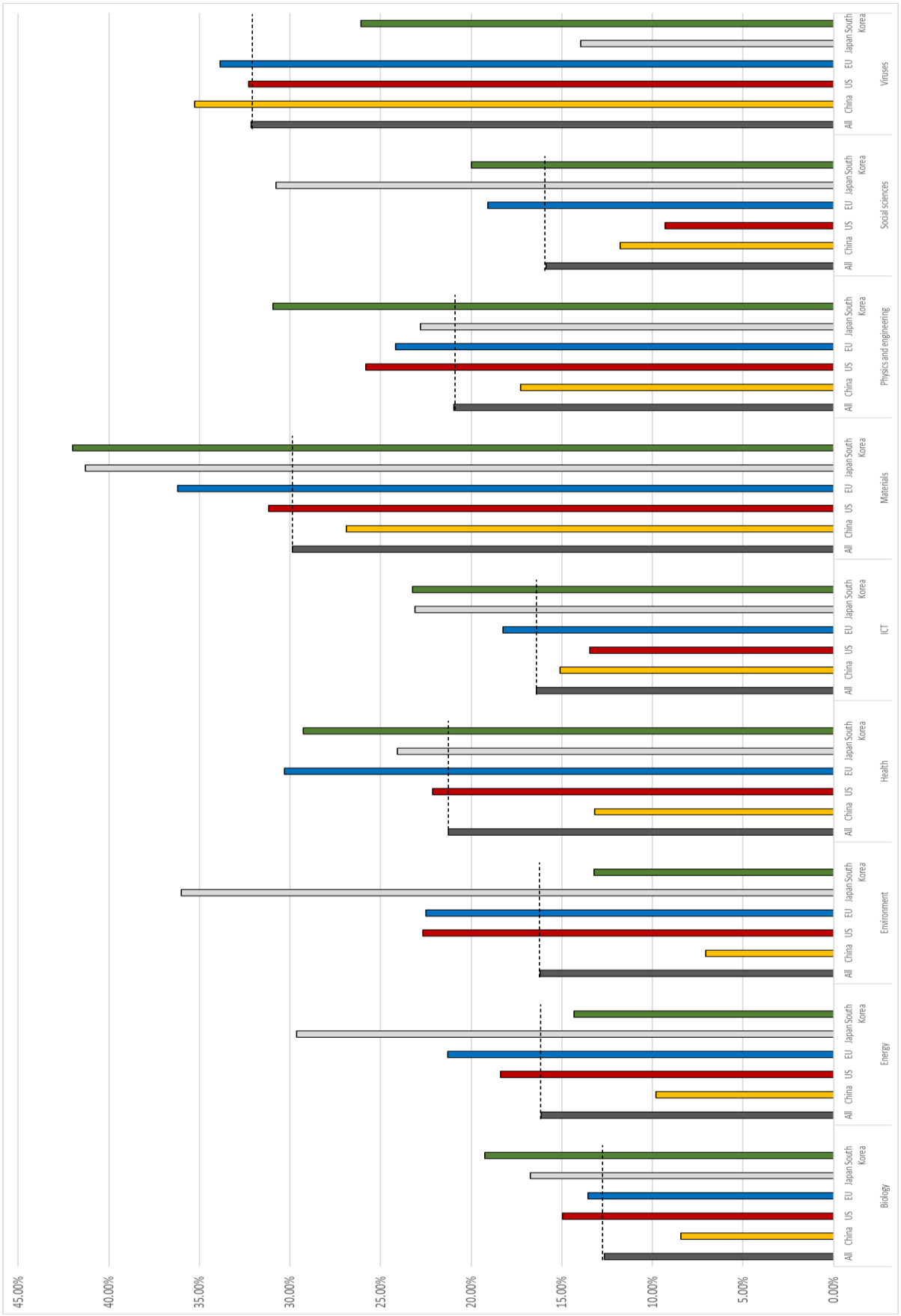


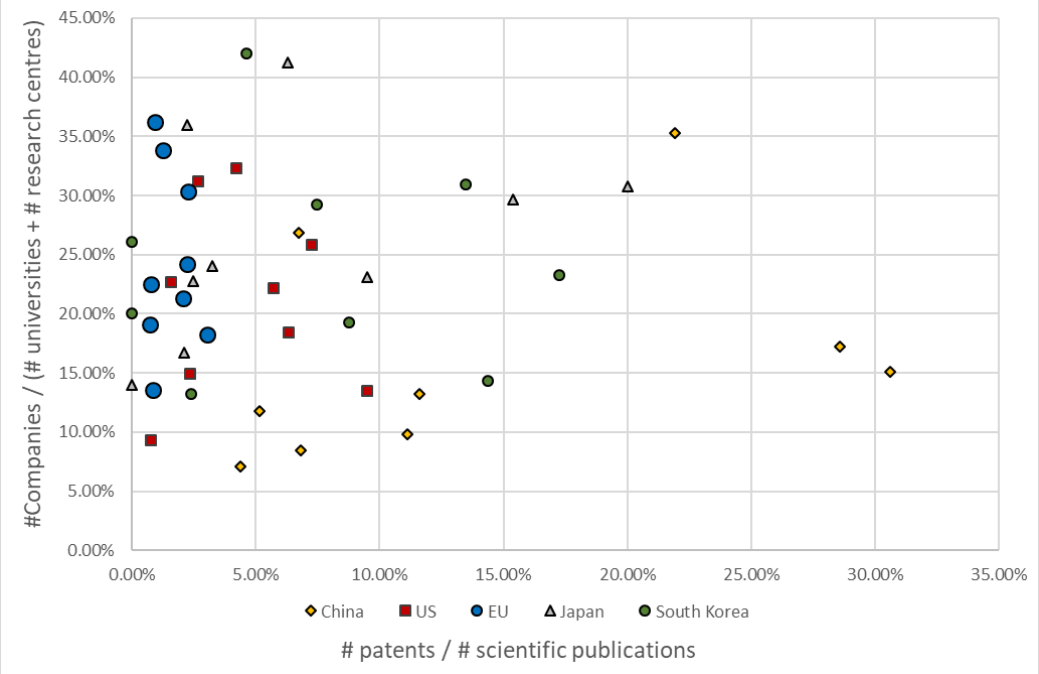
Figure 17: Proportion of companies in the nine weak signals topics and per main territory.



It can be observed from figure 17 that for Europe the proportion of companies versus universities and research centres varies between 13,5% (Biology) and 36% (Materials). The highest percentage of European companies compared to other countries is observed for "Health". For the other topics, the proportion of European companies is always above the average ratio companies/(universities + research centres). This shows that European companies are active in research and development related to the 256 weak signals. The lower efficiency in transforming knowledge into innovations observed for Europe can therefore not be attributed to a lower number of active companies.

Figure 18 sheds some light on this observation by plotting the ratio [#patents/#scientific publications] against the ratio [#companies/(# universities and research centres)] for each of the 9 topics and for each territory. A very high capacity to transform knowledge into innovations would locate data points at the bottom right of the graph: the proportion of patents is high, and the proportion of companies is low. A low capacity to transform knowledge into patents and innovations would locate the data points at the top left of the graph: the proportion of patents is low, but the proportion of companies is high. The capacity to transform knowledge into patents varies for China, Japan, South Korea, and the US: these countries have a high transformation capacity for some topics of weak signals, and lower capacity for others. It is striking to observe that Europe has a low capacity of transformation of knowledge into patents for all categories of weak signals (blue dots, all located left of figure 18), and independently of the number of companies active in the various weak signals. It does not matter how high the proportion of companies is (from 13,5% to 36%, see figure 17), the transformation ratio for Europe is always low (low proportion of patents compared to scientific publications). In other words, even when European companies are active in R&D related to one of the weak signals, they do not file as many patents as companies in other of the main territories. As we saw above (point 3.5), this cannot be directly related to differences in the European patenting system and the causes for the low capacity of European companies to transform knowledge into patents are to be found elsewhere.

Figure 18: correlation between the proportion of patents and the proportion of companies for the main territories and for each of the 9 topics of weak signals.



Considering the above, it is not surprising that measures to support patenting could be implemented for 136 weak signals. Europe is indeed lagging behind in patenting for the weak signals listed in figure 19. This could evolve in technological dependency for some of these weak signals, which could be detrimental to Europe should these technologies become strategically or commercially important.

Figure 19: weak signals for which incentives to patenting should be considered

Weak signals for which incentives for patenting are recommended					
Topic	**Weak signals**	**Topic**	**Weak signals**	**Topic**	**Weak signals**
Energy	Aqueous organic redox flow batteries	Mat	Surface heterojunction photocatalytics	ICT	Software-defined vehicular networks
Energy	Dual-carbon batteries	Mat	0d 2d heterostructures	ICT	Smart village
Energy	Accident tolerant nuclear fuels	Mat	Tin selenide crystals	ICT	Convolutional autoencoders
Energy	Non fullerene organic solar cells	Mat	Hologram metasurface	ICT	Smartphone spectrometry
Energy	Ternary polymer solar cells	Mat	Acoustic metasurface	ICT	Hierarchical recurrent neural network
Energy	Garnet electrolyte	Mat	Stanene	ICT	Dilated convolutional neural network
Energy	Sodium-metal batteries	Mat	PbTaSe2 superconductor	ICT	Ambient backscatter
Energy	Inverted solar cells	Mat	Arsenene	ICT	Online multiple object tracking
Energy	Hybrid microgrids	Mat	Biomimetic nanoparticles	ICT	3D convolutional neural networks
Energy	Flexible solar cell	Mat	PET hydrolytic enzymes	ICT	Non-orthogonal multiple access
Energy	Li-CO2 batteries	Mat	FASnI3 perovskite	ICT	LSTM neural network
Energy	Zinc-ion batteries	Mat	Alkaline hydrogen evolution reaction	ICT	Private Blockchain
Energy	Potassium-ion batteries	Mat	MASnI3 perovskite	ICT	Deep Q learning
Energy	Electrolyte free fuel-cell	Mat	Single atom catalysis	ICT	High res. image recognition by NN
Energy	Mobile maritime microgrids	Mat	Molybdenum disulfide quantum dots	ICT	Generative adversarial networks
Energy	Peer-to-peer energy trading	Mat	Perovskite quantum dots	ICT	Internet of vehicles
Energy	Home microgrids	Mat	Perovskite nanowires	ICT	YOLO
Energy	Al-Air batteries	Mat	Wearable energy storage	ICT	Consortium Blockchain
Health	Taurine-upregulated gene 1	Mat	Titanium carbides	ICT	Network slicing
Health	SC79	Mat	Planar perovskites	ICT	Digital twin in industry
Health	X-inactive specific transcript	Mat	Borophene	ICT	Low power wide area network
Health	Pegvaliase	Mat	Phosphorene	ICT	Micro-service architecture
Health	Siderophore cephalosporin	Mat	Cesium lead halide perovskite	ICT	Ultra reliable low latency communication
Health	New gout therapies	Mat	Antimonene	ICT	Heterogeneous ultra-dense networks
Health	Tyrosine kinases inhibitors	Mat	Perovskite LEDs	ICT	Drone detection
Health	Gasdermin	Mat	Perovskite nanocrystals	ICT	Massive machine type communication
Health	Heat-not-burn tobacco product	Mat	Lead free perovskite	ICT	Fog computing
Health	CAR T cells immunotherapy	Mat	Metasurface lens	ICT	Edge computing
Health	Tumor mutation burden	Mat	Wearable flexible electronic	ICT	Drone base station
Health	Ferroptosis	Mat	Wearable IoT	ICT	Mobile edge computing
Health	Programmed death-ligand 1 inhibitors	Mat	MoTe2	ICT	Public Blockchain
Health	Cyclin-dependent kinase 4/6 inhibitors	Mat	FAPbI3 perovskite	ICT	Narrowband Internet of Things
Health	Senolityc drugs	Mat	Adaptative metasurface	ICT	Ransomware detection
Phy&Eng	Capacitive wireless power transfer	Mat	Natural deep eutectic solvents	ICT	Internet of battlefield things
Phy&Eng	Cold sintering process	Biology	Double digest RAD Sequencing	ICT	Residual neural network
Phy&Eng	Wireless powered communication networks	Biology	Thanatomicrobiome	ICT	Internet of drones
Phy&Eng	Hybrid modular multilevel converter	Biology	Anti-CRISPR	Viruses	Quantitative viral outgrowth assay HIV
Phy&Eng	4D printing	Biology	Acute hepatopancreatic necrosis disease	Viruses	Porcine circovirus 3
Phy&Eng	3D Bioprinting	Biology	Diagnostics based on circular RNA	Viruses	Zika virus vaccine
Phy&Eng	Quantum machine learning	Biology	CRISPR/CPF1	Viruses	Atypical porcine pestivirus
Phy&Eng	Robocasting	Biology	Bacillus velezensis	Viruses	Ebola vaccine
Phy&Eng	Wire arc additive printing	Biology	Circular RNA	Env	Functionalised Biochar
Phy&Eng	3D Concrete printing	Biology	Spytag spycatcher protein ligase	Env	Organophosphorus flame retardant
Phy&Eng	Levitated optomechanics	Biology	Single cell RNA sequencing	Env	Cargo bikes
Phy&Eng	3D printing of tablets	Biology	Assay for transposas-acc. chromat seq		
		Biology	Retinal organoids		
		Biology	Spray-induced gene silencing		

4.6 Multiple countries patents

Figure 20 below shows the number and proportion of patents first filed in the Chinese, American, Japanese, South Korean, European patent offices (UK patent office excluded) or at the European Patent Office that are then extended to another patent jurisdiction: China, US, South Korea, Japan, EPO, or in one of the patent offices of the 27 Member States. The extension of a patent in other territories than the one where it was originally filed is considered to be an indirect indication of its economic value. Indeed, it is costly and risky to extend a patent to other countries and applicants will only engage in it if they expect a return on investment. Although Chinese organisations have filed significantly more patents than other large territories for all of the weak signals, patents that are first filed in China and then extended to other territories are actually less numerous than their US equivalent (patents first filed in US, then extended).

Figure 20: numbers of first patents filed by patent jurisdiction (left) extended to another patent jurisdiction (right).

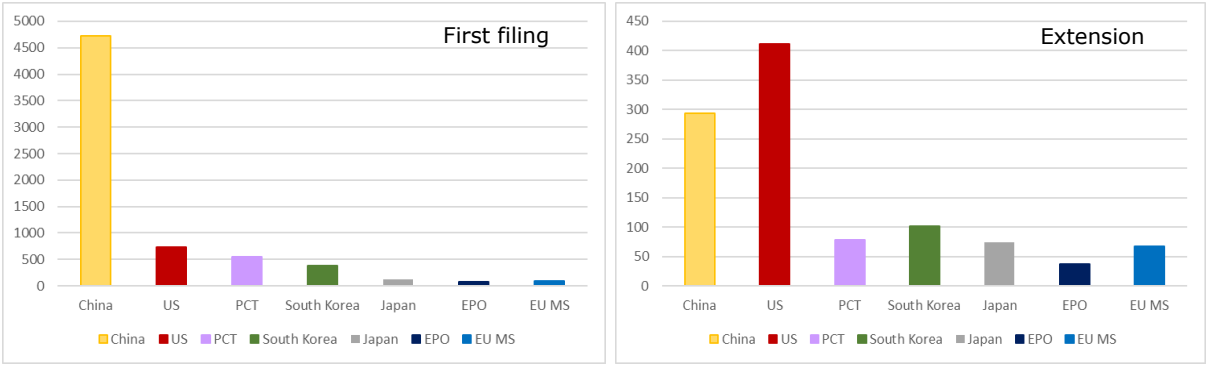
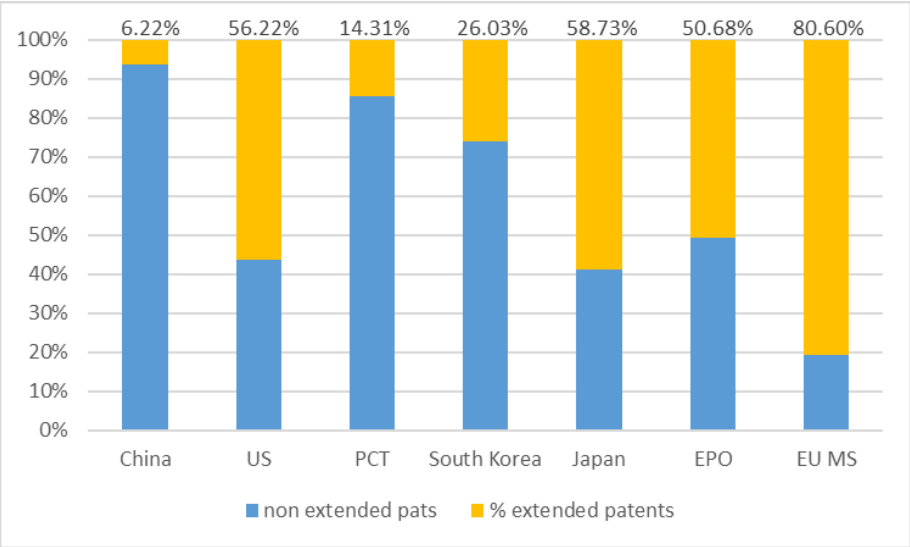


Figure 20 (left) shows that the number of patents first filed by Chinese organisations in China for all of the weak signals is around 10 times higher than patents first filed in the US (second after China). We have seen above that this striking difference is partly related to the particularities of the Chinese patent system (see 3.5). To complement this analysis, it is interesting to compare the number of patents that have been subject to an extension in at least one additional territory different than the territory of first filing. This number of extended patents for the main territories is shown in figure 20 (right). It can be observed that only around 300 patents first filed in China have been extended to at least one other territory (less than 6,2% of all the patents first filed in China). This proportion is much higher for all the other territories (figure 21).

Figure 21: Proportion of non-extended patents and extended patents by patent jurisdiction (% extended patents shown on top of the columns).



Despite a much higher number of patents first filed in China, only 6.22% are extended to another patent jurisdiction. China files a lot of patents but a small number of them are then extended to another country. The proportion of extended patents is much higher for South Korea, the US, Japan, and for the EU where 80% of the patents first filed in one of the patent office of an EU Member State is then extended to another jurisdiction. European organisations file a small number of patents but many of them are extended to at least one other country.

Even if the proportion of extended patents from China is low, it should be noted that all the patents filed by China (i.e. also those that are not extended to other countries or abandoned after a few years) will be part of what is called in the patenting system the "prior art", which consists of all the published knowledge related to an invention prior to the filing of a patent for said invention. One essential condition for patentability is novelty i.e. no publication describing an invention in whole or in part should exist prior to the filing date of said invention. If the novelty condition is not met, the invention cannot be protected by patent. By filing a massive amount of patents (even if they are not extended), China is restricting the possibilites for further patenting (by themselves or others) in many technological fields.

4.7 Research ecosystems in Europe

In science, cross-border collaboration is an important contributing factor to papers with a high scientific impact[5]. There is a clear correlation between a nation's scientific influence and the links it fosters between researchers from different countries. The implementation of measures to increase collaboration among European organisations performing R&D would be beneficial for the research ecosystem of 97 of the weak signals (Figure 22). These environments are indeed characterised by a rather high fragmentation which, for the purpose of this report, is defined as the simple ratio (number of organisations)/(number of collaborations), with a collaboration between two organisations being defined as either a co-publication, a co-patenting, or a joint participation in an EU project. Incentives to collaborations among EU organisations could therefore contribute to strengthen the impact and influence of Europe in these weak signals.

[5] "Open countries have strong science", CS Wagner, K Jonkers, Nature News 2017 550 (7674), 32.

Figure 22: weak signals with a fragmented research ecosystem.

Weak signals for which research ecosystem is fragmented					
Topic	**Weak signals**	**Topic**	**Weak signals**	**Topic**	**Weak signals**
Energy	Aqueous organic redox flow batteries	ICT	Software-defined vehicular networks	Mat	Surface heterojunction photocatalytics
Energy	Dual-carbon batteries	ICT	Smart village	Mat	Twisted and coiled polymer muscles
Energy	Non fullerene organic solar cells	ICT	Smartphone spectrometry	Mat	Phagraphene
Energy	Ternary polymer solar cells	ICT	Hierarchical recurrent neural network	Mat	Perovskite photodetectors
Energy	Garnet electrolyte	ICT	Dilated convolutional neural network	Mat	Bimetallic organic frameworks
Energy	Sodium-metal batteries	ICT	Ambient backscatter	Mat	Pet-Raft polymerisation
Energy	Hybrid microgrids	ICT	Online multiple object tracking	Mat	Cr2Ge2Te6
Energy	Flexible solar cell	ICT	3D convolutional neural networks	Mat	0d 2d heterostructures
Energy	Li-CO2 batteries	ICT	Non-orthogonal multiple access	Mat	Renal clearable nanoparticles
Energy	Zinc-ion batteries	ICT	LSTM neural network	Mat	Borophane
Energy	Potassium-ion batteries	ICT	Private Blockchain	Mat	Bismuthene
Energy	Electrolyte free fuel-cell	ICT	Deep Q learning	Mat	Hologram metasurface
Energy	Mobile maritime microgrids	ICT	High res. image recognition by NN	Mat	Acoustic metasurface
Energy	Energy justice	ICT	Generative adversarial networks	Mat	PET hydrolytic enzymes
Energy	Energy trilemma	ICT	Internet of vehicles	Mat	FASnI3 perovskite
Energy	Home microgrids	ICT	YOLO	Mat	Alkaline hydrogen evolution reaction
Energy	Al-Air batteries	ICT	Consortium Blockchain	Mat	MASnI3 perovskite
Health	Taurine-upregulated gene 1	ICT	Digital twin in industry	Mat	Molybdenum disulfide quantum dots
Health	SC79	ICT	Drone detection	Mat	Perovskite quantum dots
Health	X-inactive specific transcript	ICT	Drone base station	Mat	Titanium carbides
Health	Pegvaliase	ICT	Public Blockchain	Mat	Borophene
Health	New gout therapies	ICT	Narrowband Internet of Things	Mat	Perovskite LEDs
Health	Heat-not-burn tobacco product	ICT	Ransomware detection	Mat	Metasurface lens
Biology	Anti-CRISPR	ICT	Internet of battlefield things	Mat	Wearable flexible electronic
Biology	Acute hepatopancreatic necrosis disease	ICT	Internet of drones	Mat	Wearable IoT
Biology	CRISPR/CPF1	Phy&Eng	Capacitive wireless power transfer	Mat	MoTe2
Biology	Bacillus velezensis	Phy&Eng	Visible light positioning	Mat	Adaptative metasurface
Biology	Spytag spycatcher protein ligase	Phy&Eng	Cold sintering process	Mat	Nonlinear metasurface
Biology	Spray-induced gene silencing	Phy&Eng	Wireless powered communication networks	Mat	Dihydrolevoglucosenone
Env	Functionalised Biochar	Phy&Eng	4D printing	Viruses	Orthotospovirus
Env	Organophosphorus flame retardant	Phy&Eng	Wire arc additive printing	Viruses	MK-8591
Env	Cargo bikes	Phy&Eng	3D Concrete printing	Viruses	Grapevine red blotch virus
				Viruses	Zika virus vaccine

Various research ecosystems might also be impacted by Brexit. As organisations from the UK will formally leave the European Union, some knowledge will leave the EU and the collaboration patterns might also be affected. Organisations from the UK and the rest of Europe that were collaborating before Brexit could cease their collaborations. Although it is difficult to estimate the real consequences of Brexit on the various research ecosystems for the weak signals analysed here, figure 23 shows the research ecosystems that are more likely to be impacted by Brexit.

Figure 23: weak signals with research ecosystems that could be impacted by Brexit.

Weak signals that might be impacted by Brexit					
Topic	**Weak signals**	**Topic**	**Weak signals**	**Topic**	**Weak signals**
Phy&Eng	Cold sintering process	Mat	Hologram metasurface	ICT	Smart village
Phy&Eng	Hybrid modular multilevel converter	Mat	Acoustic metasurface	ICT	Convolutional autoencoders
Phy&Eng	Wire arc additive printing	Mat	Perovskite quantum dots	ICT	Dilated convolutional neural network
Phy&Eng	3D printing of tablets	Mat	Wearable energy storage	ICT	Online multiple object tracking
Phy&Eng	Topological photonics	Mat	Perovskite LEDs	ICT	3D convolutional neural networks
Biology	Spytag spycatcher protein ligase	Mat	Lead free perovskite	ICT	Non-orthogonal multiple access
Biology	Assay for transposas-acc. chromat seq	Mat	Metasurface lens	ICT	Private Blockchain
Biology	Retinal organoids	Mat	Wearable flexible electronic	ICT	Consortium Blockchain
Energy	Accident tolerant nuclear fuels	Mat	FAPbI3 perovskite	ICT	Drone base station
Energy	Garnet electrolyte	Mat	Nonlinear metasurface	ICT	Ransomware detection
Energy	Potassium-ion batteries	Mat	Dihydrolevoglucosenone	ICT	Residual neural network
Energy	Energy justice	Viruses	Glecaprevir/Pibrentasvir	ICT	Internet of drones
Energy	Energy trilemma	Viruses	Herpes zoster vaccine	Soc Sc.	Algorithmic fairness
Energy	Home microgrids	Health	Activated phosphoinositide 3-kin syndrom	Soc Sc.	Civic technologies
Energy	Al-Air batteries	Health	Targeted memory reactivation	Soc Sc.	Digital humanitarianism
				Soc Sc.	Drug cryptomarkets

4.8 Productivity of European R&D organisations

Although Europe is the territory with the highest proportion of small organisations with less than 10 documents retrieved, this proportion is of the same order of magnitude for the other main territories considered (figure 24). There is about the same number of small actors in Europe in terms of production of documents than in the other main territories.

Differences between Europe and the other territories appear when looking at organisations at the other end of the spectrum, the ones that produce many documents. As can be observed in figure 25, Europe has less organisations of high productivity (in terms of publishing or patenting) active in the weak signals than South Korea, the US, and China.

Figure 24: percentage of organisations for the main territories per number of documents produced (range 1 to 10 documents). Only the percentage for Europe is shown on the graphic.

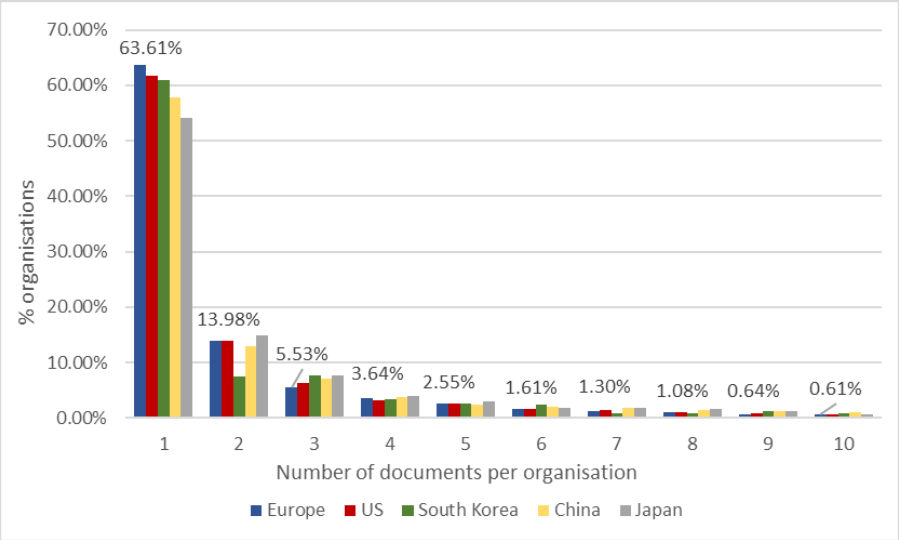
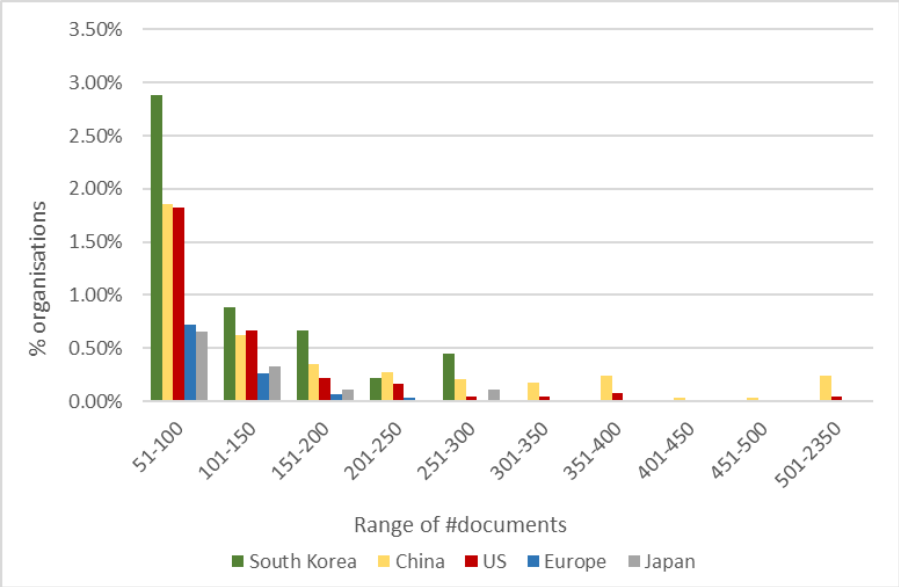


Figure 25: percentage of organisations for the main territories per number of documents produced.



4.9 Top organisations

The top 10 organisations in terms of number of documents has been extracted for each weak signal and the results aggregated by topics. Figure 26 shows the organisations that appear the most frequently in the top 10 organisations for each weak signal (grouped by topics). For example, in the topic Energy, the Chinese academy of Sciences appears in the top 10 organisations for 16 of the 24 weak signals in this topic. Chinese and US organisations are the most frequent organisations in the top 10 organisations for each weak signals i.e. they are the most prolific in terms of documents published or patents registered and they perform R&D for most of the weak signals. European organisations do not appear as often in the top 10 organisations performing research in the various weak signals. Although it is difficult to establish a direct causality, this might be related to the fact that the most productive organisations in Europe are not the most productive worldwide (see chapter about the size of organisations at the previous page).

Figure 26: Organisations most frequently present in the top 10 organisations engaged in R&D in the 256 weak signals, grouped by topics.

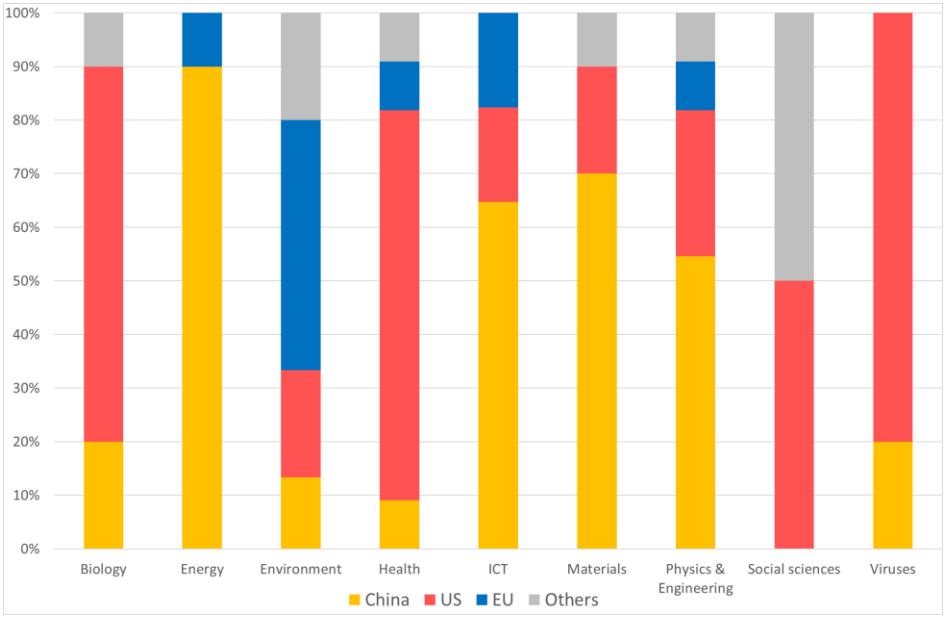
Organisations	#WS
Biology (24 weak signals)	
Chinese Academy Of Sciences	16
University of California	14
Harvard University	8
Stanford University	6
Howard Hughes Medical Institute	4
Max Planck Institute	3
MIT-Harvard	3
University of Pennsylvania	3
Sun Yat-Sen University	3
University of Queensland	3
ICT (40 weak signals)	
Chinese Academy Of Sciences	20
Beijing University of Posts and Telecommunications	18
XIDIAN UNIVERSITY	12
Tsinghua University	12
University of Electronic Science and Technology of China	9
Shanghai Jiao Tong University	9
Nokia CORP	9
University of California	8
IBM Corp	8
HUAWEI TECH CO LTD	8
Beihang University	7
University of Science and Technology of China	6
Fraunhofer Institute	6
Ericsson AB	6
Carleton University	6
Peking University	5
China University of Mining and Technology	5
Social Sciences (13 weak signals)	
University of Toronto	2
University of Melbourne	2
University of California	2
University of British Columbia	2
State University of New York	2
Queensland University of Technology	2
Northwestern University	2
McGill University	2
Harvard University	2
Curtin University	2
China US EU Others	

Organisations	#WS
Energy (24 weak signals)	
Chinese Academy Of Sciences	16
XI'AN JIAOTONG UNIVERSITY	7
Tsinghua University	6
Helmholtz Institute	6
University of Science and Technology of China	5
Nankai University	5
Tianjin University	4
Shanghai Jiao Tong University	4
Peking University	4
Central South University	4
Materials (57 weak signals)	
Chinese Academy Of Sciences	44
University of California	17
Peking University	13
Nanjing University	12
University of Science and Technology of China	10
Tsinghua University	9
Huazhong University of Science and Technology	8
Jilin University	8
Northwestern University	8
Soochow University	8
Nanjing University of Information Science and Technology (NUST)	7
Nanyang Technological University	7
National University of Singapore	7
Collaborative Innovation Center of Quantum Matter	6
Shenzhen University	6
Wuhan University	6
City University of Hong Kong	5
Harvard University	5
Oak Ridge National Laboratory	5
South China University of Technology	5
Viruses (13 weak signals)	
University of California	4
National Institutes of Health	4
Cornell University	4
Harvard University	3
Yingli Solar co.	2
University of North Carolina at Chapel Hill	2
South China Agricultural University	2
Merck and Co.	2
Johns Hopkins University	2
Centers for Disease Control and Prevention	2

Organisations	#WS
Environment (18 weak signals)	
Chinese Academy Of Sciences	7
University of California	5
University of Queensland	3
VU University Amsterdam	2
University of Western Ontario	2
University of Technology Sydney	2
University of Tasmania	2
TU Delft	2
Tsinghua University	2
Technical University of Denmark	2
European Commission	2
Curtin University	2
Cornell University	2
CNRS	2
Aarhus University	2
Physics & engineering (28 weak signals)	
Chinese Academy Of Sciences	11
Tsinghua University	8
Nanyang Technological University	7
Massachusetts Institute of Technology	5
Zhejiang University	4
University of California	4
Harvard University	4
University College London	3
NORTHWESTERN POLYTECHNICAL UNIVERSITY	3
Huazhong University of Science and Technology	3
Ghent University	3
Health (39 weak signals)	
Harvard University	21
University of California	19
CNRS	7
University of Texas M. D. Anderson Cancer Center	6
Memorial Sloan-Kettering Cancer Center	6
University of Michigan	5
National Institutes of Health	5
Cornell University	5
Chinese Academy Of Sciences	5
University of Melbourne	4
Mayo Clinic	4

Figure 27 shows the distribution of the country of origin of the top 10 organisations and confirms the top organisations are most often from China and the US. The only exception is the massive presence of organisations from Europe in the weak signals related to Environment. This could indicate that European organisations are more prone to perform edge research in the field of environment, but this should be nuanced by the fact that none of these organisations are active in more than 2 weak signals on the 18 in the topic Environment, and that the more diverse organisations are from China and the US.

Figure 27: percentage of organisations from the main territories per weak signal topic.



5 Synopsis of the recommendations for the weak signals

A summary of the recommendations is presented in the next pages for each of the scientific topic. A first table summarises the key indicators for the weak signals, and a second table then summarises the recommendations and risks.

Two types of risk are flagged, respectively on the risk of dependency to non-EU technologies and on the risk related to a knowledge imbalance, and 5 types of recommendations are considered:

- "Risk of technological dependency": crossed when there is very little knowledge developed in Europe, or very few patents owned by European organisations, of very few organisations from Europe active in R&D compared to other countries.
- Risk related to "Knowledge imbalance": checked when knowledge in Europe about the weak signal is concentrated in one or two organisations.
- "Create R&D" is checked when there is little or no R&D ongoing in Europe for the weak signal considered.
- "Reinforce R&D" is crossed when there is R&D ongoing in Europe but relatively less than in other countries.
- "Develop network" is checked when the research landscape in Europe is fragmented i.e. when there is R&D in Europe but little collaboration between organisations in Europe.
- "Foster innovation" gets a cross when patents have been retrieved for the weak signal but very little of them have been registered by European organisations.
- "Support during Brexit" is checked when Brexit will disrupt the landscape of R&D in Europe for a weak signal (when a significant proportion of knowledge (publications or patents) or of organisations are from the UK). Brexit was not considered as an issue for weak signals where there is no or very little R&D in Europe (there is nothing to disturb…).

The detailed analysis for each weak signal is presented in the annex to this report.

5.1 Energy

21 of the 24 weak signals detected are problematic: 14 in the category "EU weak in KW", 3 in the category "EU weak in IP". In addition, 4 weak signals in the two categories where EU is strong show a Brexit risk.

Figure 28: weak signals in Energy (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Number Patents	% EU Patents	% UK Patents in Europe	Number publications	% EU Publi	% UK Publi in Europe
EU weak in KW	#Patents<5 EU publi<25%ww	Aqueous organic redox flow batteries	4	0.00%	0.00%	38	18.42%	28.57%
		Dual-carbon batteries	5	0.00%	0.00%	71	12.68%	11.11%
		Accident tolerant nuclear fuels	5	0.00%	0.00%	501	11.98%	43.33%
		Non fullerene organic solar cells	20	0.00%	0.00%	300	11.67%	37.14%
		Ternary polymer solar cells	3	0.00%	0.00%	126	7.14%	33.33%
	#Patents>5 EU patents<25%ww EU publi<25%ww	Lithium-Metal batteries	143	6.29%	0.00%	607	17.96%	10.09%
		Garnet electrolyte	6	0.00%	0.00%	56	17.86%	50.00%
		Sodium-metal batteries	36	0.00%	0.00%	123	17.65%	25.00%
		Inverted solar cells	17	5.88%	0.00%	684	16.08%	30.00%
		Hybrid microgrids	61	0.00%	0.00%	538	15.80%	11.76%
		Flexible solar cell	36	0.00%	0.00%	197	11.17%	27.27%
		Li-CO2 batteries	7	0.00%	0.00%	41	9.76%	25.00%
		Zinc-ion batteries	62	0.00%	0.00%	168	9.52%	12.50%
		Potassium-ion batteries	84	1.19%	100.00%	431	6.96%	56.67%
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Electrolyte free fuel-cell	6	0.00%	0.00%	42	54.76%	13.04%
		Mobile maritime microgrids	10	10.00%	0.00%	117	45.30%	3.77%
		Peer-to-peer energy trading	10	0.00%	0.00%	224	33.04%	29.73%
EU strong in KW	#Patents<5 EU publi>25% ww	Energy justice	0	0.00%	0.00%	173	59.54%	68.93%
		Energy trilemma	0	0.00%	0.00%	53	43.40%	73.91%
		Home microgrids	5	0.00%	0.00%	75	32.00%	54.17%
		Magnesium-sulfur batteries	4	0.00%	0.00%	48	27.08%	0.00%
		Li and Mn rich layered oxides	0	0.00%	0.00%	52	25.00%	7.69%
		Sodium-metal anodes	5	20.00%	0.00%	132	25.00%	24.24%
EU strong in IP	EU patents>25%ww	Al-Air batteries	19	31.58%	66.66%	149	12.08%	33.33%

Figure 29: Summary of the recommendations for the weak signals in Energy (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Risk of technological dependency	Knowledge or patent imbalance	Create R&D	Reinforce R&D	Develop network	Foster innovation	Support during Brexit
EU weak in KW	#Patents<5 EU publi<25%ww	Aqueous organic redox flow batteries	X		X		X	X	
		Dual-carbon batteries	X		X		X	X	
		Accident tolerant nuclear fuels				X		X	X
		Non fullerene organic solar cells	X		X		X	X	
		Ternary polymer solar cells	X		X		X	X	
	#Patents>5 EU patents<25%ww EU publi<25%ww	Lithium-Metal batteries	X			X			
		Garnet electrolyte	X		X		X	X	X
		Sodium-metal batteries	X		X		X	X	
		Inverted solar cells	X			X		X	
		Hybrid microgrids	X			X	X	X	
		Flexible solar cell	X			X	X	X	
		Li-CO2 batteries	X		X		X	X	
		Zinc-ion batteries	X		X		X	X	
		Potassium-ion batteries	X		X		X	X	X
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Electrolyte free fuel-cell		X		X	X	X	
		Mobile maritime microgrids		X			X	X	
		Peer-to-peer energy trading						X	
EU strong in KW	#Patents<5 EU publi>25% ww	Energy justice		X		X	X		X
		Energy trilemma			X		X		X
		Home microgrids		X		X	X	X	X
		Magnesium-sulfur batteries							
		Li and Mn rich layered oxides							
		Sodium-metal anodes							
EU strong in IP	EU patents>25%ww	Al-Air batteries			X		X	X	X

5.2 Information and Communication

36 weak signals detected show some vulnerabilities for EU: 18 in the category “EU weak in KW”, 17 in the category “EU weak in IP”, and 1 is analysed for the specific risks related to Brexit.

Figure 30: weak signals in ICT (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Number Patents	% EU Patents	% UK Patents in Europe	Number publications	% EU Publi	% UK Publi in Europe
EU weak in KW	#Patents<5 EU publi<25%ww	Software-defined vehicular networks	3	0.00%	0.00%	282	24.11%	22.06%
		Smart village	1	0.00%	0.00%	96	23.96%	30.43%
		Convolutional autoencoders	7	0.00%	0.00%	435	23.22%	33.66%
		Smartphone spectrometry	2	0.00%	0.00%	69	20.29%	28.57%
		Hierarchical recurrent neural network	5	0.00%	0.00%	67	17.91%	35.71%
		Dilated convolutional neural network	5	40.00%	40.00%	51	17.65%	22.22%
		Ambient backscatter	5	20.00%	0.00%	131	17.56%	26.09%
		Online multiple object tracking	1	0.00%	0.00%	81	11.11%	44.44%
	#Patents>5 EU patents<25%ww EU publi<25%ww	3D convolutional neural networks	52	1.92%	100.00%	529	24.01%	25.98%
		Non-orthogonal multiple access	15	0.00%	0.00%	698	23.93%	61.68%
		LSTM neural network	114	0.00%	0.00%	2188	23.90%	25.05%
		Private Blockchain	44	9.09%	50.00%	200	22.50%	22.22%
		Deep Q learning	6	0.00%	0.00%	172	20.93%	33.33%
		High res. image recognition by NN	60	1.67%	0.00%	426	19.48%	21.69%
		Generative adversarial networks	205	2.44%	20.00%	2050	19.41%	34.17%
		Internet of vehicles	1116	0.90%	0.00%	777	18.40%	24.48%
		YOLO	25	4.00%	0.00%	336	13.10%	11.36%
		Consortium Blockchain	14	0.00%	0.00%	81	11.11%	44.44%
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Network slicing	82	15.85%	0.00%	483	61.08%	18.31%
		Digital twin in industry	42	23.81%	0.00%	172	57.56%	8.08%
		Low power wide area network	136	17.65%	0.00%	611	56.46%	9.57%
		Micro-service architecture	37	5.41%	0.00%	407	50.86%	11.11%
		Ultra reliable low latency communication	141	10.64%	6.67%	1115	47.53%	18.30%
		Heterogeneous ultra-dense networks	10	0.00%	0.00%	147	44.22%	26.15%
		Drone detection	30	6.67%	0.00%	105	40.00%	9.52%
		Massive machine type communication	26	15.38%	0.00%	338	35.50%	15.83%
		Fog computing	91	1.10%	0.00%	2573	34.78%	20.00%
		Edge computing	251	9.56%	20.83%	3667	33.92%	22.59%
		Drone base station	55	3.64%	0.00%	74	32.43%	45.83%
		Mobile edge computing	108	15.74%	10.53%	1342	25.48%	32.02%
		Public Blockchain	17	0.00%	0.00%	111	31.53%	22.86%
		Narrowband Internet of Things	830	5.42%	2.22%	397	31.23%	16.94%
		Ransomware detection	31	3.23%	0.00%	97	28.87%	42.86%
		Internet of battlefield things	19	10.53%	0.00%	315	25.71%	20.99%
		Residual neural network	12	0.00%	0.00%	126	25.40%	40.63%
EU strong in KW	#Patents<5 EU publi>25% ww	Internet of drones	4	25.00%	100.00%	27	48.15%	15.38%
		Mobile edge caching	5	20.00%	0.00%	78	35.90%	25.00%
		Crypto supersingular isogeny	1	0.00%	0.00%	52	34.62%	33.33%
		Quaternion valued neural network	1	0.00%	0.00%	101	26.73%	11.11%
EU strong in IP	EU patents>25%ww	5G Security	11	27.27%	0.00%	132	37.88%	32.00%

Figure 31: Summary of the recommendations for the weak signals in ICT (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Risk of technological dependency	Knowledge or patent imbalance	Create R&D	Reinforce R&D	Develop network	Foster innovation	Support during Brexit
EU weak in KW	#Patents<5 EU publi<25%ww	Software-defined vehicular networks	X				X	X	
		Smart village				X	X	X	X
		Convolutional autoencoders				X		X	X
		Smartphone spectrometry			X		X	X	
		Hierarchical recurrent neural network	X		X		X	X	
		Dilated convolutional neural network				X	X	X	X
		Ambient backscatter			X		X	X	
		Online multiple object tracking	X		X		X	X	X
	#Patents>5 EU patents<25%ww EU publi<25%ww	3D convolutional neural networks	X			X	X	X	X
		Non-orthogonal multiple access					X	X	X
		LSTM neural network					X	X	
		Private Blockchain	X		X		X	X	X
		Deep Q learning				X	X	X	
		High res. image recognition by NN	X				X	X	
		Generative adversarial networks	X				X	X	
		Internet of vehicles	X			X	X	X	
		YOLO	X		X		X	X	
		Consortium Blockchain	X		X		X	X	X
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Network slicing						X	
		Digital twin in industry		X			X	X	
		Low power wide area network						X	
		Micro-service architecture	X					X	
		Ultra reliable low latency communication		X				X	
		Heterogeneous ultra-dense networks	X					X	
		Drone detection	X				X	X	
		Massive machine type communication	X	X		X		X	
		Fog computing	X					X	
		Edge computing						X	
		Drone base station	X				X	X	X
		Mobile edge computing		X				X	
		Public Blockchain	X			X	X	X	
		Narrowband Internet of Things	X			X	X	X	
		Ransomware detection	X		X		X	X	X
		Internet of battlefield things	X			X	X	X	
		Residual neural network	X			X		X	X
EU strong in KW	#Patents<5 EU publi>25% ww	Internet of drones				X	X	X	X
		Mobile edge caching							
		Crypto supersingular isogeny							
		Quaternion valued neural network							
EU strong in IP	EU patents>25%ww	5G Security							

5.3 Health

17 weak signals are analysed: 8 are related to a lack of knowledge in Europe, 7 are related to a weakness in IP, and 2 are related to Brexit.

Figure 32: weak signals in Health (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Number Patents	% EU Patents	% UK Patents in Europe	Number publications	% EU Publi	% UK Publi in Europe
EU weak in KW	#Patents<5 EU publi<25%ww	Taurine-upregulated gene 1	3	0.00%	0.00%	139	5.04%	57.14%
		SC79	0	0.00%	0.00%	14	7.14%	100.00%
		X-inactive specific transcript	1	0.00%	0.00%	69	18.84%	0.00%
		Pegvaliase	0	0.00%	0.00%	10	20.00%	100.00%
		Siderophore cephalosporin	1	100.00%	0.00%	57	24.56%	28.57%
	#Patents>5 EU patents<25%ww EU publi<25%ww	New gout therapies	26	0.00%	0.00%	56	16.07%	33.33%
		Tyrosine kinases inhibitors	57	1.75%	0.00%	1074	21.23%	25.00%
		Gasdermin	7	0.00%	0.00%	198	22.22%	15.91%
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Heat-not-burn tobacco product	88	0.00%	0.00%	135	25.19%	35.29%
		CAR T cells immunotherapy	106	2.83%	0.00%	1471	25.70%	24.87%
		Tumor mutation burden	9	11.11%	0.00%	338	26.92%	15.38%
		Ferroptosis	7	0.00%	0.00%	240	30.83%	14.86%
		Programmed death-ligand 1 inhibitors	304	3.62%	31.58%	1956	35.79%	15.86%
		Cyclin-dependent kinase 4/6 inhibitors	62	4.84%	33.33%	816	37.13%	20.79%
		Senolityc drugs	6	16.67%	100.00%	140	46.43%	41.54%
EU strong in KW	#Patents<5 EU publi>25% ww	Christensenellaceae	3	33.33%	0.00%	24	33.33%	25.00%
		Activated phosphoinositide 3-kin syndrom	1	100.00%	0.00%	27	48.15%	61.54%
		Network neuroscience	0	0.00%	0.00%	81	25.93%	28.57%
		Radiomics machine learning	2	0.00%	0.00%	137	30.66%	23.81%
		New synthetic opioids	0	0.00%	0.00%	109	31.19%	17.65%
		Nlrp3 inhibitor	0	0.00%	0.00%	106	35.85%	23.68%
		Anti-PDGFR monoclonal antibodies	5	20.00%	0.00%	93	38.71%	25.00%
		Glymphatic system	2	50.00%	0.00%	179	40.78%	21.92%
		Nusinersen	0	0.00%	0.00%	126	41.27%	26.92%
		Adenosine deaminase 2 deficiency	1	0.00%	0.00%	100	44.00%	29.55%
		Androgen receptors inhibition	2	50.00%	0.00%	76	46.05%	14.29%
		Chronnectomics	0	0.00%	0.00%	21	47.62%	30.00%
		Semaglutide	0	0.00%	0.00%	23	47.83%	45.45%
		Radiotheranostics	0	0.00%	0.00%	60	48.33%	20.69%
		Targeted memory reactivation	0	0.00%	0.00%	45	53.33%	54.17%
		Tau PET	12	16.67%	0.00%	361	30.47%	25.64%
		Anti-CGRP antibodies	0	0.00%	0.00%	120	54.17%	32.31%
		Flash Glucose Monitoring	2	0.00%	0.00%	126	56.35%	33.80%
		Rovalpituzumab tesirine	0	0.00%	0.00%	21	57.14%	25.00%
		Precision psychiatry	1	0.00%	0.00%	42	57.14%	29.17%
		Fluorescence lifetime imaging ophthalmos	0	0.00%	0.00%	36	61.11%	0.00%
EU strong in IP	EU patents>25%ww	PCSK9 inhibitors	6	50.00%	0.00%	798	53.63%	28.74%
		Octapeptins	5	60.00%	0.00%	16	18.18%	0.00%
		Anti-CD38 antibodies	14	64.29%	0.00%	57	56.14%	9.38%

Figure 33: Summary of the recommendations for the weak signals in Health (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Risk of technological dependency	Knowledge or patent imbalance	Create R&D	Reinforce R&D	Develop network	Foster innovation	Support during Brexit
EU weak in KW	#Patents<5 EU publi<25%ww	Taurine-upregulated gene 1	X		X		X	X	
		SC79	X		X		X	X	
		X-inactive specific transcript				X	X	X	
		Pegvaliase			X		X	X	
		Siderophore cephalosporin				X		X	
	#Patents>5 EU patents<25%ww EU publi<25%ww	New gout therapies	X		X		X	X	
		Tyrosine kinases inhibitors	X					X	
		Gasdermin						X	
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Heat-not-burn tobacco product	X			X	X	X	
		CAR T cells immunotherapy	X					X	
		Tumor mutation burden	X					X	
		Ferroptosis	X					X	
		Programmed death-ligand 1 inhibitors	X					X	
		Cyclin-dependent kinase 4/6 inhibitors	X					X	
		Senolityc drugs				X		X	
EU strong in KW	#Patents<5 EU publi>25% ww	Christensenellaceae							
		Activated phosphoinositide 3-kin syndrom				X			X
		Network neuroscience							
		Radiomics machine learning							
		New synthetic opioids							
		Nlrp3 inhibitor							
		Anti-PDGFR monoclonal antibodies							
		Glymphatic system							
		Nusinersen							
		Adenosine deaminase 2 deficiency							
		Androgen receptors inhibition							
		Chronnectomics							
		Semaglutide							
		Radiotheranostics							
		Targeted memory reactivation				X			X
		Tau PET							
		Anti-CGRP antibodies							
		Flash Glucose Monitoring							
		Rovalpituzumab tesirine							
		Precision psychiatry							
		Fluorescence lifetime imaging ophthalmos							
EU strong in IP	EU patents>25%ww	PCSK9 inhibitors							
		Octapeptins							
		Anti-CD38 antibodies							

5.4 Biology

16 weak signals are analysed: 11 are related to a lack of knowledge in Europe, 2 are related to a weakness in IP, and 3 are related to Brexit.

Figure 34: weak signals in Biology (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Number Patents	% EU Patents	% UK Patents in Europe	Number publications	% EU Publi	% UK Publi in Europe
EU weak in KW	#Patents<5 EU publi<25%ww	Synthetic Notch	0	0.00%	0.00%	10	0.00%	0.00%
		Transcriptome metabolome wide associat.	0	0.00%	0.00%	5	0.00%	0.00%
		Double digest RAD Sequencing	0	0.00%	0.00%	128	21.88%	25.00%
		Thanatomicrobiome	0	0.00%	0.00%	53	22.64%	33.33%
		Anti-CRISPR	3	0.00%	0.00%	91	23.08%	19.05%
		De-extinction	0	0.00%	0.00%	77	23.38%	61.11%
	#Patents>5 EU patents<25%ww EU publi<25%ww	Acute hepatopancreatic necrosis disease	10	0.00%	0.00%	135	8.89%	25.00%
		Diagnostics based on circular RNA	11	9.09%	0.00%	453	7.51%	11.76%
		CRISPR/CPF1	39	5.13%	0.00%	184	21.20%	30.77%
		Bacillus velezensis	59	1.69%	0.00%	167	15.57%	3.85%
		Circular RNA	146	2.74%	0.00%	2138	17.82%	13.91%
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Spytag spycatcher protein ligase	6	0.00%	0.00%	94	28.72%	55.56%
		Single cell RNA sequencing	8	0.00%	0.00%	1124	33.81%	44.74%
EU strong in KW	#Patents<5 EU publi>25% ww	CRISPR interference	2	0.00%	0.00%	192	29.69%	29.82%
		Brain organoids	2	0.00%	0.00%	154	30.52%	27.66%
		Biomolecular condensates	0	0.00%	0.00%	82	31.71%	19.23%
		Assay for transposas-acc. chromat seq	5	0.00%	0.00%	288	32.29%	39.78%
		In silico DNA-DNA hybridization	0	0.00%	0.00%	345	33.62%	14.66%
		Parageobacillus thermoglucosidasius	0	0.00%	0.00%	14	42.86%	0.00%
		Retinal organoids	1	0.00%	0.00%	78	47.44%	43.24%
		Spray-induced gene silencing	3	0.00%	0.00%	13	53.85%	42.86%
		Dynamic in vitro digestion	0	0.00%	0.00%	56	64.29%	16.67%
		Seed microbiome	0	0.00%	0.00%	19	68.42%	7.69%
		Melt Electrowriting	0	0.00%	0.00%	39	87.18%	5.88%
EU strong in IP	EU patents>25%ww							

Figure 35: Summary of the recommendations for the weak signals in Biology (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Risk of technological dependency	Knowledge or patent imbalance	Create R&D	Reinforce R&D	Develop network	Foster innovation	Support during Brexit
EU weak in KW	#Patents<5 EU publi<25%ww	Synthetic Notch			X				
		Transcriptome metabolome wide associat.			X				
		Double digest RAD Sequencing				X		X	
		Thanatomicrobiome				X		X	
		Anti-CRISPR			X		X	X	
		De-extinction			X				
	#Patents>5 EU patents<25%ww EU publi<25%ww	Acute hepatopancreatic necrosis disease			X		X	X	
		Diagnostics based on circular RNA	X			X		X	
		CRISPR/CPF1	X			X	X	X	
		Bacillus velezensis	X			X	X	X	
		Circular RNA	X					X	
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Spytag spycatcher protein ligase					X	X	X
		Single cell RNA sequencing						X	
EU strong in KW	#Patents<5 EU publi>25% ww	CRISPR interference							
		Brain organoids							
		Biomolecular condensates							
		Assay for transposas-acc. chromat seq						X	X
		In silico DNA-DNA hybridization							
		Parageobacillus thermoglucosidasius							
		Retinal organoids				X		X	X
		Spray-induced gene silencing			X		X	X	
		Dynamic in vitro digestion							
		Seed microbiome							
		Melt Electrowriting							
EU strong in IP	EU patents>25%ww								

5.5 Viruses

11 weak signals are analysed: 7 are related to a lack of knowledge in Europe, 1 is related to a weakness in IP, and 3 are related to Brexit.

Figure 36: weak signals in Viruses (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Number Patents	% EU Patents	% UK Patents in Europe	Number publications	% EU Publi	% UK Publi in Europe
EU weak in KW	#Patents<5 EU publi<25%ww	Orthotospovirus	0	0.00%	0.00%	33	15.15%	0.00%
		MK-8591	1	0.00%	0.00%	13	15.38%	0.00%
		Grapevine red blotch virus	0	0.00%	0.00%	52	17.31%	0.00%
		Quantitative viral outgrowth assay HIV	0	0.00%	0.00%	69	21.74%	20.00%
		Tomato mottle mosaic virus	0	0.00%	0.00%	18	22.22%	0.00%
	#Patents>5 EU patents<25%ww EU publi<25%ww	Porcine circovirus 3	21	0.00%	0.00%	77	23.38%	27.78%
		Zika virus vaccine	29	13.79%	25.00%	192	21.35%	29.27%
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Atypical porcine pestivirus	6	0.00%	0.00%	41	36.59%	6.67%
EU strong in KW	#Patents<5 EU publi>25% ww	Ebola vaccine	3	0.00%	0.00%	222	25.68%	52.63%
		Glecaprevir/Pibrentasvir	1	0.00%	0.00%	94	40.43%	52.63%
		Nonavalent human papillomavirus vaccine	0	0.00%	0.00%	87	47.13%	39.02%
		Herpes zoster vaccine	1	0.00%	0.00%	48	60.42%	41.38%
		Staphylococcal kayvirus	0	0.00%	0.00%	9	100.00%	11.11%
EU strong in IP	EU patents>25%ww							

Figure 37: Summary of the recommendations for the weak signals in Viruses (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Risk of technological dependency	Knowledge or patent imbalance	Create R&D	Reinforce R&D	Develop network	Foster innovation	Support during Brexit
EU weak in KW	#Patents<5 EU publi<25%ww	Orthotospovirus			X		X		
		MK-8591			X		X		
		Grapevine red blotch virus			X		X		
		Quantitative viral outgrowth assay HIV				X		X	
		Tomato mottle mosaic virus			X				
	#Patents>5 EU patents<25%ww EU publi<25%ww	Porcine circovirus 3	X			X		X	
		Zika virus vaccine	X			X	X	X	
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Atypical porcine pestivirus				X		X	
EU strong in KW	#Patents<5 EU publi>25% ww	Ebola vaccine						X	
		Glecaprevir/Pibrentasvir							X
		Nonavalent human papillomavirus vaccine							
		Herpes zoster vaccine				X			X
		Staphylococcal kayvirus							
EU strong in IP	EU patents>25%ww								

5.6 Materials

47 weak signals are analysed: 40 are related to a lack of knowledge in Europe, 5 is related to a weakness in IP, and 2 are related to Brexit.

Figure 38: weak signals in Materials (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Number Patents	% EU Patents	% UK Patents in Europe	Number publications	% EU Publi	% UK Publi in Europe
EU weak in KW	#Patents<5 EU publi<25%ww	Surface heterojunction photocatalytics	3	0.00%	0.00%	53	3.77%	0.00%
		Twisted and coiled polymer muscles	0	0.00%	0.00%	18	5.56%	0.00%
		Phagraphene	0	0.00%	0.00%	23	8.70%	50.00%
		Perovskite photodetectors	4	0.00%	0.00%	175	9.71%	29.41%
		Bimetallic organic frameworks	3	0.00%	0.00%	169	10.06%	5.88%
		Pet-Raft polymerisation	0	0.00%	0.00%	76	10.53%	62.50%
		Cr2Ge2Te6	0	0.00%	0.00%	37	10.81%	25.00%
		0d 2d heterostructures	1	0.00%	0.00%	194	12.89%	44.00%
		Renal clearable nanoparticles	2	0.00%	0.00%	46	13.04%	0.00%
		Borophane	0	0.00%	0.00%	24	16.67%	0.00%
		Tin selenide crystals	5	0.00%	0.00%	168	17.26%	13.79%
		Bismuthene	3	0.00%	0.00%	51	19.61%	0.00%
		Nanocinnamon	0	0.00%	0.00%	10	20.00%	50.00%
		Hologram metasurface	4	0.00%	0.00%	236	20.34%	52.08%
		Acoustic metasurface	3	0.00%	0.00%	193	20.73%	27.50%
		Stanene	4	0.00%	0.00%	255	20.78%	13.21%
		PbTaSe2 superconductor	0	0.00%	0.00%	24	20.83%	0.00%
		Eutectic high entropy alloy	2	0.00%	0.00%	61	21.31%	0.00%
		Arsenene	0	0.00%	0.00%	179	14.53%	7.69%
		Biomimetic nanoparticles	0	0.00%	0.00%	131	21.37%	3.57%
		PET hydrolytic enzymes	2	0.00%	0.00%	14	21.43%	66.67%
		FASnI3 perovskite	0	0.00%	0.00%	45	22.22%	20.00%
		Alkaline hydrogen evolution reaction	3	0.00%	0.00%	180	22.78%	7.32%
		MASnI3 perovskite	1	0.00%	0.00%	46	23.91%	18.18%
		Single atom catalysis	1	0.00%	0.00%	124	24.19%	16.67%
	#Patents>5 EU patents<25%ww EU publi<25%ww	Molybdenum disulfide quantum dots	28	0.00%	0.00%	81	6.17%	40.00%
		Perovskite quantum dots	133	0.00%	0.00%	426	7.28%	45.16%
		Perovskite nanowires	18	0.00%	0.00%	162	11.73%	15.79%
		Wearable energy storage	68	2.94%	0.00%	317	12.62%	42.50%
		Titanium carbides	44	0.00%	0.00%	576	13.54%	23.08%
		Planar perovskites	23	0.00%	0.00%	1172	14.93%	32.00%
		Borophene	6	0.00%	0.00%	265	15.09%	7.50%
		Phosphorene	77	0.00%	0.00%	1469	17.09%	16.33%
		Cesium lead halide perovskite	111	0.00%	0.00%	1466	17.19%	34.92%
		Antimonene	14	0.00%	0.00%	189	19.58%	5.41%
		Perovskite LEDs	46	0.00%	0.00%	397	19.65%	56.41%
		Perovskite nanocrystals	34	0.00%	0.00%	712	20.93%	25.50%
		Lead free perovskite	31	3.23%	0.00%	563	21.14%	40.34%
		Metasurface lens	23	4.35%	0.00%	445	22.25%	38.38%
		Wearable flexible electronic	59	6.78%	0.00%	863	24.41%	33.33%
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Wearable IoT	26	0.00%	0.00%	356	26.12%	21.51%
		MoTe2	14	7.14%	100.00%	533	26.27%	20.71%
		FAPbI3 perovskite	10	10.00%	100.00%	407	27.27%	27.93%
		Adaptative metasurface	24	0.00%	0.00%	225	29.78%	23.88%
		Natural deep eutectic solvents	7	14.29%	0.00%	185	47.57%	9.09%
EU strong in KW	#Patents<5 EU publi>25% ww	Gelatin methacrylate hydrogel	2	0.00%	0.00%	265	28.30%	29.33%
		Nonlinear metasurface	2	0.00%	0.00%	184	30.98%	43.86%
		Cs2HfCl6	0	0.00%	0.00%	16	37.50%	0.00%
		Triple cation perovskites	0	0.00%	0.00%	94	39.36%	37.84%
		CrMnFeCoNi high entropy alloys	1	0.00%	0.00%	83	40.96%	14.71%
		Microplastics sampling	4	0.00%	0.00%	104	47.12%	20.41%
		Dihydrolevoglucosenone	2	50.00%	0.00%	27	51.85%	71.43%
		CaKFe4As4 superconductor	0	0.00%	0.00%	32	53.13%	11.76%
		Microplastic ingestion	0	0.00%	0.00%	103	58.25%	40.00%
EU strong in IP	EU patents>25%ww	ReS2	20	10.00%	0.00%	238	12.61%	31.82%
		Platinium free catalysts	33	24.24%	0.00%	271	32.10%	22.99%
		Vitrimers	10	50.00%	20.00%	144	33.33%	10.42%

Figure 39: Summary of the recommendations for the weak signals in Materials (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Risk of technological dependency	Knowledge or patent imbalance	Create R&D	Reinforce R&D	Develop network	Foster innovation	Support during Brexit
EU weak in KW	#Patents<5 EU publi<25%ww	Surface heterojunction photocatalytics	X		X		X	X	
		Twisted and coiled polymer muscles	X		X		X		
		Phagraphene	X		X		X		
		Perovskite photodetectors	X		X		X		
		Bimetallic organic frameworks	X		X		X		
		Pet-Raft polymerisation	X		X		X		
		Cr2Ge2Te6	X		X		X		
		0d 2d heterostructures				X	X	X	
		Renal clearable nanoparticles	X		X		X		
		Borophane	X		X		X		
		Tin selenide crystals				X		X	
		Bismuthene			X		X		
		Nanocinnamon			X				
		Hologram metasurface				X	X	X	X
		Acoustic metasurface				X	X	X	X
		Stanene				X		X	
		PbTaSe2 superconductor			X			X	
		Eutectic high entropy alloy			X				
		Arsenene				X		X	
		Biomimetic nanoparticles				X		X	
		PET hydrolytic enzymes			X		X	X	
		FASnI3 perovskite			X		X	X	
		Alkaline hydrogen evolution reaction			X		X	X	
		MASnI3 perovskite			X		X	X	
		Single atom catalysis				X		X	
	#Patents>5 EU patents<25%ww EU publi<25%ww	Molybdenum disulfide quantum dots	X		X		X	X	
		Perovskite quantum dots	X			X	X	X	X
		Perovskite nanowires	X			X		X	
		Wearable energy storage	X			X		X	X
		Titanium carbides	X			X	X	X	
		Planar perovskites	X			X		X	
		Borophene	X			X	X	X	
		Phosphorene	X					X	
		Cesium lead halide perovskite	X					X	
		Antimonene	X			X		X	
		Perovskite LEDs	X			X	X	X	X
		Perovskite nanocrystals	X					X	
		Lead free perovskite	X					X	X
		Metasurface lens	X			X	X	X	X
		Wearable flexible electronic	X			X	X	X	X
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Wearable IoT	X				X	X	
		MoTe2	X				X	X	
		FAPbI3 perovskite	X					X	X
		Adaptative metasurface	X				X	X	
		Natural deep eutectic solvents	X					X	
EU strong in KW	#Patents<5 EU publi>25% ww	Gelatin methacrylate hydrogel							
		Nonlinear metasurface				X	X		X
		Cs2HfCl6							
		Triple cation perovskites							
		CrMnFeCoNi high entropy alloys							
		Microplastics sampling							
		Dihydrolevoglucosenone			X		X		X
		CaKFe4As4 superconductor							
		Microplastic ingestion							
EU strong in IP	EU patents>25%ww	ReS2							
		Platinium free catalysts							
		Vitrimers							

5.7 Physics and Engineering

19 weak signals are analysed: 11 are related to a lack of knowledge in Europe, 7 are related to a weakness in IP, and 1 is related to Brexit.

Figure 40: weak signals in Physics and Engineering (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Number Patents	% EU Patents	% UK Patents in Europe	Number publications	% EU Publi	% UK Publi in Europe
EU weak in KW	#Patents<5 EU publi<25%ww	Photoelectrochemical aptasensors	0	0.00%	0.00%	76	2.63%	0.00%
		Photoelectrochemical immunosensors	5	0.00%	0.00%	91	4.40%	25.00%
		Photoinduced force microscopy	0	0.00%	0.00%	39	12.82%	0.00%
		Spatial heterodyne raman spectrometer	4	0.00%	0.00%	31	12.90%	75.00%
		Underwater wireless power transfer	2	0.00%	0.00%	34	17.65%	0.00%
	#Patents>5 EU patents<25%ww EU publi<25%ww	Stretchable strain sensor	7	0.00%	0.00%	155	9.03%	42.86%
		Capacitive wireless power transfer	16	6.25%	0.00%	257	14.01%	19.44%
		Visible light positioning	115	0.00%	0.00%	189	14.29%	48.15%
		Cold sintering process	20	5.00%	0.00%	127	19.69%	48.00%
		Wireless powered communication networks	60	3.33%	0.00%	332	20.48%	29.90%
		Hybrid modular multilevel converter	22	0.00%	0.00%	145	23.45%	70.59%
		4D printing	34	0.00%	0.00%	266	23.68%	34.92%
				0.00%			0.00%	
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	3D Bioprinting	558	2.51%	27.27%	1043	25.60%	29.21%
		Quantum machine learning	7	14.29%	0.00%	140	28.57%	40.00%
		Robocasting	15	0.00%	0.00%	496	34.48%	25.15%
		Wire arc additive printing	27	3.70%	100.00%	326	41.72%	58.09%
		3D Concrete printing	36	0.00%	0.00%	124	42.74%	1.89%
		Levitated optomechanics	6	16.67%	0.00%	157	55.41%	31.03%
		3D printing of tablets	8	0.00%	0.00%	56	57.14%	81.25%
				0.00%			0.00%	
EU strong in KW	#Patents<5 EU publi>25% ww	Topological photonics	2	0.00%	0.00%	203	26.11%	43.40%
		Out-of-time-ordered correlator	0	0.00%	0.00%	118	34.75%	24.39%
		Ratiometric thermometer	0	0.00%	0.00%	161	44.10%	1.41%
		Structure-from-motion photogrammetry	0	0.00%	0.00%	146	60.27%	39.77%
		Dynamic in vitro digestion	0	0.00%	0.00%	56	64.29%	16.67%
		Air-Filled Substrate Integrated Waveguide	1	0.00%	0.00%	51	74.51%	0.00%
		Supraharmonics	0	0.00%	0.00%	65	78.46%	7.84%
		Ultra-fast silicon detectors	0	0.00%	0.00%	35	91.43%	0.00%
				0.00%			0.00%	
EU strong in IP	EU patents>25%ww	Remote photoplethysmography	7	71.43%	0.00%	120	53.33%	1.56%

Figure 41: Summary of recommendations for weak signals in Physics & Engineering (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Risk of technological dependency	Knowledge or patent imbalance	Create R&D	Reinforce R&D	Develop network	Foster innovation	Support during Brexit
EU weak in KW	#Patents<5 EU publi<25%ww	Photoelectrochemical aptasensors	X		X				
		Photoelectrochemical immunosensors	X		X				
		Photoinduced force microscopy	X		X				
		Spatial heterodyne raman spectrometer	X		X				
		Underwater wireless power transfer	X		X				
	#Patents>5 EU patents<25%ww EU publi<25%ww	Stretchable strain sensor	X		X				
		Capacitive wireless power transfer	X			X	X	X	
		Visible light positioning				X	X		
		Cold sintering process	X		X		X	X	X
		Wireless powered communication networks	X			X	X	X	
		Hybrid modular multilevel converter	X		X			X	X
		4D printing	X			X	X	X	
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	3D Bioprinting	X					X	
		Quantum machine learning	X					X	
		Robocasting	X					X	
		Wire arc additive printing	X			X	X	X	X
		3D Concrete printing	X			X	X	X	
		Levitated optomechanics				X		X	
		3D printing of tablets	X			X		X	X
EU strong in KW	#Patents<5 EU publi>25% ww	Topological photonics				X			X
		Out-of-time-ordered correlator							
		Ratiometric thermometer							
		Structure-from-motion photogrammetry							
		Dynamic in vitro digestion							
		Air-Filled Substrate Integrated Waveguide							
		Supraharmonics							
		Ultra-fast silicon detectors							
EU strong in IP	EU patents>25%ww	Remote photoplethysmography							

5.8 Social Sciences

Europe is strong in knowledge and in IP for all of the weak signals related to Social Sciences. Four weak signals are analysed for the risks related to Brexit.

Figure 42: weak signals in Social Sciences (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Number Patents	% EU Patents	% UK Patents in Europe	Number publications	% EU Publi	% UK Publi in Europe
EU weak in KW	#Patents<5							
	#Patents>5 EU patents<25%ww EU publi<25%ww							
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww							
EU strong in KW	#Patents<5 EU publi>25% ww	Algorithmic fairness	0	0.00%	0.00%	84	28.57%	40.74%
		Biophilic cities	0	0.00%	0.00%	82	29.27%	25.00%
		Circular bioeconomy	0	0.00%	0.00%	70	74.29%	15.38%
		Civic technologies	0	0.00%	0.00%	68	50.00%	47.06%
		Digital consitutionalism	0	0.00%	0.00%	9	55.56%	0.00%
		Digital humanitarianism	0	0.00%	0.00%	31	41.94%	69.23%
		Drug cryptomarkets	0	0.00%	0.00%	59	55.93%	60.61%
		Immersive journalism	0	0.00%	0.00%	54	62.96%	17.65%
		Sociology of quantification	0	0.00%	0.00%	25	68.00%	17.65%
		Small private online course	2	0.00%	0.00%	130	31.54%	2.44%
		Crowd shipping	3	0.00%	0.00%	49	46.94%	4.35%
		Take over request in self driving	4	25.00%	0.00%	71	80.28%	5.26%
EU strong in IP	EU patents>25%ww	Algorithmic journalism	6	33.33%	0.00%	238	33.33%	20.17%

Measures to support organisations active in “algorithmic fairness”, “civic technologies”, “digital humanitarism”, and “drug cryptomarkets” could be put in place during the Brexit transition.

5.9 Environment

7 weak signals are analysed: 5 are related to a lack of knowledge in Europe, 2 are related to a weakness in IP.

Figure 43: weak signals in Environment (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Number Patents	% EU Patents	% UK Patents in Europe	Number publications	% EU Publi	% UK Publi in Europe
EU weak in KW	#Patents<5 EU publi<25%ww	Coastal blue carbon	0	0.00%	0.00%	29	20.69%	50.00%
		Marine heatwave	0	0.00%	0.00%	74	24.32%	44.44%
		Black soldier fly larvae biodiesel	1	0.00%	0.00%	32	15.63%	0.00%
	#Patents>5 EU patents<25%ww EU publi<25%ww	Peroxymonosulfate activation	13	0.00%	0.00%	404	4.95%	5.00%
		Functionalised Biochar	16	0.00%	0.00%	334	16.77%	30.36%
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Organophosphorus flame retardant	6	0.00%	0.00%	90	45.56%	4.88%
		Cargo bikes	15	20.00%	0.00%	43	86.05%	2.70%
EU strong in KW	#Patents<5 EU publi>25% ww	Climate clubs	0	0.00%	0.00%	26	34.62%	11.11%
		Deep decarbonization	0	0.00%	0.00%	30	56.67%	35.29%
		Environmental DNA metabarcoding	0	0.00%	0.00%	110	43.64%	37.50%
		Flex crops	0	0.00%	0.00%	24	62.50%	26.67%
		Land degradation neutrality	0	0.00%	0.00%	68	64.71%	34.09%
		Octane on demand	0	0.00%	0.00%	28	35.71%	30.00%
		Ultra-low-temp. district heating	0	0.00%	0.00%	16	100.00%	0.00%
		Comammox	1	0.00%	0.00%	65	38.46%	16.00%
		Ecoacoustic	1	0.00%	0.00%	231	45.89%	33.02%
		Electro-fermentation	1	0.00%	0.00%	47	40.43%	21.05%
		NOB suppression	2	0.00%	0.00%	28	28.57%	12.50%
EU strong in IP	EU patents>25%ww							

Figure 44: Summary of the recommendations for the weak signals in Environment (Brexit risk highlighted in orange).

Type of weak signal		Weak signals	Risk of technological dependency	Knowledge or patent imbalance	Create R&D	Reinforce R&D	Develop network	Foster innovation	Support during Brexit
EU weak in KW	#Patents<5 EU publi<25%ww	Coastal blue carbon			X				
		Marine heatwave			X				
		Black soldier fly larvae biodiesel			X				
	#Patents>5 EU patents<25%ww EU publi<25%ww	Peroxymonosulfate activation	X		X				
		Functionalised Biochar	X			X	X	X	
EU weak in IP	#Patents>5 EU patents<25%ww EU publi>25%ww	Organophosphorus flame retardant					X	X	
		Cargo bikes					X	X	
EU strong in KW	#Patents<5 EU publi>25% ww	Climate clubs							
		Deep decarbonization							
		Environmental DNA metabarcoding							
		Flex crops							
		Land degradation neutrality							
		Octane on demand							
		Ultra-low-temp. district heating							
		Comammox							
		Ecoacoustic							
		Electro-fermentation							
		NOB suppression							
EU strong in IP	EU patents>25%ww								

5.10 Persistent weak signals

Documents (patents, scientific publications, EU projects) have been accumulating over many years for some of the weak signals. Figure 45 below shows the distribution of the weak signals per number of years in which documents were produced.

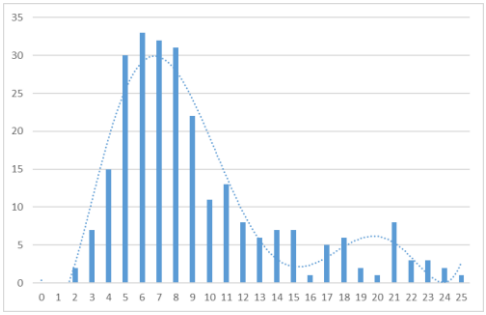


Figure 45: Distribution of weak signals per number of years for which documents were retrieved

Most of the weak signals show a number of years with documents between 3 and 12. Even though it is field dependant, this time range could correspond to some standard speed of research and development. But for some of these weak signals, this number of years for which documents were retrieved is higher (up to 25 years). The "persistent" weak signals with documents retrieved for more than 14 years are listed in figure 46.

This constitutes some kind of paradox: how to explain that R&D spreads over 25 years for weak signals i.e. new technologies? The indicators used by JRC to detect the weak signals have been used precisely to include weak signals of this sort (with many years of documents accumulation)[6]. Although it was not the main objective of the study, the aim was to also detect weak signals that correspond to a new application/product/service related to an existing and well-known technology. These signals would be characterised both by a peak of documents over the last years (signature of a typical weak signal) and by an accumulation of documents over many years (signature of a known technology).
There are various reasons for such accumulations of documents over a long period of time. For most of the persistent weak signals, the research phase is simply longer than for others. For some, it is the retrieval of false positive documents (noise) during the semantic queries that explains the persistence in whole or in part. Although semantic queries are optimised, they are never perfect. For some, it could be explained by the discovery of a new application of a known technology or by a longer R&D phase than average, for example due to some technological barrier. For some others, it could be related to a policy decision that triggered a renewed interest for a particular known technology or topic of research.

Out of these 46 persistent weak listed in figure 46, 9 have been linked to new applications of known technologies or materials (in green), 2 were linked to technological barriers that have been resolved or about to be resolved (in blue), and 1 was linked to a policy making decision that triggered a surge in R&D (in orange).

Figure 46: List of persistent weak signals.

Weak signals	#Years doc retrieved	Weak signals	#Years doc retrieved
Edge computing	25	Ecoacoustic	18
ReS2	24	Perovskite nanowires	18
Circular RNA	24	Ebola vaccine	18
Lithium-Metal batteries	23	Al-Air batteries	17
Platinium free catalysts	23	0d 2d heterostructures	17
Programmed death-ligand 1 inhibitors	23	Perovskite nanocrystals	17
Levitated optomechanics	22	Tau PET	17
High res. image recognition by NN	22	Gasdermin	17
Anti-PDGFR monoclonal antibodies	22	Sodium-metal batteries	16
Cold sintering process	21	Topological photonics	15
MoTe2	21	Internet of battlefield things	15
LSTM neural network	21	New synthetic opioids	15
Cyclin-dependent kinase 4/6 inhibitors	21	Bacillus velezensis	15
Robocasting	21	Alkaline hydrogen evolution reaction	15
Algorithmic fairness	21	X-inactive specific transcript	15
Algorithmic journalism	21	Biomolecular condensates	15
Wearable flexible electronic	21	Planar perovskites	14
Lead free perovskite	20	Anti-CD38 antibodies	14
Wearable energy storage	19	Photoelectrochemical immunosensors	14
Internet of vehicles	19	Metasurface lens	14
Wireless powered communication networks	18	Hybrid microgrids	14
Tin selenide crystals	18	Biomimetic nanoparticles	14
Organophosphorus flame retardant	18	Phosphorene	14

[6] Various "activeness" indicators have been used. See report EUR 29900 EN

6 Conclusions

1. Europe is:
   - Strong in 80 of the weak signals detected (30%);
   - Not transforming its scientific leadership into patents in 44 of the weak signals (17%);
   - Lacking scientific knowledge and lagging behind in patenting in 114 weak signals (45%).

2. Europe is strong in weak signals related to social Sciences, Health, and Environment. Europe shows vulnerabilities in Physics & Engineering, Biology, ICT, Viruses, Energy, and Materials.

3. Looking at sub-topics, Europe is strong in weak signals related to biomaterials, microbiology, neurosciences, new medicines, and digital social sciences. Europe is vulnerable in weak signals related to the 27 other sub-topics, including perovskite, solar cells, 5G, Internet of Things, 3D printing, Neural Networks, viruses, new materials (2D materials, nanomaterials, metasurfaces, new catalysts).

4. Overall, European companies are participating in research and development efforts in the various weak signals. The proportion of companies versus universities and research centres varies between 13,5% (Biology) and 36% (Materials). Europe has the highest percentage of companies active in the topic "Health" and this proportion for the other topics is always above the average ratio of company participation.

5. Europe suffers from a low capacity of transformation of knowledge into patents for many of the weak signals. Even when European companies are very active, there is not as many patents filed in Europe than in the other main territories like the US, China, Japan, or South Korea.

6. Europe has less large size organisations (publishing or patenting) involved in the weak signals than South Korea, the US, and China. There is about the same number of small actors in Europe than in the other main territories.

7. Despite a much higher number of patents first filed in China (10 times more than the US which is second in patenting), a small number of these patents (6.22%) are extended to another patent jurisdiction. The proportion of patents extended is much higher for South Korea, the US, Japan, and for the EU.

8. European organisations file a smaller number of patents than organisations in the US, Japan, South Korea or Japan, but many of them are extended to at least one other country (80% of the patents first filed in one of the patent office of an EU Member State is then extended to another jurisdiction).

9. In terms of absolute numbers of patents, organisations in the US are the ones extending the most patents to other jurisdictions. China is second ahead of South Korea, Japan, and the EU.

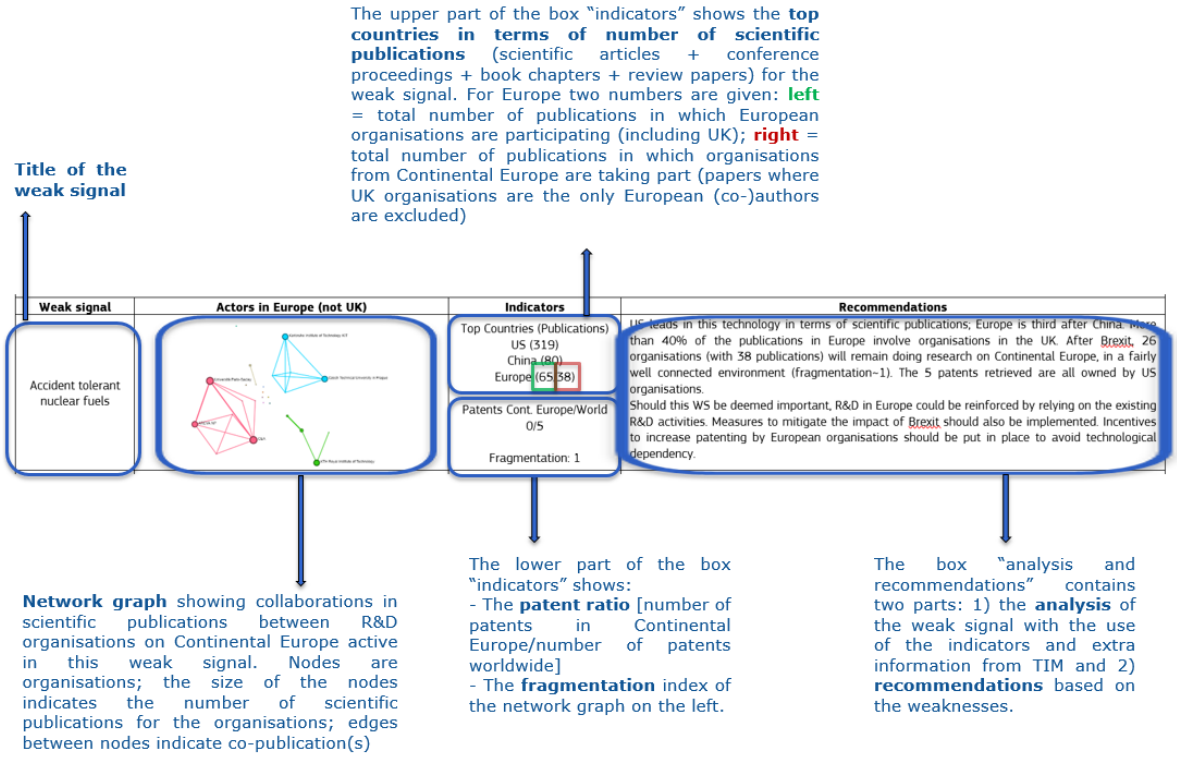
10. Leading organisations are most often from China and the US, with the exception of weak signals in Environment where the majority of the top organisations are form Europe.

11. Recommendations:
    - 98 weak signals present a risk of future technology dependency of Europe.
    - There is an imbalance of knowledge distribution in Europe for 8 of the weak signals (knowledge monopoly or duopoly).
    - There is no or little R&D activities in Europe for 64 weak signals, requiring the creation of R&D activities (very few or no active EU organisations).
    - The research ecosystems in 66 weak signals should be reinforced (there are EU actors but they are not leading and there is a risk of Europe losing grip).
    - Research ecosystems in Europe are fragmented in 97 of the weak signals and measures to develop collaborations among EU organisations should be implemented.
    - Incentives to innovation and patenting should be put in place for more than half (136) of the weak signals.
    - Measures to support European R&D ecosystems during Brexit are suggested for 42 of the weak signals.

7 Annex

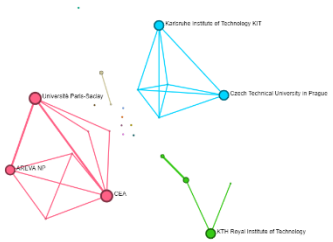
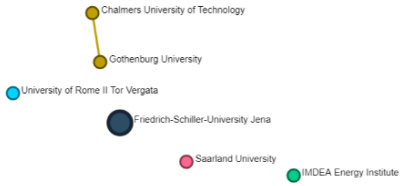
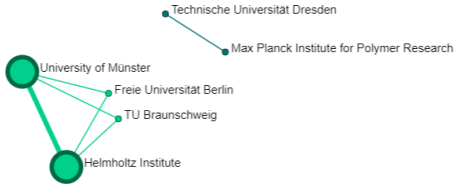
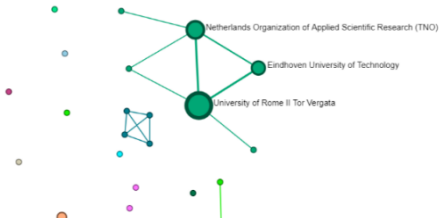
Figure 47 shows the information displayed for each weak signal that is analysed in the annex of the present report.

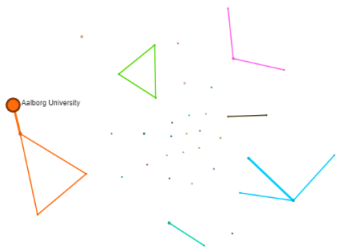
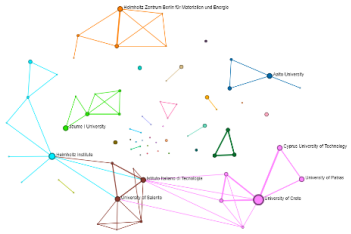
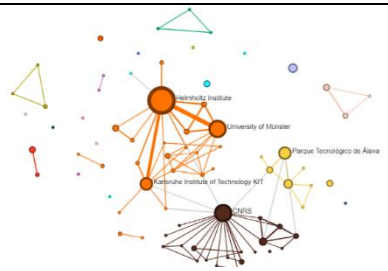
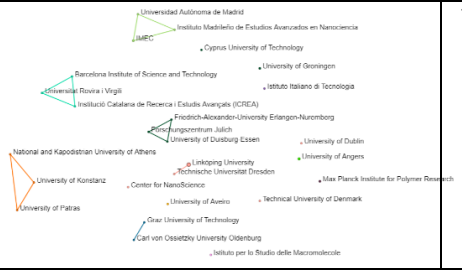
Figure 47: Information contained in the analysis of the weak signals.

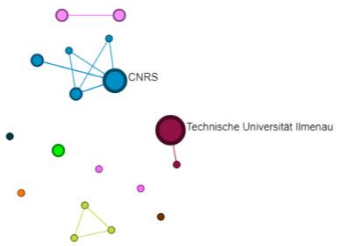
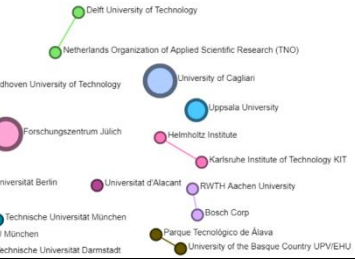
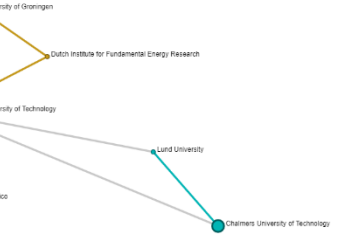
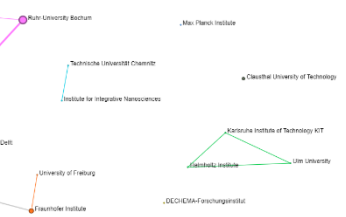


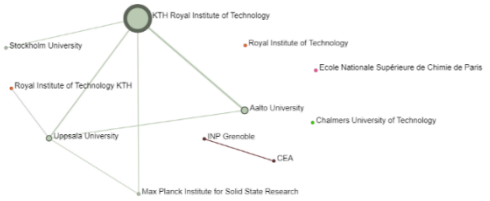
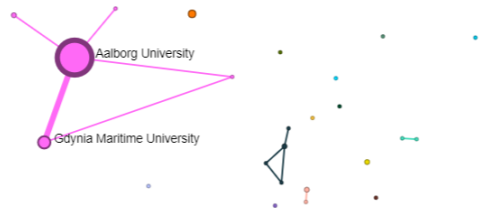
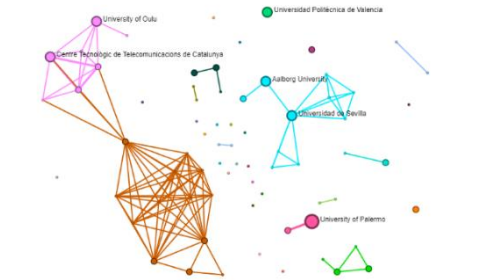
7.1 Energy

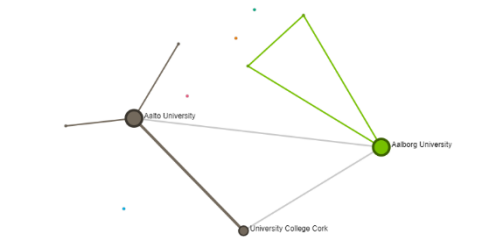
EU is weak in knowledge production

Weak signal	Actors in Europe (not UK)	Indicators	Analysis and recommendations
Accident tolerant nuclear fuels		Top Countries (Publications) US (319) China (80) Europe (65/38) Patents Cont. Europe/World 0/5 Fragmentation: 1	US leads in this technology in terms of scientific publications; Europe is third after China. More than 40% of the publications in Europe involve organisations in the UK. After Brexit, 26 research organisations (with 38 publications) will remain in Europe, in a fairly well connected environment (fragmentation~1). The 5 patents retrieved are all owned by US organisations. Should this WS be deemed important, R&D in Europe could be reinforced by relying on the existing R&D activities. Measures to mitigate the impact of Brexit should also be implemented. Incentives to increase patenting by European organisations should be put in place to avoid technological dependency.
Aqueous organic redox flow batteries		Top Countries (Publications) US (27) South Korea (8) Europe (8/6) Patents Cont. Europe/World 0/4 Fragmentation: 1,66	There is little R&D activities for this technology (38 publications worldwide). Europe is third in publications behind South Korea (2nd) and the US which is leading by far. There are very few actors in Europe and they do not collaborate with each other (high fragmentation). 4 patents have been filed, all owned by US organisations. If this technology appears to be of strategic importance for Europe, major efforts will have to be made to make sure R&D and patenting activities take place in Europe. There is a significant risk of technological dependency.
Dual-carbon batteries		Top Countries (Publications) China (55) US (9) Europe (9/8) Patents Cont. Europe/World 0/5 Fragmentation: 1	There is little R&D activities for this technology (71 publications worldwide). Europe occupies the third place in terms of publications behind China (leading by far) and the US. There are very few actors in Europe, all located in Germany. Some degree of collaboration is observed. 4 of the patents retrieved are owned by Chinese organisations, one by a US organisation. Should this WS be deemed important, major efforts will have to be made to reinforce R&D activities in Europe. Measures to encourage innovation and patenting should also be considered. There is a significant risk of technological dependency for Europe in this technology.
Flexible solar cell		Top Countries (Publications) China (118) South Korea (57) US (40), Europe (27/21) Patents Cont. Europe/World 0/36 Fragmentation: 1,6	Europe is fourth in terms of scientific publications, after the US (3rd), South Korea (2nd), and China (1st). The research landscape in Europe is fragmented i.e. there is little collaboration. The community around TU Eindhoven, TNO, and the University of Rome II is strong and produces most of the research in Europe. 36 patents have been filed worldwide but none has been registered by EU actors so far. 35 of these patents are owned by Chinese organisations or individuals. Should this WS be deemed important, R&D in Europe could be reinforced by relying on the existing strong research community. Incentives to increase patenting by European organisations should be put in place to avoid future technological dependency.
Garnet electrolyte		Top Countries (Publications) US (26) China (25) Europe (10/7) Patents Cont. Europe/World 0/6 Fragmentation: 0,81	There is little R&D activities for this technology (56 publications worldwide). China and the US lead the R&D, with Europe following. Very few patents have been filed worldwide (6 patents all owned by US organisations). One can notice that the actors in Europe are from Spain of from Germany. Should this WS be deemed important, major efforts will have to be made to develop the R&D activities in Europe. Patenting activities should also be encouraged.

Hybrid microgrids		Top Countries (Publications) China (217) Europe (91/79) US (65) Patents Cont. Europe/World 0/61 Fragmentation 2,93	538 publications and 61 patents were retrieved for this weak signal. China clearly leads the field and Europe comes in second position. The research landscape in Europe is fragmented i.e. there is little scientific collaboration. The organisation leading in EU is the Aalborg University, and it is also the leader worldwide (34 publications). This knowledge monopole makes the research landscape fragile. Despite this leadership, none of the patents retrieved have been filed by European organisations (58 for China, 2 for US, 1 for South Korea). Should this WS be deemed important, R&D in Europe could be reinforced by relying on existing knowledge in Aalborg University. Incentives to increase patenting by European organisations should be put in place to avoid technological independency.
Inverted solar cells		Top Countries (Publications) China (394) US (111) Europe (120/85) Patents Cont. Europe/World 1/17 Fragmentation: 0,98	With 684 publications, this weak signal is characterised by a rather intensive ongoing research. China clearly leads the field, followed by the US then Europe. A rather high degree of collaboration is observed for actors in Europe (fragmentation~1). Among the 17 patents retrieved, only one was filed by a European actor while 13 are from China. Should this WS be deemed important, R&D in Europe could be reinforced by relying on the existing R&D networks. The knowledge built in EU but is not (yet) translated into patents, and measures to incentivise patenting by European organisations should be put in place to avoid technological independency.
Li-CO2 batteries		Top Countries (Publications) China (40) US (8), Japan (5) Europe (4/3) Patents Cont. Europe/World 0/7 Fragmentation: 1,88	R&D activities on this weak signal are still limited (41 publications worldwide). Europe is clearly lagging behind with only 3 publications and comes fourth behind China, the US, and Japan. There are 5 actors in Europe. 7 patents have been filed for this technology, all by Chinese organisations. Should this WS be deemed important, major efforts will have to be made to develop R&D activities in Europe. There is very little knowledge to rely on and no strong R&D community working on this technology. There is a significant risk of technological dependency.
Lithium-Metal batteries		Top Countries (Publications) China (346) US (226) Europe (123/102) Patents Cont. Europe/World 6/143 Fragmentation 0,86	With 607 publications and 143 patents retrieved, this weak signal is characterised by a rather intensive ongoing research and patenting. China clearly leads the R&D in this technology, followed by the US and Europe. A rather high degree of collaboration is observed for actors in Europe. One can observe two strong R&D communities respectively around German and French organisations. Among the 143 patents retrieved, only 6 were filed by European actors (Philips, TNO, Bosch, and Volkswagen). China leads in patenting with 54 patents. South Korea and the US follow with respectively 35 and 30 patents. Should this WS be deemed important, R&D in Europe could be reinforced by relying on the existing research communities. There is knowledge available in Europe but it is not (yet) translated into patents. Measures to incentivise patenting by European organisations should be put in place for EU to be technologically independent.
Non-fullerene organic solar cells		Top Countries (Publications) China (216) US (43), Honk Kong (31) Europe (39/30) Patents Cont. Europe/World 0/20 Fragmentation 1,93	This weak signal is characterised by a rather high research activity (300 publications retrieved) but still modest patenting activity (20 patents detected). Europe is 4th in publications behind China (leading by far), the US, and Honk-Kong. There are few organisations active in research on Europe, with only 30 publications (9 publications with only UK organisations), and the collaboration landscape is fragmented. None of the 20 patents has been registered by an organisation based in Europe; 17 out of these patents are owned by Chinese organisations. Should this WS be deemed important, massive efforts will have to be made to develop research, collaboration and patenting in Europe. There is little knowledge to rely on, the R&D community working on this technology is very fragmented. There is a significant risk of technological dependency.

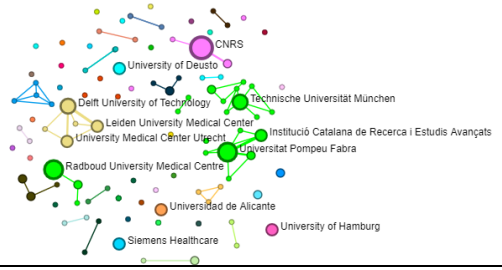
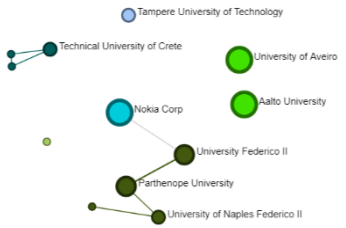
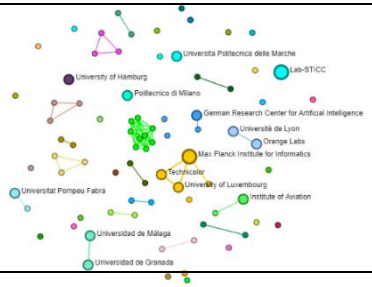
Potassium-ion batteries		Top Countries (Publications) China (384) US (87), Australia (32) Europe (37/20) Patents Cont. Europe/World 0/84 Fragmentation 1,64	431 publications and 84 patents were retrieved for this weak signal. There is little R&D ongoing in Europe with few actors, a fragmented collaboration landscape, and only 20 scientific publications (17 publications involving only UK organisations). Europe is 4th in publications behind China (leading by far), the US, and Australia. Out of the 84 patents retrieved, 75 are owned by Chinese organisations (US: 3, JP:1, UK:1) and none has been registered by a European organisation. Should this WS be deemed important, massive efforts will have to be made to support R&D and patenting in Europe. There is very little knowledge to rely on and the R&D community working on this technology is very fragmented. There is a significant risk of technological dependency.
Sodium-metal batteries		Top Countries (Publications) US (68), China (49) South Korea (19) Europe (22/18) Patents Cont. Europe/World 0/36 Fragmentation 2,57	123 publications and 26 patents were retrieved for this weak signal. There is little R&D ongoing in Europe with few actors, a fragmented collaboration landscape, and only 18 publications (4 publications involving only UK organisations). Europe is 4th in publications behind the US, China and South Korea. Out of the 36 patents retrieved, 15 are from the US, 10 from China, and 8 from South Korea. No patents have been registered by European organisations. Should this WS be deemed important, massive efforts will have to be made to create R&D and patenting activities in Europe. There is very little knowledge to rely on and the R&D community working on this technology is fragmented. The possibility of a future technological dependency should not be underestimated.
Ternary polymer solar cells		Top Countries (Publications) China (95), US (19) South korea (10) Europe (7/4) Patents Cont. Europe/World 0/3 Fragmentation 1	126 publications and only 3 patents were retrieved for this weak signal. There is very little R&D ongoing in Europe with only 6 organisations involved in 4 publications. China, the US and South Korea occupy the three top positions in publications. Only 3 patents owned by Chinese organisations were retrieved. Should this technology be deemed important, massive efforts will have to be made to create R&D and patenting activities in Europe. There is very little knowledge to rely on and there is a risk of technological dependency.
Zinc-ion batteries		Top Countries (Publications) China (141), US (30) South Korea (21) Europe (17/16) Patents Cont. Europe/World 0/62 Fragmentation 1,6	168 publications and 62 patents were retrieved for this weak signal. There is little R&D ongoing in Europe with few actors, a fragmented collaboration landscape, and only 16 publications. Europe is 4th in publications and far behind China. Out of the 62 patents retrieved, none has been filed by a European organisation (China:54 ,Japan:2, US: 2, South Korea:4). Should this WS be deemed important, massive efforts will have to be made to have R&D and patenting activities in Europe. There is very little knowledge to rely on and the R&D community working on this technology is fragmented. There is a significant risk of technological dependency.

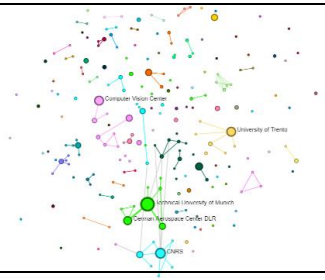
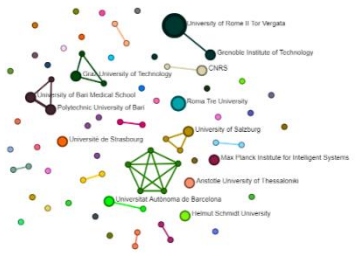
EU is weak in patenting			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Electrolyte free fuel-cell		Top Countries (Publications) China (25) EU (23/22) US (4) Patents Cont. Europe/World 0/6 Fragmentation 1,38	Only 36 publications and 6 patents were retrieved for this weak signal. EU and China produce most of the knowledge in this weak signal. There is a strong collaboration between Europe and China (18 joint-publications), with a strong collaboration between the KTH institute in Sweden and Hubei University in China (11 joint publications). EU organisations are involved in more than 63% of the publications, mainly through research ongoing at the KTH royal institute of technology of Sweden, which leads the field. Despite European leadership in knowledge production, none of the 6 patents retrieved were filed by a European organisation (China:3, US:2, Japan:1). Efforts to support R&D activities in Europe in this technology should build on the existing knowledge, which is rather fragile as it mainly relies on one organisation. Measures to encourage innovation and patenting should be implemented as well.
Mobile maritime microgrids		Top Countries (Publications) EU (55/49) US (45) China (21) Patents Cont. Europe/World 0/10 Fragmentation 2,18	EU and the US produce most of the knowledge in this weak signal with EU organisations involved in about 45% of the publications. Research activities in Europe are mostly performed by a community of five organisations centred on Aalborg University, which leads in number of publications worldwide. Despite European leadership in knowledge production, none of the 10 patents retrieved were filed by European organisations (China: 6, Japan: 2, Norway: 1, US: 1). Efforts to support R&D activities of European organisations in this technology should build on the existing knowledge, which is rather fragile as it mainly relies on one organisation. Measures to encourage patenting should be considered to ensure Europe acquires IP rights and avoid technological dependency.
Peer-to-peer energy trading		Top Countries (Publications) China (83) EU (81/51) US (43) Patents Cont. Europe/World 0/10 Fragmentation 1,32	234 publications, 10 patents, and 5 EU projects were retrieved for this weak signal. European organisations account for 25% of the publications in the field, which places Europe second with 81 publications behind China (after Brexit: 51 publications). Research activities in Europe are fragmented with R&D communities around e.g. University of Oulu, Aalborg University, CNRS, University of Palermo, ATOS. Despite R&D activities in Europe by both research centres and companies (e.g. ATOS, EDF, Engineering, Nokia, Energynautics, ENDESA), none of the 10 patents retrieved were filed by organisations in Europe (China: 7, US: 2, Australia: 1). Support to R&D activities in Europe in this technology have been made (5 EU projects) and should be pursued. Measures to encourage patenting should be considered to ensure Europe could gain some technological independence.

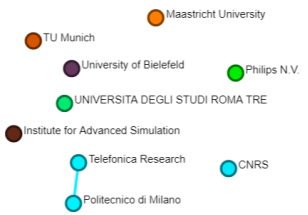
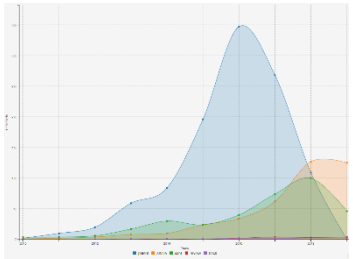
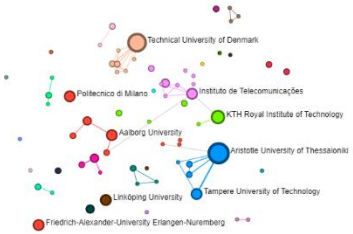
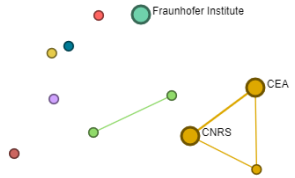
Weak signals with Brexit-risk			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Al-Air batteries		Top Countries (Publications) China (92) EU (25/13) US (12) Patents Cont. Europe/World 2/19 Fragmentation 3,75	Chinese organisations are involved in 92 publications out of 149 and 50% of the patents. While Europe is strong in patents for this weak signal (6 patents out of 19), 4 of these patents are from the UK ad only 2 from Europe. In addition, 33% of the publications involve UK organisations (China leads with 7 patents). Brexit will therefore create a significant loss of knowledge for Europe in this technology. The landscape of R&D activities on Europe is very fragmented with very few actors. Should this WS be deemed important, massive efforts will have to be made to reinforce R&D and patenting activities in Europe after Brexit. There is little knowledge to rely on and no research communities. The possibility of a future technological dependency should not be underestimated.
Energy justice		Top Countries (Publications) UK (53) EU (102/49) US (48) Patents Cont. Europe/World 0/0 Fragmentation: 4,57	This weak signal relates to an emerging cross-cutting issue in energy policy. UK organisations are involved in more publications than the rest of European organisations together, and a significant loss of knowledge will occur due to Brexit. The landscape of research on this topic will drastically change, with a high fragmentation of the research environment in Europe after Brexit. Should the loss of policy knowledge on this topic be deemed important, efforts will have to be made to reinforce research activities in Europe and to develop scientific collaboration. There is some knowledge to rely on, mainly located at Aarhus University, but the landscape is very fragmented.
Energy trilemma		Top Countries (Publications) UK (17) EU (22/7) Patents Cont. Europe/World 0/0 Fragmentation 2.25	This weak signal relates to an emerging cross-cutting issue in of energy policy. UK organisations publish or are involved in most of the publications in the field (32%), a significant loss of knowledge due to Brexit will therefore occur. The landscape of research on this topic will drastically change, with a high fragmentation and very few organisations active in Europe. Should the loss of policy knowledge on this topic be deemed important, massive efforts will have to be made to reinforce research activities. There is little knowledge to rely on and the landscape in Europe is fragmented.
Home microgrids		Top Countries (Publications) EU (25/17) China (15) US (15) UK (13) Patents Cont. Europe/World 0/5 Fragmentation: 1,83	In this technology, European organisations are involved in 32% of the publications. Due to Brexit, this proportion will be reduced to 21% (17 publications). None of the patents retrieved have been registered by organisations in Europe (China: 3, South Korea: 1, India: 1). Should this technology be deemed important for Europe, and considering the loss of knowledge due to Brexit, massive efforts will have to be made to reinforce research activities in Europe. There is little knowledge to rely on, mainly located at Aalto and Aalborg Universities, and the landscape in Europe is fragmented. Measures to push patenting activities should also be considered.

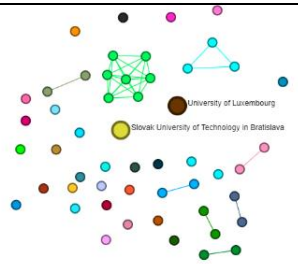
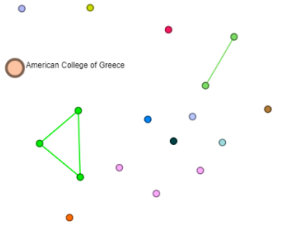
7.2 Information and Communication

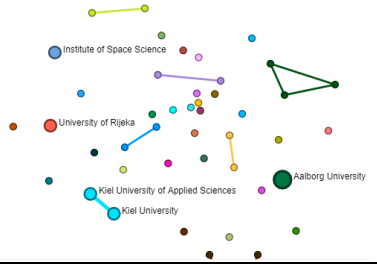
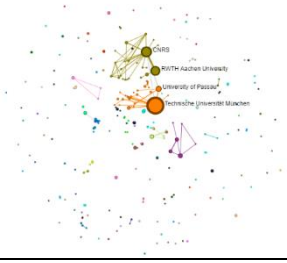
EU is weak in knowledge production

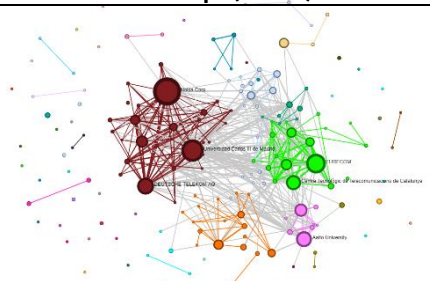
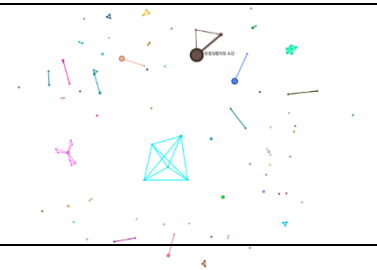
Weak signal	Actors in Europe (not UK)	Indicators	Analysis and recommendations
3D convolutional neural networks		Top Countries (Publications) China (245) US (145) EU (137/100) Patents Cont. Europe/World 0/52 Fragmentation 1,64	Chinese organisations are involved in 46% of the publications in this technology. Organisations from Europe are involved in 100 publications (37 only with UK organisations). None of the 52 patents retrieved has been filed by a European organisation (China: 47/52 patents, 1 patent in the UK). The landscape of R&D activities in Europe is fragmented. Should this WS be deemed important, measures to accompany the Brexit transition should be put in place, together with long term measures to support R&D, increase collaboration among organisations in Europe (EU projects) and, more importantly, push innovation using EU knowledge (patenting activities). There is a risk of future technological dependency.
Ambient backscatter		Top Countries (Publications) China (71) US (35), South Korea (27) EU (27/22) Patents Cont. Europe/World 1/5 Fragmentation 1,86	131 publications and 5 patents were retrieved for this technology. EU comes at the fourth place in terms of scientific publications (16% of worldwide publications). There are very few actors in Europe and the landscape is fragmented. One of the five patents retrieved was filed by an Austrian organisation. Should this WS be deemed important, some efforts will have to be made to support R&D activities. Measures to ensure that knowledge is transformed into innovations and patents should also be considered. EU projects could be launched to increase the number of organisations active in this technology and connect them to each other.
Consortium Blockchain		Top Countries (Publications) China (66) US (15) Australia (7) EU (5/3) Patents Cont. Europe/World 0/14 Fragmentation: 3	Only 3 publications were retrieved for Europe, which is lagging behind in this technology. China leads in terms of scientific publications, followed by the US and Australia. Only 3 organisations in Europe have published and none of the 14 patents are from a European organisation (China: 12 patents, US: 2). Should this WS be deemed important, massive efforts will have to be made to develop research activities in Europe. There is indeed very little knowledge available and very few actors in Europe. Measures to ensure that knowledge is transformed into patents will also need to be devised.
Convolutional autoencoders		Top Countries (Publications) China (169) EU (105/65) US (96) Patents Cont. Europe/World 0/7 Fragmentation 1,31	Chinese organisations lead in this technology in terms of publications. Europe comes second with 105 publications, but slightly less than 40% of them are only involving UK organisations. In Europe, 84 actors are involved in 65 publications and the research environment is slightly fragmented with no obvious leader. 7 patents have been filed with 5 from Chinese organisations, 1 from the US, and 1 from South Korea. Should this WS be deemed important, some efforts will have to be made to support research activities, but mostly to push innovation and patenting. There is knowledge in EU but the possibility of a future technological dependency should not be underestimated. Support during the Brexit phase could also be envisaged.

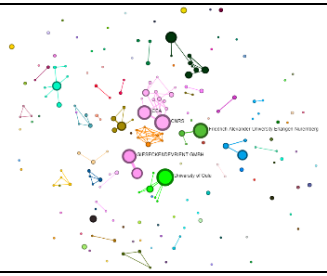
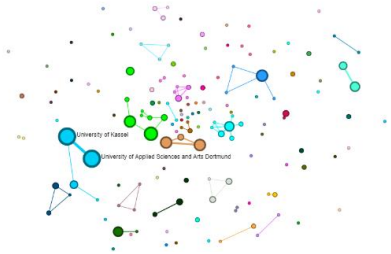
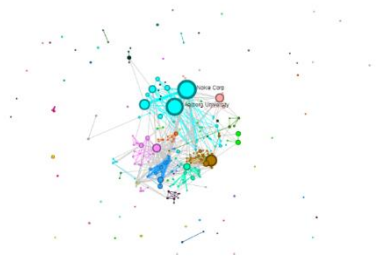
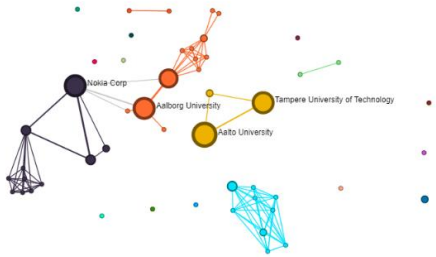
Deep Q learning		Top Countries (Publications) China (70) US (44) EU (41/29) Patents Cont. Europe/World 0/6 Fragmentation 7,75	172 publications and 6 patents were retrieved for this weak signal. EU comes at the third place in terms of scientific publications. There are a few actors in Europe and the research environment is very fragmented. None of the 6 patents retrieved were filed by a European organisation (China: 5, US: 1). Should this WS be deemed important, measures to reinforce R&D in Europe and create a network of knowledgeable actors will have to be implemented. This could possibly be done through EU funding projects. Measures to ensure that knowledge is transformed into innovations and patents should also be considered.
Dilated convolutional neural network		Top Countries (Publications) China (27) EU (12/8) US (10) Patents Cont. Europe/World 0/5 Fragmentation 1,5	Few publications and patents have been retrieved for this technology. With 27 publications, China clearly leads in knowledge production. The number of actors in Europe is very small. Out of the five patents detected, 2 are from UK, 2 from US, and 1 from China. Should this WS be deemed important, massive efforts will have to be made to reinforce R&D in Europe and create a network of knowledgeable actors. This could possibly be done EU funded projects. Measures to ensure that knowledge is transformed into innovations and patents should also be considered.
Generative adversarial networks		Top Countries (Publications) China (964) US (612) EU (445/274) Patents Cont. Europe/World 2/205 Fragmentation 2	2050 publications and 205 patents have been retrieved for this weak signal most of which have published or registered since 2017. European organisations China leads in number of publications and in patenting (181 patents). Other countries follow: US (14), Australia (4), south Korea (3). There are many R&D actors in Europe but they are not highly connected. Only 2 patents have been filed by organisations in Europe (Ericsson and Philips, 1 patent each), This shows a clear lack of capability to transform knowledge into innovation. Should this WS be deemed important, measures to connect R&D actors and to ensure that the EU knowledge is transformed into innovations and patents should be put in place. There is a significant risk of technology dependency.
High res. image recognition by NN		Top Countries (Publications) China (240) US (94) EU (90/68) Patents Cont. Europe/World 0/60 Fragmentation 2,53	China leads in publications for this weak signal, before the US and Europe. In Europe, there is production of knowledge (with 68 publications) but the research environment is fragmented. None of the patents retrieved has been filed by a European organisation, and China owns 56 of these 60 patents. Should this WS be deemed important, measures to connect R&D actors and to push patenting activities should be put in place. There is a risk of future technological dependency.

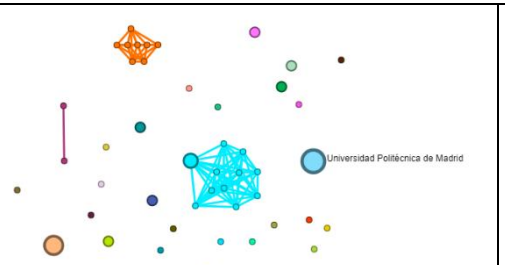
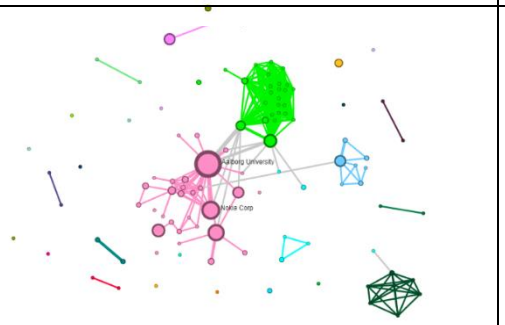
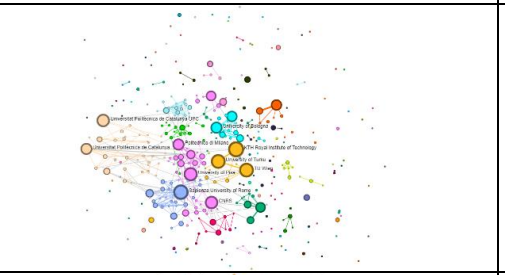
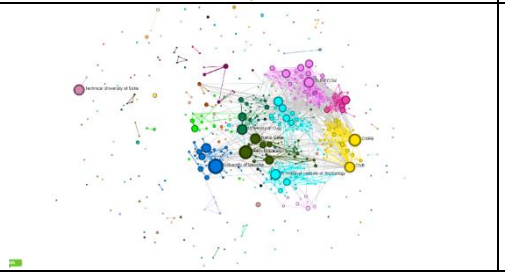
Hierarchical recurrent neural network		Top Countries (Publications) China (32) Japan (9) EU (14/7) Patents Cont. Europe/World 0/5 Fragmentation: 9	Few publications and patents have been retrieved for this WS. With 32 publications, China leads in knowledge production. The number of actors in Europe is very small (each actor only has 1 publication). None of the five patents detected originates from EU (US: 2, China: 2, Japan: 1). Should this WS be deemed important, massive efforts will have to be made to create R&D activities in Europe and create a network of knowledgeable actors. This could possibly be done through EU funded projects. Measures to ensure that knowledge is transformed into innovations and patents should also be considered to avoid technology dependency in the future.
Internet of vehicles		Top Countries (Publications) China (428) US (137) EU (167/111) Patents Cont. Europe/World 2/1116 Fragmentation 2,15	This is one of the few weak signals for which the filing of patents precedes the publication of scientific articles. Looking only at scientific publications, this technology shows the characteristics of a weak signal. But its foreseen market potential has pushed the industry, mostly in China, to invest massively in patenting. Although there is knowledge produced, Europe, but also the US, is lagging behind in publication of scientific articles. But the striking feature here is the patenting strategy of China which, owning 1066 of the 1116 patents retrieved, can be qualified as IP flooding strategy (US :14, Taiwan: 7, SK: 6, JP:4, EU : 2 patents)  Should this technology be deemed important, massive support should be allocated to academic and industrial actors in Europe. The risk of technological dependency is very high.
Non-orthogonal multiple access		Top Countries (Publications) China (357) EU (181/90) US (110) Patents Cont. Europe/World 0/15 Fragmentation 1,47	EU is second in terms of publications behind China. But if the publications where the only European organisations involved are from the UK are removed, Europe occupies the third place behind the US with 90 publications, with a slightly fragmented collaboration environment. Brexit will have a significant impact for this technology (35 very active research actors will leave the EU). There were very little number of patents retrieved, none of which was registered by an EU organisation (China: 8, South Korea: 5, US:2). Although there are very few patents filed so far, measures to make sure that European organisations have incentives to transform their knowledge into innovations should be put in place. Knowledge creation should also be reinforced through appropriate measures.
Online multiple object tracking		Top Countries (Publications) China (31), US (23) South Korea (19) EU (14/10) Patents Cont. Europe/World 0/1 Fragmentation 2,75	A small number of publications and patents was retrieved for this weak signal. With only 10 publications from Europe (14 including publications where only UK organisations are involved from Europe), EU is fourth behind China, the US and South Korea. The number of R&D actors in EU is also very small, with only 11 actors detected. Only one patent was retrieved and it is owned by Xerox in the US. If this weak signal is deemed as important for EU, massive support should be provided to R&D actors. The number of actors should be increased and scientific collaboration fostered. Measures to ensure the transformation of knowledge into innovations should also be put in place to avoid technology dependency.

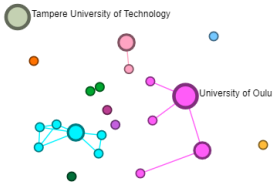
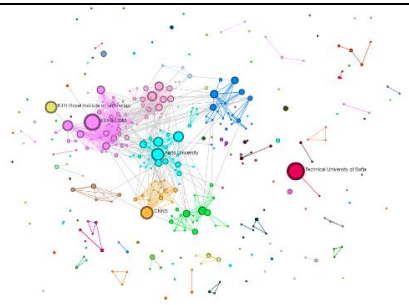
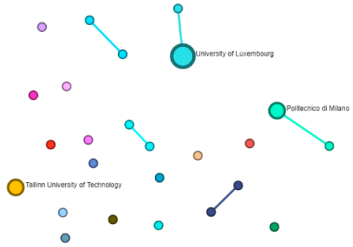
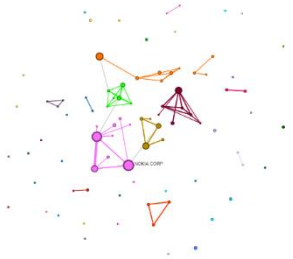
Private Blockchain		Top Countries (Publications) US (66) China (59) EU (53/33) Patents Cont. Europe/World 2/44 Fragmentation 1,73	EU is third in knowledge production and appear to be close to the US and China. But if the 20 publications from UK organisations are removed, the gap between Europe and the two leaders increases. It is again in the transformation of knowledge into innovations that EU (2 patents) lags behind China (10 patents), the US (17 patents), and other countries. There are not many actors in Europe and they do not strongly collaborate together (fragmentation > 1). If this weak signal is deemed as important for EU, massive support should be provided to R&D organisations in Europe. The number of actors should be increased and the creation of research communities encouraged. Measure to ensure the transformation of knowledge into innovations should also be put in place to avoid technology dependency for this sensitive technology.
Smartphone spectrometry		Top Countries (Publications) US (27) EU (17/11) Patents Cont. Europe/World 0/2 Fragmentation 1,42	The US lead in terms of scientific publications for this technology, Europe is second. Very few actors are active in Europe, with VTT taking a leading role (but with only 2 publications…). Both patents retrieved are owned by US organisations. Although little R&D activities has been detected for this technology, Europe is already lagging behind the US in research. The importance of this WS and the positioning of EU organisations should be monitored to ensure timely measures are put in place to support European actors if necessary.
Smart village		Top Countries (Publications) India (28) EU (26/16) US (23) Patents Cont. Europe/World 0/1 Fragmentation 5	India leads in terms of number of scientific publications, with Europe occupying the second position (third position if Brexit is taken into account). Very few actors in Europe are engaged in research, with a very high fragmentation of the collaboration environment. 1 patent has been retrieved and no conclusions can be drawn. R&D activities are only starting and EU is well placed in knowledge production. Measures to support actors in Europe should be put in place, both to support research and innovation. Some transitional support during Brexit could be considered.
Software-defined vehicular networks		Top Countries (Publications) China (87) EU (68/54) US (44) Patents Cont. Europe/World 0/3 Fragmentation 2,7	282 publications and only 3 patents were retrieved for this weak signal. China leads in terms of publications, with EU at the second position (even if the 14 publications from UK are removed). There is some R&D activities ongoing in Europe with CNRS and the University of Luxembourg leading. Collaboration in Europe is limited, with a rather high fragmentation of the research environment. The 3 patents retrieved are owned by Chinese (2) and US (1) organisations. Should this WS be deemed important, efforts will have to be made to support R&D in Europe and defragment the research environment. Measures to ensure European organisations engage into patenting should also be considered.

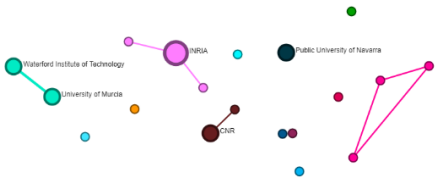
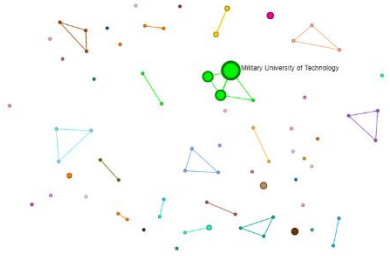
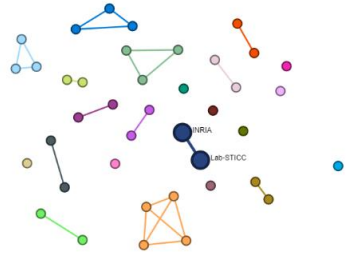
YOLO		Top Countries (Publications) China (162) EU (51/41) US (46) Patents Cont. Europe/World 1/25 Fragmentation 4,5	EU lags behind both in publications and patenting (41 publications in Europe). China leads in both (162 publications, 24 patents). There are only a few actors in Europe with a high fragmentation of the research landscape. Should this WS be deemed important, massive efforts will have to be made to allow European actors to catch up in publications and patenting. There is little knowledge to rely on and the research community working on this technology is very fragmented. There is a significant risk of future technological dependency.
LSTM neural network		Top Countries (Publications) China (799) EU (549/437) US (514) Patents Cont. Europe/World 0/114 Fragmentation 1,81	Europe is second in publications with around 25% of the scientific articles, but will be third after Brexit with 437 publications. China and the US lead both in publications and patenting (China: 77, US: 28). There is significant knowledge in Europe but within a fragmented research environment, characterised by two large research communities around TU Munich and CNRS and a lot of isolated smaller actors. With none of the patents retrieved coming from a European organisation, Europe so far failed to transform this knowledge into innovations. Strong measures are needed to encourage patenting should if one wishes to avoid technological dependency in the future. Some measures could also be put in place to connect more R&D actors in Europe in this field.

EU is weak in patenting			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Network slicing		Top Countries (Publications) EU (314/247) China (144) US (86) Patents Cont. Europe/World 15/82 Fragmentation 0,51	483 publications, 82 patents, and 11 EU projects were retrieved for this technology. European organisations lead in terms of publications in the field (50% of the publications), with China and US respectively second and third. This leadership position is maintained for Europe if UK publications are not taken into account (247 publications). Research actors in Europe are well-connected scientifically (fragmentation < 1). Despite R&D activities in Europe by both research centres and companies (e.g. Nokia, Deutsch Telekom) only 15 of the 82 patents detected were filed by European organisations (China: 34, South Korea: 12, US: 12, Japan:6). Measures to encourage patenting should be considered to ensure Europe can continue competing in this field. In this technology, EU support to R&D activities in Europe has been given (11 EU projects), which resulted in a highly collaborative environment.
Digital twin in industry		Top Countries (Publications) EU (118/90) US (40) China (34) Patents Cont. Europe/World 11/42 Fragmentation: 1,46	EU leads in publications (even if UK publications are removed). Although EU is one of the leader, the landscape of research is fragmented and dominated by one strong actor: Siemens. All of the patents from Europe have been registered by one single company (Siemens). 22 patents are owned by US organisations, 11 by Chinese organisations. EU leading position in this technology is fragile as both its knowledge and patenting mainly relies on one strong actor (Siemens). Measures could be put in place to build a community of R&D actors around Siemens, to better connect research actors in Europe, and to break the IP monopoly of Siemens by encouraging patenting activities by other actors.

Low power wide area network		Top Countries (Publications) EU (371/294) China (92) US (79) Patents Cont. Europe/World 20/136 Fragmentation 1,77	EU leads by far in publications (even considering Brexit) and is third in patenting (20 patent), behind China with 60 patents and South Korea with 33 patents. 7 European companies own patents but the strongest actors are the German companies Gieseck&Devrient gmbh and Deutsche Telekom. The landscape of research is relatively fragmented. Measures to encourage the transformation of knowledge into innovations should be put in place. The leading position of Europe in terms of publications should be reflected in strong IP portfolios.
Micro-service architecture		Top Countries (Publications) EU (213/188) US (62) China (45) Patents Cont. Europe/World 2/37 Fragmentation 2,52	EU leads by far in publications and is third in patenting (2 patent), far behind China and the US both with 13 patents in this technology. Despite a relatively high number of actors, the landscape of research in Europe is fragmented. The two patents in Europe are owned by SAP (China: 21, US: 13). European organisations did not manage to translate their knowledge on this technology into innovations protected by patents. Measures to encourage the transformation of knowledge into innovations should be put in place.
Ultra reliable low latency communication		Top Countries (Publications) EU (581/478) China (276) US (266) Patents Cont. Europe/World 12/141 Fragmentation 0,45	EU leads in terms of publications and is fifth in patenting with 12 patents, behind the US (61), China (33), South Korea (25). There is a significant number of R&D actors (>300) and the landscape of research in Europe is not fragmented. Out of the 12 European patents, 9 are owned by Nokia and 3 by Ericsson. European organisations did not manage to translate their knowledge on this technology into innovations protected by patents. In addition, the few patents by European organisations are owned by two companies, which makes the IP rights situation fragile. Measures to encourage patenting should be put in place to transform the significant knowledge of EU organisations into innovations.
Heterogeneous ultra-dense networks		Top Countries (Publications) China (93) EU (67/49) US (20) Patents Cont. Europe/World 0/10 Fragmentation 0,5	EU is second behind China in terms of publications. Despite the relatively low number of actors, the landscape of research in Europe is not fragmented. This low fragmentation could be the result of the 2 European projects funded by the EU in this technology. All of the ten patents retrieved are owned by Chinese organisations. China leads both in publications and patenting. Europe has some knowledge in the field but none of the patents retrieved have been filed by European organisations. Measures to encourage the transformation of knowledge into innovations should be put in place to ensure that Europe keeps some technological sovereignty.

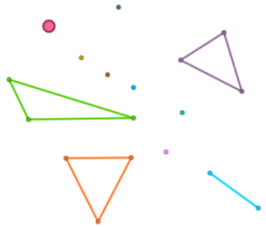
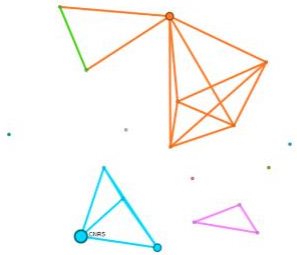
Drone detection		Top Countries (Publications) EU (47/38) US (28) South Korean (22) Patents Cont. Europe/World 2/30 Fragmentation 0,58	EU leads in terms of publications but is fourth in patenting behind China (5), the US (11), and South Korea (9), with only 2 patents. There are very few R&D actors in this technology but the four EU projects funded on this topic have ensured some connections between European organisations (low fragmentation). European organisations did not manage so far to translate their knowledge on this technology into innovations protected by patents. Measures to encourage patenting should be put in place to transform the significant knowledge of EU organisations into innovations. Support to EU organisations engaged in R&D could be envisaged to allow EU to keep its leading position in this technology. Collaboration between EU organisations should also be encouraged.
Massive machine type communication		Top Countries (Publications) EU (138/109) China (111) US (36) Patents Cont. Europe/World 4/26 Fragmentation 0,28	Europe and China lead in terms of publications. In patenting, South Korea leads with 6 patents, followed by the US and China (5 patents each) and Japan and the EU (4 patents each). The R&D landscape in Europe is not fragmented, which is possibly the consequence of the 4 EU projects funded on this. All patents originating from Europe are owned by Ericsson. Competition in this weak signal is still open, as the five major actors (Japan, South Korea, the US, China, and Europe) have all produced around 5 patents each. EU is leading in terms of publications and could therefore potentially remain technologically independent in this field if knowledge is effectively transformed into IP rights. The industrial champion in this field is Ericsson, owning all of the EU patents, which makes the IP position of EU fragile. Measures relying on the existing knowledge and actors should be put in place to reinforce R&D in this field and to ensure that more innovations are patented.
Fog computing		Top Countries (Publications) EU (915/737) China (645) US (555) Patents Cont. Europe/World 1/91 Fragmentation 1,06	EU leads in publications with more than 30% of the scientific articles (even if Brexit is considered). China and the US are respectively second and third in number of publications, but they lead in patenting with 53 Chinese patents and 20 US patents. Only one of the 91 patents retrieved coming from Europe (Erle robotics). There is significant knowledge in the field in Europe with a relatively well connected landscape. Organisations in Europe have so far failed to transform their knowledge into innovations. .Strong measures are needed to encourage patenting should if one wishes to avoid technological dependency in the future.
Edge computing		Top Countries (Publications) EU (1317/1010) China (1177) US (1050) Patents Cont. Europe/World 22/251 Fragmentation 0,46	China, the US and the EU are producing the same range of number of publications. Europe leads for the moment but will be at the third position after Brexit. There is significant knowledge in the field in Europe with a well-connected landscape and many R&D actors. In patenting, China (122) and the US (61 patents) are by far leading. 22 patents are owned by organisations in Europe, most of which are owned by Nokia (16/22). No measures are needed to support research in Europe on this topic, as the number of R&D actors is very high and the landscape not fragmented. But strong measures are needed to encourage patenting should one wishes to avoid technological dependency in the future.

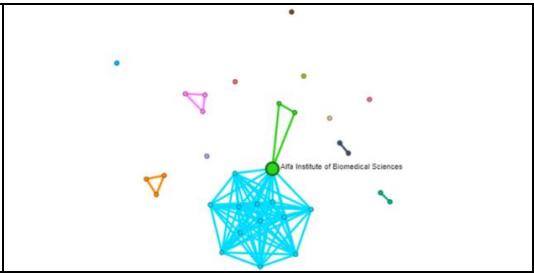
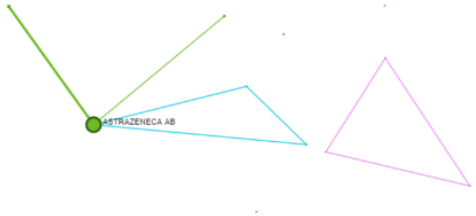
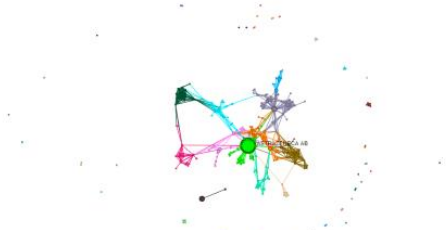
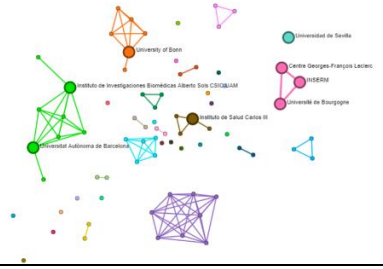
Drone base station		Top Countries (Publications) China (34) US (27) EU (26/18) Patents Cont. Europe/World 2/55 Fragmentation 1 ,46	China leads in terms of publications in this technology. There is little knowledge in Europe with few actors and a slightly fragmented landscape. When it comes to patenting, EU (2 patent) is far behind China (33), South Korea (12) and the US (5), reflecting the strong capacity of China and the US to transform knowledge into innovation, contrary to Europe. Should this weak signal be deemed important, measures to support both the research activities and patenting in Europe are needed. The risk of technological dependency should not be underestimated.
Mobile edge computing		Top Countries (Publications) China (560) EU (438/328) US (262) Patents Cont. Europe/World 18/108 Fragmentation 0,51	China leads in publishing in this WS, with EU and the US respectively second and third. There is significant knowledge in the field in Europe with a well-connected landscape and many R&D actors. In patenting, China (49 patents) leads in front of the US (21) and EU (17). 14 of the 17 patents in EU are owned by Nokia. No specific measures are needed to support research in Europe on this topic, as the number of R&D actors is very high and the landscape not fragmented. Some knowledge is transformed into innovations by European organisations, but most of the patents in Europe is in the hands of Nokia, which makes the EU IP position fragile. Measures to encourage patenting should be put in place to transform the significant knowledge of EU organisations into innovations and to increase the number of European actors owning inventions in the WS.
Public Blockchain		Top Countries (Publications) US (37) EU (35/24) China (29) Patents Cont. Europe/World 0/17 Fragmentation 5	The US is leading in terms of publications in this technology, followed by China and the EU. There is little knowledge in Europe with few actors and a very fragmented research environment. When it comes to patenting, European organisations have not filed any patents (US: 6 patents, South Kore: 6 patents, China: 3 patents). Should this weak signal be deemed important, measures to support both the research activities and patenting in Europe are needed. There is a risk of technological dependency in the near future.
Narrowband Internet of Things		Top Countries (Publications) China (534) EU (188/123) US (98) Patents Cont. Europe/World 37/830 Fragmentation 1,41	Chinese organisations lead by far in publishing of scientific articles. EU and the US follow with roughly four to five times less publications. In patenting, China also leads with 648 patents, followed by the US (73) and South Korea (40). Europe is fourth with 37 patents. There is some knowledge in Europe but not a high number of actors, which could be more connected (slight fragmentation). There is a risk of technological dependency for this weak signal if specific support is not put in place to encourage European organisations to transform knowledge into innovations and file patents. There is knowledge in this technology in Europe, but measures to increase the number of active organisations and to create a well-connected landscape could be considered.

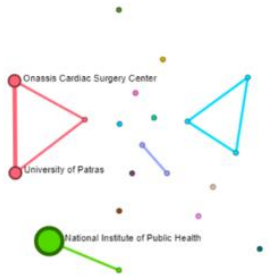
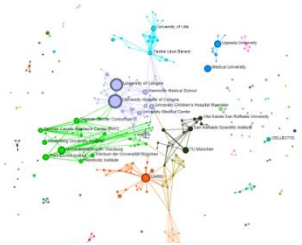
Ransomware detection		Top Countries (Publications) EU (29/18) US (26) China (13) Patents Cont. Europe/World 0/31 Fragmentation 2,71	A small number of publications has been retrieved for this weak signal (97). EU and the US produce most of the publications. There are very few actors in Europe and they are not collaborating much (high fragmentation). In patenting, US and Chinese organisations lead (US: 15 patents, China: 10 patents). No patents has been filed so far by European organisations. Should this weak signal be deemed important, measures to support both the research activities and patenting in Europe are needed. The risk of technological dependency will be real if European organisations do not engage in patenting.
Internet of battlefield things		Top Countries (Publications) EU (93/70) US (84) China (63) Patents Cont. Europe/World 0/19 Fragmentation 2,2	315 publications has been retrieved for this weak signal. The US, EU and China produce most of the publications. There are very few actors in Europe and they are not collaborating much (fragmentation > 2). In Europe, the community of R&D actors built around the Polish Military university of Technology is quite strong in publications. With only 19 patents filed worldwide, patenting activities are only starting. China and South Korea have respectively 13 and 4 patents. No patents has been filed so far by European organisations. Should this weak signal be deemed important, measures to support both the research activities and patenting in Europe are needed. The risk of technological dependency will be real if European organisations do not engage in more R&D and in patenting.
Residual neural network		Top Countries (Publications) China (60) US (38) EU (36/22) Patents Cont. Europe/World 0/12 Fragmentation 1,67	China, the US and EU produce most of the publications in this technology. There are very few actors in Europe and they could collaborate more together. With only 12 patents filed worldwide, patenting activities are only starting. All patents have been filed by Chinese organisations. Should this weak signal be deemed important, measures to support both the research activities and patenting in Europe are needed. The risk of technological dependency will be real if European organisations do not engage in more R&D and in patenting.

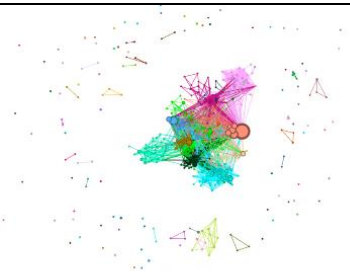
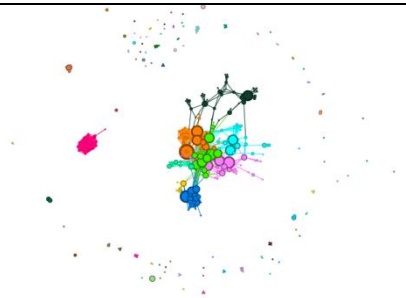
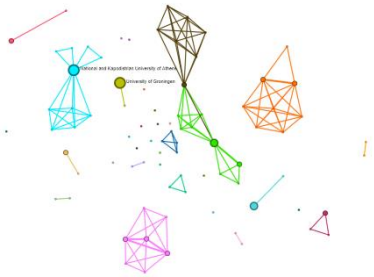
Weak signals with Brexit-risk			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Internet of drones		Top Countries (Publications) EU (14/10) US (6) China (6) Patents Cont. Europe/World 0/4 Fragmentation 2,2	R&D and patenting started very recently for this weak signal. With 14 publications out of 27, EU is well placed in research activities. Due to Brexit, 2 of the 13 actors will quit the research environment, leaving 11 actors in Europe. The landscape is fragmented and the main actor is the Polytechnic institute of Porto. In patenting, 1 out of the 4 patents is owned by a UK based organisation and will therefore leave the European sphere (China: 1, US: 1, South Korea: 1). Brexit will impact the R&D environment for this technology. Measures to reinforce research activities and patenting should be considered.

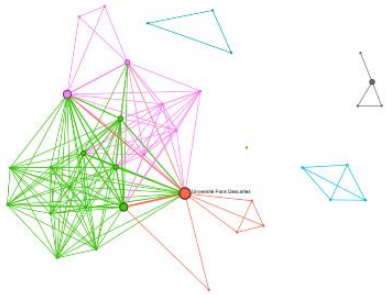
7.3 Health

EU is weak in knowledge production			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Taurine-upregulated gene 1		Top Countries (Publications) China (113) EU (14/12) US (11) Patents Cont. Europe/World 0/3 Fragmentation 1,8	Chinese organisations have taken a clear role in this weak signal, with ten times more publications than US and EU. There are very few European actors and the landscape of R&D activities in Europe is fragmented. Should this WS be deemed important, important efforts will have to be made to develop European R&D in this area as there is very little knowledge and actors to rely on. Measures to ensure that knowledge is transformed into innovations and patents should also be considered to avoid future technology dependency.
SC79		Top Countries (Publications) China (10) US (3) Japan (2) EU, South Korea, Taiwan (1) Patents Cont. Europe/World 0/0 Fragmentation -	China leads the R&D and only one publications from EU was retrieved. This EU publication comes from an organisation in the UK and no knowledge in Europe has been detected. The volume of publications is also very small for other territories. No patents were retrieved. There is no knowledge detected for Europe for this weak signal, which should be monitored to ensure adequate measures to support R&D and patenting in Europe can be timely taken should it become an important technology.
X-inactive specific transcript		Top Countries (Publications) China (45) EU (17/13) US (13) Patents Cont. Europe/World 0/1 Fragmentation 0,91	China leads the R&D, followed by the EU and the US. Twenty organisations in Europe are involved in 13 publications. These organisations are fairly well connected. One patent was retrieved (China). Should this WS be deemed important, significant efforts will have to be made to support R&D activities in Europe and ensure that knowledge is transformed into innovations.
Pegvaliase		Top Countries (Publications) US (9) EU (2) Patents Cont. Europe/World 0/0 Fragmentation -	The US leads the R&D (but with only 9 publications) and only two publications from EU were retrieved. These publication come from UK-based organisations and no knowledge in Europe has been detected. No patents were retrieved. There is no knowledge detected for Europe for this weak signal, which should be monitored to ensure adequate measures to support R&D and patenting in Europe can be timely taken should it become an important technology.

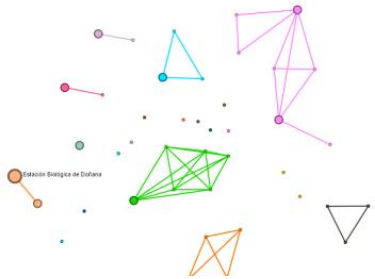
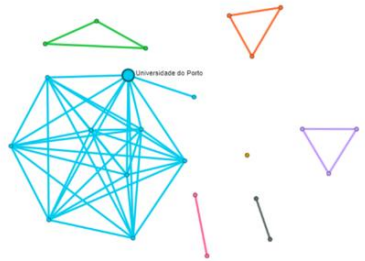
Siderophore cephalosporin		Top Countries (Publications) US (32) Japan (29) EU (18/13) Patents Cont. Europe/World 1/1 Fragmentation 0,35	R&D activities in this weak signal are led by the US and Japan. EU comes third with 18 publications. There are not many actors in Europe but they are fairly well connected together (low fragmentation). One patent was retrieved and is owned by a European organisation (Mutabilis, France). Should this WS be deemed important, some efforts will have to be made to reinforce R&D activities in Europe. There is some knowledge and a network of collaboration to rely on. Measures to ensure that knowledge is transformed into innovations and patents should also be considered.
New gout therapies		Top Countries (Publications) US (32) EU (18/15) China (11) Patents Cont. Europe/World 0/26 Fragmentation 1,25	US organisations are leading research activities in this weak signal. EU is second in terms of scientific publications. Only ten active organisations in Europe have been detected for a slightly fragmented landscape. Astrazeneca seems to play a key role, which should be considered in view of Brexit. 26 patents were retrieved: none were filed by organisations in Europe, 25 were filed by Chinese organisations. Should this WS be deemed important, measures to support the nascent R&D activities in Europe should be implemented. Patenting activities have started and measures to foster innovation in Europe should be put in place to avoid technological dependency in the future.
Tyrosine kinases inhibitors		Top Countries (Publications) China (484) EU (281/250) US (238), Japan (139) Patents Cont. Europe/World 1/57 Fragmentation 0,36	Europe is second in scientific publications, well behind China but before the US and Japan. 313 organisations in Europe are active in R&D for this weak signal. Many collaborations link the EU actors together (low fragmentation of the R&D environment). Despite a relatively high knowledge production, only 1 patents out of the 57 patents retrieved have been filed by an organisations in Europe (Astrazeneca, UK-Swedish company). 51 of the 57 patents are owned by Chinese organisations. Should this WS be deemed important, measures to push innovation and to ensure that IP rights are obtained by European organisations should be put in place to avoid future dependency on non-EU patents.
Gasdermin		Top Countries (Publications) China (69) US (64) EU (45/41) Patents Cont. Europe/World 0/7 Fragmentation 0,85	China and the US lead in terms of scientific publications for this weak signal. In Europe, there is production of knowledge (41 publications) and active organisations are fairly well connected. None of the seven patents retrieved was registered by a European organisation, which may be an early sign of the difficulty to transform knowledge into innovations in Europe for this specific weak signal. 3 patents are owned by US organisations, 3 by Chinese ones and 1 by Japan. Should this WS be deemed important, measures to push innovation based on the acquired knowledge and to ensure that IP rights are obtained by European organisations should be put in place.

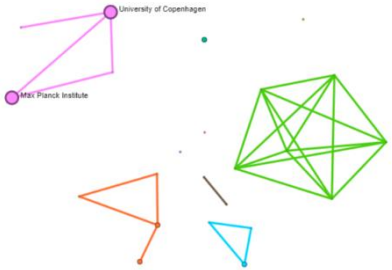
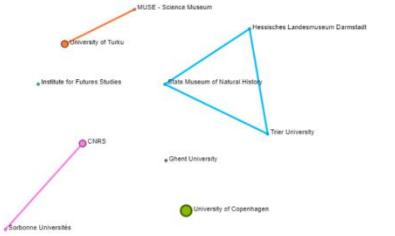
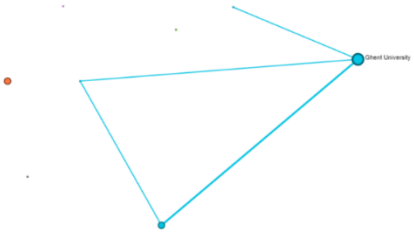
EU is weak in patenting			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Heat-not-burn tobacco product		Top Countries (Publications) US (45) EU (38/19) Switzerland (34) China (19) Patents Cont. Europe/World 0/88 Fragmentation 2,62	134 scientific publications and 88 patents were retrieved for this weak signal. The US lead in terms of publications in the field, with Europe second (but third if Brexit is taken into account). Only 21 actors from Europe were spotted and they do not collaborate much together (high fragmentation of the landscape). Although EU is active in knowledge production, none of the 88 patents retrieved has been filed by an organisation from Europe. Most of the patents (84) are indeed owned by Chinese tobacco companies. Should this weak signal be deemed of importance to Europe, measures to develop further R&D activities and to ensure the transformation of this knowledge into innovations should be put in place to avoid technology dependency.
CAR T cells immunotherapy		Top Countries (Publications) US (863) EU (408/311) China (239) Patents Cont. Europe/World 4/106 Fragmentation 0,68	The US leads this area of research with more scientific publications than EU and China together. There is a significant number of actors in Europe (>300), with a well-connected R&D landscape. As observed for many other WS, very few patents have been filed by EU organisations (4 out of 106). China and the US are leading with respectively 53 and 32 patents. There is knowledge and ongoing collaborations in Europe in this weak signal. But measures should be put in place to encourage patenting should if one wishes to avoid technological dependency in the future.
Tumor mutation burden		Top Countries (Publications) US (189) EU (103/92) China (54) Patents Cont. Europe/World 1/11 Fragmentation 0,62	The US leads this area of research with more scientific publications than EU and China together. There is a high number of actors in Europe (>150), evolving in a well-connected R&D environment. One out of the 11 patents retrieved has been filed by an EU organisation (Siemens), 10 of the 11 patents are owned by US organisations. There is knowledge and ongoing collaborations in Europe in this weak signal. But measures should be put in place to encourage patenting to avoid technological dependency in the future.
Ferroptosis		Top Countries (Publications) US (99) China (79) EU (78/69) Patents Cont. Europe/World 0/7 Fragmentation 0,625	Europe is at the third position in term of scientific publications, behind the US (1st) and China (2nd). There is more than a hundred organisations with knowledge in this field in Europe, with a fairly high number of scientific collaborations (low fragmentation). None of the 7 patents retrieved is owned by an EU organisations (4 patents in the US, 2 in South Korea, 1 in Japan). There is some knowledge and ongoing collaborations in Europe in this weak signal. But measures should be put in place to encourage patenting should if one wishes to avoid possible technological dependency in the future.

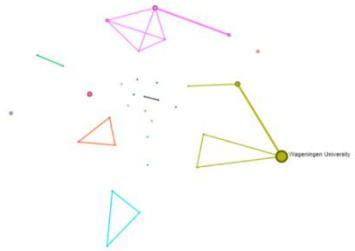
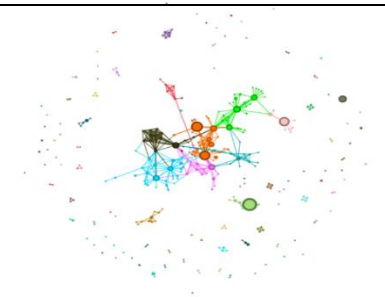
Programmed death-ligand 1 inhibitors		Top Countries (Publications) US (1033) EU (786/659) China (331) Japan (308) Patents Cont. Europe/World 11/304 Fragmentation 0,23	The US are leading in terms of scientific publications. There are many active organisations in Europe (>800) and scientific collaboration is very intense (very low fragmentation). Despite this knowledge, Europe is lagging behind in patenting with only 11 patents out of 304 (86 patents from the US, 85 from China). Europe is very knowledgeable in this weak signal but European organisations did not manage to translate their knowledge into innovations protected by patents. Measures to encourage the transformation of knowledge into innovations should be put in place to avoid technological dependency.
Cyclin-dependent kinase 4/6 inhibitors		Top Countries (Publications) US (455) EU (309/250) China (105) Patents Cont. Europe/World 2/62 Fragmentation 0,33	US leads in terms of scientific publications. Europe is second in knowledge production, with a significant number of R&D actors (>300). The R&D landscape in Europe is very well connected (no fragmentation). Despite this, Europe is lagging behind in patenting with only 2 patents out of 62 retrieved (15 from the US, 22 from China). For this WS, European organisations did not manage to translate their knowledge into innovations protected by patents. Measures to encourage patenting should be put in place to transform the significant knowledge of EU organisations into innovations.
Senolityc drugs		Top Countries (Publications) US (82) EU (66/47) China (9) Patents Cont. Europe/World 0/6 Fragmentation 0,67	The US are leading in terms of scientific publications, Europe is second. 83 organisations are active in Europe and they collaborate together. None of the 6 patents retrieved is owned by an EU organisations (5 in the US, 1 in the UK). There is knowledge and ongoing collaborations in Europe in this weak signal. To avoid possible technological dependency in the future, measures should be put in place to make sure EU organisations develop innovations protected by patents.

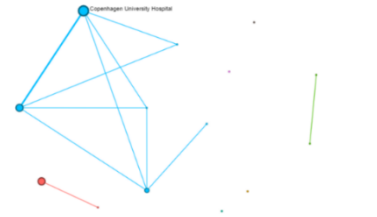
Weak signals with Brexit-risk			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Activated phosphoinositide 3-kin syndrom		Top Countries (Publications) US (17) EU (14/10) Patents Cont. Europe/World 1/1 Fragmentation 0,24	R&D and patenting started very recently for this weak signal. With only 17 publications for the US (leading) and 14 for the EU (2nd). Due to Brexit, the knowledge of 28 UK organisations will leave Europe. These organisations were involved in 8 of the 13 publications from EU and their departure will create significant perturbations in ongoing R&D activities. The only patent detected for this WS is owned by UCB based in Belgium. Brexit will have a significant impact in this weak signal if measures to reinforce currently ongoing research activities are not put in place.
Targeted memory reactivation		Top Countries (Publications) EU (25/12) US (21) Patents Cont. Europe/World 0/0 Fragmentation 1,2	R&D and patenting started very recently for this weak signal. Europe leads in terms of scientific output, but with only 25 publications. Due to Brexit, half of this knowledge will leave Europe, leaving only 14 R&D organisations in a fragmented landscape. Brexit will have significant impact in this weak signal and measures to reinforce currently ongoing research activities and to promote patenting should be put in place.

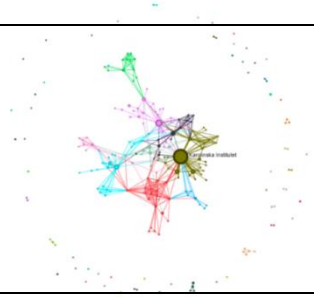
7.4 Biology

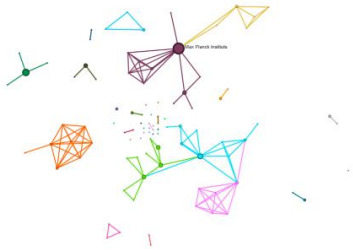
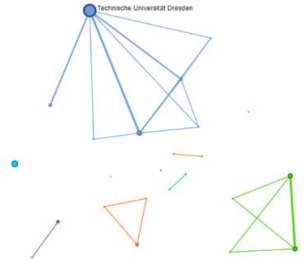
EU is weak in knowledge production			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Synthetic Notch		Top Countries (Publications) US (10) Patents Cont. Europe/World 0/0 Fragmentation -	R&D activities started very recently in this weak signal. All publications retrieved have been published by US organisations. Should this WS be deemed important, massive efforts will have to be made to support R&D in Europe and to make sure that the acquired knowledge is transformed into innovations protected by patents. There will be a risk of future technological dependency if this weak signal turns out to become an important technology.
Transcriptome metabolome wide associat.		Top Countries (Publications) US (5) South Korea (1) Patents Cont. Europe/World 0/0 Fragmentation -	All publications retrieved for this weak signal have been published by US and South Korea. Should this WS be deemed important, massive efforts will have to be made to support R&D in Europe and to make sure that the acquired knowledge is transformed into innovations protected by patents. There will be a risk of future technological dependency if this weak signal turns out to become an important technology.
Double digest RAD Sequencing		Top Countries (Publications) US (58) EU (33/31) China (19) Japan (18) Patents Cont. Europe/World 0/0 Fragmentation 1,075	EU is second in production of scientific knowledge for this technology, even if Brexit is taken into account. The US is leading and China is not far behind. A small number of actors are active in Europe and the landscape is slightly fragmented. The risk here is to see US organisations continuing to lead and China catching up fast, leaving EU behind. The R&D activities in this WS should be monitored, and should it appear to be important for Europe, measures to support current ongoing R&D in Europe will have to be put in place (little knowledge so far and few actors). Measures to ensure that patenting activities are pursued will also need to be devised.
Thanatomicrobiome		Top Countries (Publications) US (38) EU (14/8) Patents Cont. Europe/World 0/0 Fragmentation 0,5	EU is second in production of scientific knowledge for this WS, with US leading. 24 organisations based in Europe have been detected as active in R&D in the field. They are already fairly well connected together. The risk here is to see US organisations continuing to lead and other countries catching up fast, leaving EU behind. The R&D activities in this WS should be monitored, and should it appear to be important for Europe, measures to support current ongoing R&D in Europe will have to be put in place (little knowledge so far and few actors). Measures to ensure that patenting activities are pursued will also need to be devised.

Anti-CRISPR		Top Countries (Publications) US (50) Canada (24) EU (23/20) China (13) Patents Cont. Europe/World 0/3 Fragmentation 0,85	EU comes at the third place in terms of scientific publications, after the US and Canada. Despite the few actors in Europe, the research environment is not fragmented, which might be due to the 3 EU projects related to this technology. The 3 patents retrieved were all filed by US organisations. Should this WS be deemed important, some efforts will have to be made to reinforce R&D in Europe and create a network of knowledgeable actors. This could possibly be done through the EU funding programme Horizon Europe. Measures to ensure that knowledge is transformed into innovations and patents should also be considered.
De-extinction		Top Countries (Publications) US (36) EU (19/10) Australia (12) Patents Cont. Europe/World 0/0 Fragmentation 2	Few publications and patents have been retrieved for this WS. With 36 publications, US leads in knowledge production. Almost half of the European knowledge in this technology is located in the UK. The number of actors in Europe is very small (10) and the landscape is fragmented. No patents were detected yet. Should this WS be deemed important, massive efforts will have to be made to create R&D activities in Europe and create a network of knowledgeable actors. This could possibly be done through the EU funding programme Horizon Europe.
Acute hepatopancreatic necrosis disease		Top Countries (Publications) Thailand (53), US (34) China (26), Japan (16) EU (16/12) Patents Cont. Europe/World 0/10 Fragmentation 2	EU is lagging behind in terms of number of scientific publications in this weak signal which is led by organisations from Thailand. The number of actors in Europe is very small (8) and the landscape is fragmented. 10 patents were detected but none is owned by an organisations from the EU. Should this WS be deemed important, massive efforts will have to be made to create R&D activities in Europe and create a network of knowledgeable actors. This could possibly be done through the EU funding programme Horizon Europe. Measures to ensure that knowledge is transformed into patented innovations should also be considered.
Diagnostics based on circular RNA		Top Countries (Publications) China (402) EU (60/53) US (52) Patents Cont. Europe/World 1/11 Fragmentation 0,86	With 396 publications, China leads in knowledge production in this technology. Europe is second with 53 publications and an R&D landscape that shows some degree of collaborations between actors. One out of the 11 patents has been filed by a European organisation, all the others are owned by Chinese entities. Should this WS be deemed important, measures to further develop R&D in Europe, to connect R&D actors and to ensure that IP rights are obtained by European organisations should be implemented. There is a risk of technological dependency if Europe does not invest in patenting.

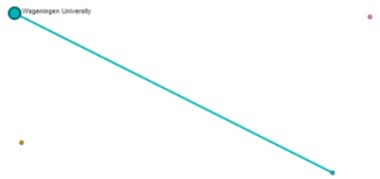
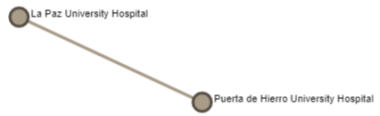
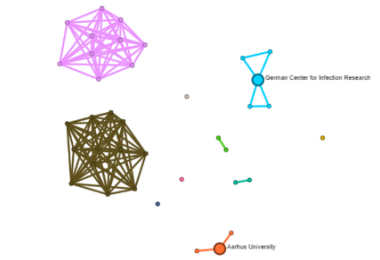
CRISPR/CPF1		Top Countries (Publications) US (92) China (84) EU (42/34) Patents Cont. Europe/World 2/39 Fragmentation 1,65	Europe is in 3rd position in number of publications in this WS. The R&D landscape is slightly fragmented and only 2 out of the 39 patents retrieved are owned by European organisations. Organisations in China and the US owning respectively 21 and 10 patents. Should this WS be deemed important, measures to further develop R&D in Europe, to connect R&D actors and to ensure that IP rights are obtained by European organisations should be implemented. There is a risk of technological dependency.
Bacillus velezensis		Top Countries (Publications) China (89) EU (35/30) South Korea (33), US (25) Patents Cont. Europe/World 1/59 Fragmentation 5,17	Europe is in second in number of publications in this WS, behind China (third behind China and South Korea if Brexit is taken into account). The R&D landscape is highly fragmented and there are few European actors. Only 1 out of the 59 patents retrieved are owned by European organisations. Chinese and South Korean organisations own more than half of the patents (China: 33 patents, South Korea: 22 patents). Should this WS be deemed important, measures to further develop R&D in Europe, to connect R&D actors and to ensure that IP rights are obtained by European organisations should be implemented. There is a risk of technological dependency.
Circular RNA		Top Countries (Publications) China (1461) EU (467/417) US (418) Patents Cont. Europe/World 4/146 Fragmentation 0,68	More than 2000 scientific publications related to circular RNA have been retrieved. China clearly leads, followed by EU and the US. Europe accounts only for around 18% of the publications in the field. There is a significant number of actors in Europe (336) and there is high level of collaboration (low fragmentation). Only 4 patents out of the 146 retrieved are owned by organisations in Europe (Germany). 13 patents are owned by US organisations, 121 by Chinese individuals or organisations. Europe does produce knowledge in this weak signal but account for less than 18% of the publications in the field. European organisations did not manage so far to translate this knowledge into innovations protected by patents. Measures to encourage R&D and the transformation of knowledge into innovations should be put in place to avoid future technological dependency.

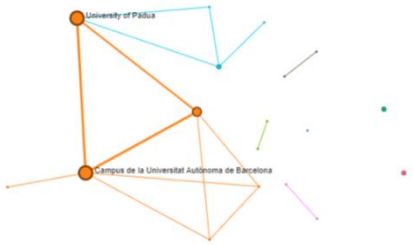
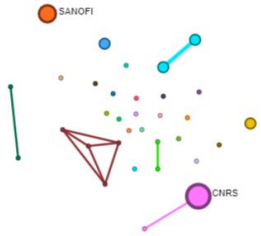
EU is weak in patenting			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Spytag spycatcher protein ligase		Top Countries (Publications) China (37), US (31) EU (28/13) Patents Cont. Europe/World 0/6 Fragmentation 1,4	30 out of the 88 scientific publications in this WS are from European organisations. With half of these published by (or in collaboration with) organisations located in the UK, Brexit will significantly disturb this nascent R&D community. Only 14 R&D organisations in Europe will be active after Brexit. In addition, none of the 6 patents retrieved was filed by an organisations from Europe (US:1, Australia:1, China:4). Should this WS be deemed important, measures to further develop R&D in Europe, to connect R&D actors and to ensure that IP rights are obtained by European organisations should be implemented.

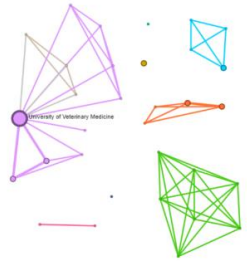
Single cell RNA sequencing		Top Countries (Publications) US (693) EU (418/283) China (161) Patents Cont. Europe/World 0/8 Fragmentation 0,46	34% of the scientific publications in this technology involve European organisations, placing EU at the second place in knowledge production after the US. But with 44% of these publications published by (or in collaboration with) organisations located in the UK, Brexit will significantly disturb the European R&D community. Nevertheless, even with UK organisations leaving EU, there will still be significant R&D actors in Europe, in a very well connected landscape (low fragmentation). In patenting, EU owns none of the patent out of the eight detected (US: 6, China:2). Should this WS be deemed important, measures to ensure that knowledge developed by European organisations are transformed into innovations and that IP rights are acquired should be implemented.

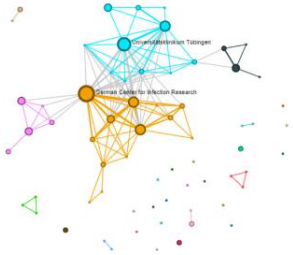
Weak signals with Brexit-risk			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Assay for transposas-acc. chromat seq		Top Countries (Publications) US (210) EU (103/73) China (26) Patents Cont. Europe/World 0/5 Fragmentation 0,84	In terms of publications, Europe is second for this weak signal behind China. As UK is involved or responsible for around 40% of the scientific publications, Brexit will disturb the R&D landscape in Europe. After Brexit, 98 R&D actors will still be active in Europe and they will be relatively well connected through scientific collaborations. In patenting, all patents are owned by Chinese organisations. Brexit will have significant impact in this weak signal if measures to reinforce research activities and patenting are not put in place. In addition, measures to support innovation in the field should be implemented.
Retinal organoids		Top Countries (Publications) US (38) EU (37/24) China (8) Patents Cont. Europe/World 0/1 Fragmentation 1,04	Europe occupies the second position in terms of publications. As UK is involved or responsible for around 43% of the scientific publications, Brexit will disturb the R&D landscape in Europe. After Brexit, only 24 R&D actors will still be active in Europe and they will be weakly connected. In patenting, only one patents was retrieved in this field and is owned by a US based company. Brexit will have significant impact in this weak signal if measures to reinforce research activities and patenting are not put in place. In addition, measures to support innovation in the field should be implemented.
Spray-induced gene silencing		Top Countries (Publications) US (7) EU (7/4) Patents Cont. Europe/World 0/3 Fragmentation: 4	Europe and the US “lead” in this technology where R&D started very recently. 8 European organisations are involved and with Brexit, 4 of these will leave Europe and leave only 4 actors in EU. In patenting, none of the three patents is from an EU based organisations, but the field is very recent. All patents are owned by Monsanto. Brexit will cut in half the number of actors from Europe in this WS characterized by a very nascent R&D. Should the technology be deemed important for Europe, measures to reinforce research activities and patenting have to be in place. In addition, measures to support innovation in the field should be implemented to avoid technology dependency.

7.5 Viruses

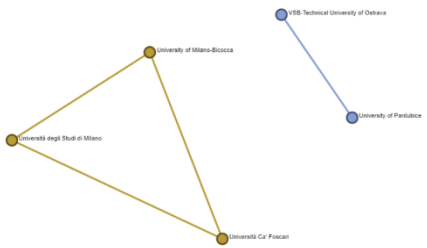
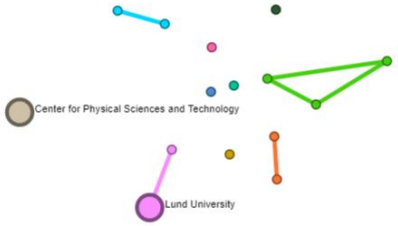
EU is weak in knowledge production			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Orthotospovirus		Top Countries (Publications) US (12), India (7) China, Brazil (5) EU (5/4) Patents Cont. Europe/World 0/0 Fragmentation 4	Only 33 publications were retrieved for this WS, with the US leading. Very few publications from European organisations and very few actors. No patents were retrieved. Little R&D activity has been detected in this weak signal and it is too early to recommend specific support measures. The importance of this WS and the positioning of EU organisations should be monitored to ensure timely measures are put in place to support European actors if necessary.
MK-8591		Top Countries (Publications) US (12) EU (2/1) Patents Cont. Europe/World 1/1 Fragmentation 2	Very few publications were retrieved for this WS, with the US involved in 12 of the 13 scientific publications. In Europe, Spanish institutions have published on this topic. One patent was filed by a US-based organisation. Little R&D activities have been detected in this weak signal and it is too early to recommend specific support measures. The importance of this WS and the positioning of EU organisations should be monitored to ensure timely measures are put in place to support European actors if necessary.
Grapevine red blotch virus		Top Countries (Publications) US (37) EU (12/12) Patents Cont. Europe/World 0/0 Fragmentation 2,6	52 publications were retrieved for this WS, with the US leading. Very few publications from European organisations and very few actors. No patents were retrieved. Little R&D activities have been detected in this weak signal and it is too early to recommend specific support measures. The importance of this WS and the positioning of EU organisations should be monitored to ensure timely measures are put in place to support European actors if necessary.
Quantitative viral outgrowth assay HIV		Top Countries (Publications) US (56) EU (14/12) Canada (13) Patents Cont. Europe/World 0/0 Fragmentation 0,31	69 publications were retrieved for this WS .The US has a clear leading role with involvement in 56 publications. 38 organisations in Europe are collaborating in this WS (low fragmentation). No patents were retrieved. This WS and the positioning of EU organisations should be monitored to ensure timely measures are put in place to support R&D by European actors if necessary. The US have taken a clear leading role and this could lead to technological dependency if European organisations do not engage in patenting.

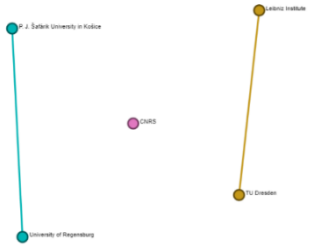
Tomato mottle mosaic virus		Top Countries (Publications) US (8) China (7) EU (4/4) Patents Cont. Europe/World 0/0 Fragmentation 4	Very few publications (18) were retrieved for this WS. 4 European organisations are active (4 publications) but are not collaborating together. No patent were retrieved. Little R&D activities have been detected in this weak signal and it is too early to recommend specific support measures. The importance of this WS and the positioning of EU organisations should be monitored to ensure timely measures are put in place to support European actors if necessary.
Porcine circovirus 3		Top Countries (Publications) China (60) EU (24/16) US (11) Patents Cont. Europe/World 0/21 Fragmentation 1,125	77 publications were retrieved for this WS. China leads with Chinese organisations taking part in 60 publications, EU is second. 18 European organisations in Europe are engaged in R&D and are fairly well connected. Out of the 21 patents retrieved, 20 are owned by Chinese organisations. Should this WS be deemed important, measures to support R&D activities in Europe and to encourage European organisations to transform knowledge into innovations and that IP rights are acquired should be put in place. There is a risk of technological dependency if European organisations do not engage in patenting activities.
Zika virus vaccine		Top Countries (Publications) US (122) EU (53/35) Patents Cont. Europe/World 3/29 Fragmentation 3,4	The US lead this weak signal with 122 publications, well in front Europe (47). R&D organisations active in Europe are not collaborating much with each other (high fragmentation). 3 patents out of 29 are owned by French organisations (Sanofi and Institut Pasteur). China and the US own the others. Should this WS be deemed important, measures to connect R&D actors and to ensure that IP rights are obtained by European organisations should be put in place. There is a risk of technological dependency if European organisations do not engage in patenting activities.

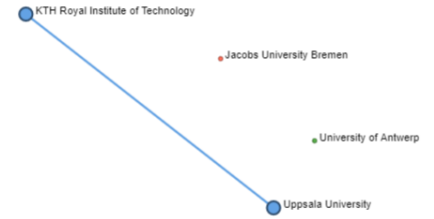
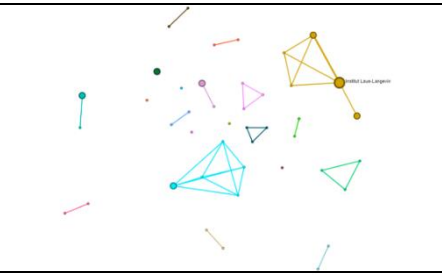
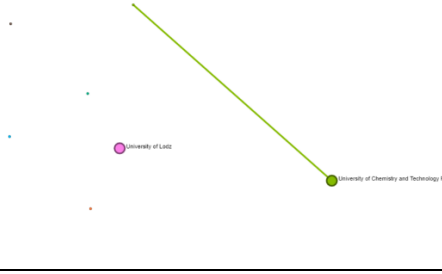
EU is weak in patenting			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Atypical porcine pestivirus		Top Countries (Publications) China (20) EU (16/16) US (11) Patents Cont. Europe/World 0/6 Fragmentation 0,58	China leads for this weak signal in terms of publications. R&D actors in Europe are well connected. In patenting, Chinese and US organisations are owning the 6 patents retrieved. Should this WS be deemed important, measures will be needed to ensure that Europe continues to lead and to push patenting.

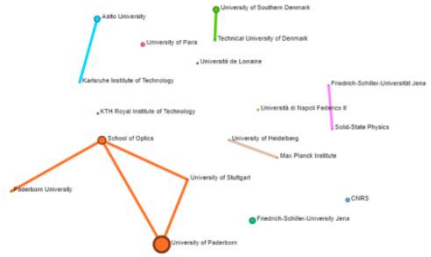
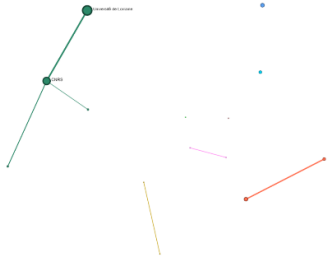
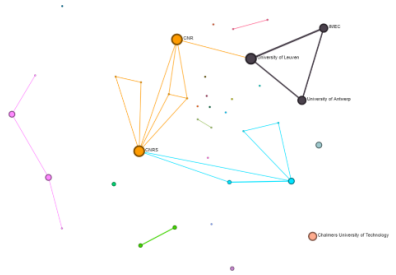
Weak signals with Brexit-risk			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Ebola vaccine		Top Countries (Publications) US (122) EU (80/53) Switzerland (29) Patents Cont. Europe/World 0/3 Fragmentation 0,54	Europe comes second in terms of scientific publications for this weak signal. More than half of the publications from Europe involve organisations from the UK. Actors in Europe will remain fairly well connected after Brexit (low fragmentation). In patenting, no patent is owned by European organisations. 20% of the R&D actors in Europe are based in the UK. Brexit will disturb the research environment but organisations in Europe should resist the perturbation. Measures to ensure Europe is able to patent its knowledge in this field should be put in place.
Glecaprevir/Pibrentasvir		Top Countries (Publications) US (64) EU (41/36) Japan (20) Patents Cont. Europe/World 0/1 Fragmentation 0,54	Europe comes second in terms of scientific publications for this WS. More than half of the publications from Europe involve organisations from the UK. Actors in Europe will remain fairly well connected (low fragmentation). The patent retrieved is owned by a US company. 15 UK based organisations will leave Europe after Brexit. This should not affect too much R&D actors in Europe (83) which are fairly well connected, but measures to support this research ecosystem could be considered.
Herpes zoster vaccine		Top Countries (Publications) EU (29/23) US (28) Australia (7) Patents Cont. Europe/World 0/1 Fragmentation 0,55	Europe and the US lead in R&D on Herpes Zoster Vaccine. 7 R&D organisations from the UK, including GSK, are involved (20% of the European actors). Organisations in Europe will remain connected (low fragmentation). Due to the low number of R&D organisations in Europe, Brexit could impact negatively currently ongoing R&D activities. Measures to support R&D actors active on this topic should be considered.

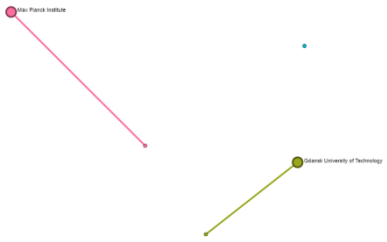
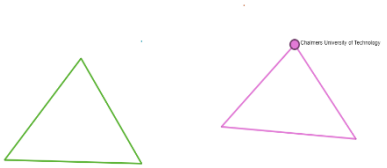
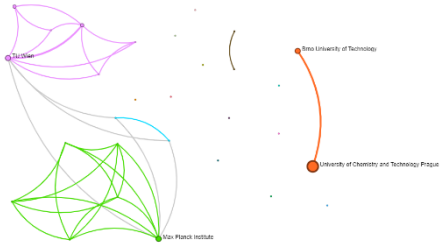
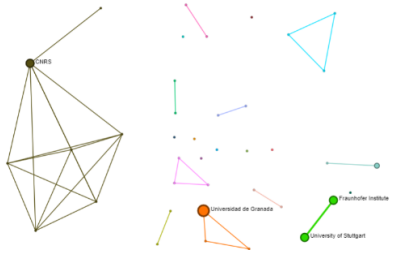
7.6 Materials

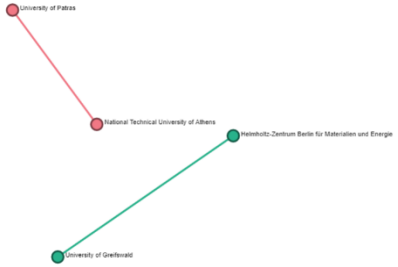
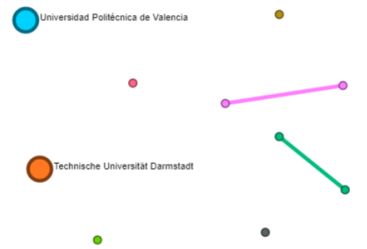
EU is weak in knowledge production			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Surface heterojunction photocatalytics		Top Countries (Publications) China (49) Saudi Arabia (5) Taiwan (3) US , Japan, EU Australia (2) Patents Cont. Europe/World 0/3 Fragmentation 1,25	Europe (and other countries) is lagging behind for this weak signal, with China clearly leading. They are very few actors in Europe and little knowledge production. All three patents were filed by Chinese organisations. Should this WS be deemed important, significant support will have to be put in place to create R&D activities and patenting in Europe. There is very little knowledge in EU and there is a possibility of technological dependency.
Twisted and coiled polymer muscles		Top Countries (Publications) US (16) EU, China (1) Patents Cont. Europe/World 0/0 Fragmentation -	Europe is lagging behind for this weak signal, with US being clearly ahead in terms of publications. Only one research organisation from Europe was spotted. Should this WS be deemed important, significant support will have to be put in place to create R&D activities and patenting in Europe. There is very little knowledge in EU and there is a possibility of technological dependency.
Phagraphene		Top Countries (Publications) China (12), US (5) Russia (4), Brazil (3) EU (3/2) Patents Cont. Europe/World 0/0 Fragmentation -	Europe is lagging behind for this weak signal, with US being clearly ahead in terms of publications. Only one research organisation from Europe was spotted. Should this WS be deemed important, significant support will have to be put in place to create R&D activities and patenting in Europe. There is very little knowledge in EU and there is a possibility of technological dependency.
Perovskite photodetectors		Top Countries (Publications) China (136) US (41) EU (19/12) Patents Cont. Europe/World 0/4 Fragmentation 4	Chinese organisations are leading in publishing in this WS. There are very few R&D organisations from Europe engaged in R&D on this topic. The 4 patents detected were filed by Chinese organisations. Should this WS be deemed important, significant supporting measures will have to be put in place to support R&D and to push innovation. There is very little knowledge in EU and there is a possibility of technological dependency.

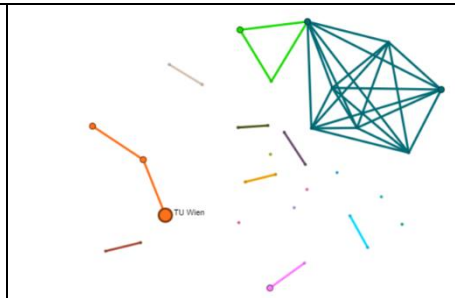
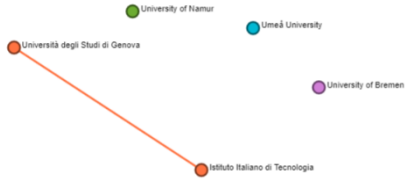
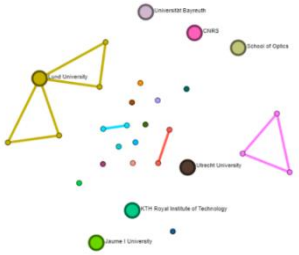
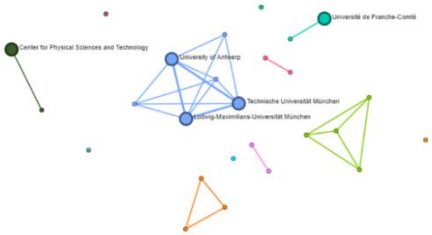
Bimetallic organic frameworks		Top Countries (Publications) China (115) US (21) EU (20/19) Patents Cont. Europe/World 0/3 Fragmentation 3,6	Chinese organisations are leading in publishing in this WS. There are few R&D organisations from Europe engaged in R&D on this topic, and they are not well connected through scientific collaboration. The 3 patents retrieved were filed by Chinese organisations. Should this WS be deemed important, significant supporting measures will have to be put in place to support R&D and to push innovation. There is very little knowledge in EU and there is a possibility of technological dependency.
Pet-Raft polymerisation		Top Countries (Publications) China (48) Australia (24) US (19) EU (8) Patents Cont. Europe/World 0/0 Fragmentation 3	Europe is lagging behind for this weak signal, with China being clearly ahead in terms of publications. Out of the 8 publications retrieved for Europe, 5 are from UK based organisations. After Brexit, only 3 organisations will be active on this topic in Europe. No patents were retrieved. Should this WS be deemed important, significant support will have to be put in place to create R&D activities and patenting in Europe. There is very little knowledge in EU and there is a possibility of technological dependency.
Cr2Ge2Te6		Top Countries (Publications) China (21), US (13) Japan (10), South Korea (4) EU (4/3) Patents Cont. Europe/World 0/0 Fragmentation 2,5	Europe is behind in this weak signal, with China leading in terms of publications. 5 organisations from Europe have published on the topic. No patents were retrieved. Should this WS be deemed important, significant support will have to be put in place to create R&D activities and patenting in Europe. There is very little knowledge in EU and there is a possibility of technological dependency.
0d 2d heterostructures		Top Countries (Publications) China (116) US (43) EU (31/21) Patents Cont. Europe/World 0/1 Fragmentation 2,11	EU occupies the third place in terms of scientific publications. China is in the lead. 19 organisations in Europe are engaged in R&D in this particular technology. Despite 2 EU projects on the matter, the R&D landscape in Europe could be more collaborative. The patent retrieved is owned by a Chinese organisation. In this WS, measures to support R&D should be put in place. There is some knowledge developed in Europe on which to rely on. Patenting should be pushed whenever possible.

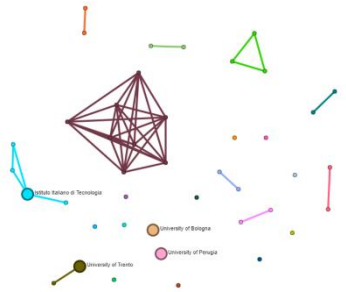
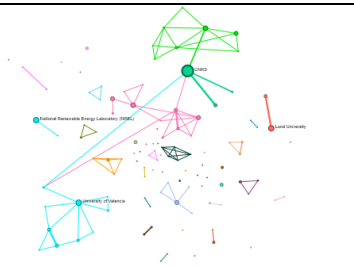
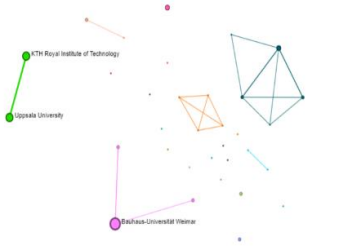
Renal clearable nanoparticles		Top Countries (Publications) China (25) US (25) EU (7/6) Patents Cont. Europe/World 0/2 Fragmentation 2	Europe is behind in this weak signal, with China and the US leading in terms of publications. Only 10 organisations from Europe have published on the topic. The two patents retrieved were filed by US organisations. Should this WS be deemed important, significant support will have to be put in place to create R&D activities and patenting in Europe. There is very little knowledge in EU and there is a possibility of technological dependency.
Borophane		Top Countries (Publications) China (14) EU (4/4) US (3) Patents Cont. Europe/World 0/0 Fragmentation 4	Only 24 scientific publications have been retrieved. Europe is behind (so are other countries), China leads. Only 4 organisations from EU have been involved in knowledge production. No patents were retrieved for this weak signal. The evolution of this WS should be monitored. If it turns out to be of strategic relevance (important innovations related to it), significant measures to support R&D in Europe will have to be put in place. There is very little knowledge in EU and there is a possibility of technological dependency.
Tin selenide crystals		Top Countries (Publications) China (80) EU (31/28) US (28) Patents Cont. Europe/World 0/5 Fragmentation 1,26	EU and the US occupy the 2nd and 3rd position in terms of publications, behind China. 44 organisations in Europe are engaged in R&D activities. The collaboration landscape could be denser (slight fragmentation). The 5 patent retrieved are owned by Chinese organisations. In this WS, measures to support R&D and increase the degree of collaboration should be put in place. There is some knowledge to rely on in Europe. Transformation of knowledge into innovations and patents should be encouraged.
Bismuthene		Top Countries (Publications) China (37) US (13) EU (10/10) Patents Cont. Europe/World 0/3 Fragmentation 7/1	Only 50 publications and 3 patents were retrieved for this WS. China leads in publications and patenting. In Europe, the 6 organisations engaged in R&D do not collaborate together (high fragmentation). The evolution of this WS should be monitored. If it turns out to be of strategic relevance (important innovations related to it), significant measures to support R&D in Europe will have to be put in place as there is very little knowledge in EU and very few actors.

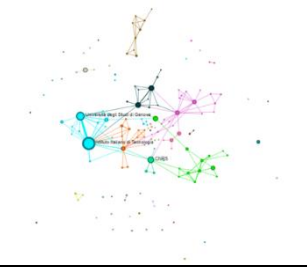
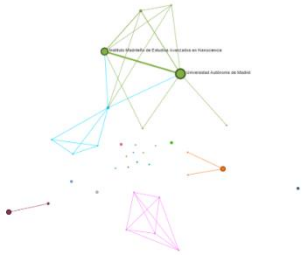
Nanocinnamon		Top Countries (Publications) Malaysia (7) EU (3/2) Patents Cont. Europe/World 0/0 Fragmentation -	Very few publications have been retrieved for this weak signal. Only one organisation in Europe has some research activities. The evolution of this WS should be monitored. If it turns out to be of strategic relevance (important innovations related to it), significant measures to support R&D in Europe will have to be put in place as there is very little knowledge in EU and only one actor.
Hologram metasurface		Top Countries (Publications) China (119) US (90) EU (51/28) Patents Cont. Europe/World 0/4 Fragmentation 2,375	EU occupies the third place in terms of scientific publications. China is in the lead. After Brexit, 19 organisations in Europe will be engaged in R&D in this particular technology. The R&D landscape in Europe could be more collaborative. The patents retrieved are owned by US, Taiwanese, and Chinese organisations. In this WS, measures to support R&D should be put in place. There is some knowledge developed in Europe on which to rely on. Patenting should be encouraged to avoid future technology dependency.
Acoustic metasurface		Top Countries (Publications) China (118) EU (41/30) US (39) Patents Cont. Europe/World 0/3 Fragmentation 2,33	EU is second behind China in terms of scientific publications. Only 14 organisations in Europe are engaged in R&D in a slightly fragmented landscape. All three patents are owned by Chinese organisations. In this WS, measures to support R&D should be put in place. There is some knowledge developed in Europe on which to rely on. Patenting has started and measures to encourage EU organisations to innovate should be put in place to avoid future technology dependency.
Stanene		Top Countries (Publications) China (99) EU (54/47) US (53) Patents Cont. Europe/World 0/4 Fragmentation 1,52	EU and the US are second behind China in terms of scientific publications. 38 organisations in Europe are engaged in R&D in a slightly fragmented landscape. The retrieved patents are owned by Chinese and Malaysian organisations. In this WS, measures to support R&D should be put in place. Patenting activity has started and measures to encourage EU organisations to innovate should be put in place to avoid future technology dependency.

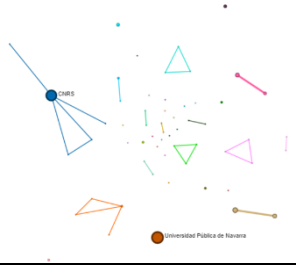
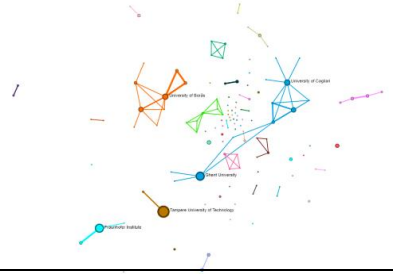
PbTaSe2 superconductor		Top Countries (Publications) China (15), US (12) Taiwan (9) EU (5/5) Patents Cont. Europe/World 0/0 Fragmentation 2,5	Only 24 scientific articles were retrieved. China and the US are involved in most of the publications, Europe is fourth in terms of publishing. Only 5 organisations performing R&D on this topic have been spotted in Europe. No patents were retrieved. The evolution of this WS should be monitored. If it turns out to be of strategic relevance (important innovations related to it), significant measures to support R&D in Europe will have to be put in place as there is very little knowledge in EU and very few actors.
Eutectic high entropy alloy		Top Countries (Publications) China (38) EU (13/13) India (11) Patents Cont. Europe/World 0/2 Fragmentation 1,33	China leads for this technology in terms of scientific publications, with EU second. There are only 8 organisations in Europe active in R&D. The 2 patents retrieved are owned by Chinese organisations. The evolution of this WS should be monitored. If it turns out to be of strategic relevance (important innovations related to it), significant measures to support R&D in Europe will have to be put in place as there is very little knowledge in EU and very few actors.
Arsenene		Top Countries (Publications) China (123) EU (27/25) US (25) Patents Cont. Europe/World 0/0 Fragmentation 0,85	China leads by far for this weak signal in terms of scientific publications, with EU and the US second. 29 European organisations are performing research. No patents were retrieved. The evolution of patenting for this WS should be monitored. If the patent race started, measures will be needed to encourage patenting by organisations in EU. If it turns out to be of strategic relevance, measures to support R&D in Europe will have to be put in place as there is very little knowledge in EU and few actors.
Biomimetic nanoparticles		Top Countries (Publications) US (60) China (52) EU (29/28) Patents Cont. Europe/World 0/0 Fragmentation 1,22	US and Chinese organisations lead in scientific publications for this WS. Europe lags a bit behind. There are 39 actors in Europe in a fairly well connected collaborative landscape. No patents have been retrieved for this technology. Should this WS be deemed important, measures to support R&D actors in Europe should be put in place. There is some knowledge developed in Europe on which to rely on. Patenting has not started yet and measure to encourage EU organisations to innovate should be put in place to avoid future technology dependency.

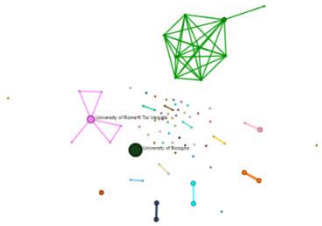
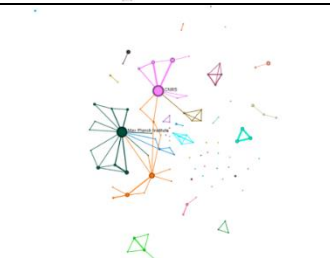
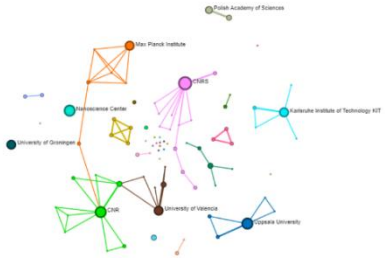
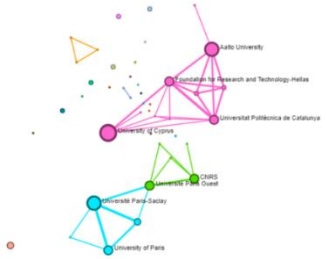
PET hydrolytic enzymes		Top Countries (Publications) China (7) EU (4/2) Japan (3) US (2) Patents Cont. Europe/World 0/2 Fragmentation 2	Only 14 scientific articles were retrieved and no leading role can be attributed at this point. Only 4 actors were detected in Europe. The two patents retrieved are owned by Chinese entities. The evolution of this WS should be monitored. If it turns out to be of strategic relevance (important innovations related to it), significant measures to support R&D in Europe will have to be put in place as there is very little knowledge in EU and very few actors. Patenting activities should be encouraged as well.
FASnI3 perovskite		Top Countries (Publications) US (21) China (17) EU (13/11) Patents Cont. Europe/World 0/0 Fragmentation 4,5	45 scientific publications were retrieved, with US and China taking a leading role. In Europe, 9 organisations are engaged in research in this topic. The collaboration landscape is fragmented. No patents were retrieved. Should this WS be deemed important, measures to support R&D actors in Europe should be put in place. There is some knowledge developed in Europe on which to rely on. Patenting has not started yet and measure to encourage EU organisations to innovate should be put in place to avoid future technology dependency.
Alkaline hydrogen evolution reaction		Top Countries (Publications) China (69) EU (43/37) US (25) Patents Cont. Europe/World 0/3 Fragmentation 1,63	Chinese organisations lead in scientific publications for this technology, with Europe at the second position, even if Brexit is taken into account. There are 31 actors in Europe in a slightly fragmented collaborative landscape. No patents from EU for this technology. Should this WS be deemed important, measures to support R&D actors in Europe should be put in place. There is some knowledge developed in Europe on which to rely on. Measures to encourage EU organisations to innovate should be put in place to avoid future technology dependency.
MASnI3 perovskite		Top Countries (Publications) US (14) EU (12/11) Japan (10) China (10) Patents Cont. Europe/World 0/1 Fragmentation 5	45 scientific publications were retrieved for this material. No clear leading role can be attributed at this stage. In Europe, 10 organisations are engaged in research. The collaboration landscape is fragmented. The patent retrieved belongs to a Chinese organisation. Should this WS be deemed important, measures to support R&D actors in Europe should be put in place. There is some knowledge developed in Europe on which to rely on. Patenting has not started yet and measure to encourage EU organisations to innovate should be put in place to avoid future technology dependency.

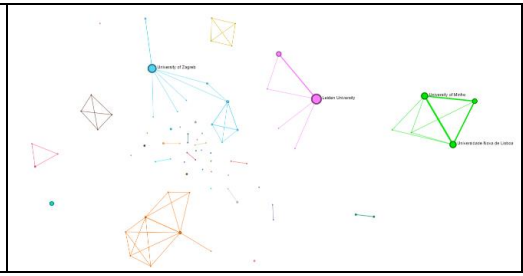
Single atom catalysis		Top Countries (Publications) China (85) US (30) EU (29/25) Patents Cont. Europe/World 0/1 Fragmentation 1	Chinese organisations lead in scientific publications for this WS, with Europe coming third shortly after the US. There are 33 actors in Europe in a fairly well connected collaboration landscape. The patent that was retrieved for this technology is owned by a Chinese organisation. Should this WS be deemed important, measures to support R&D actors in Europe should be put in place. There is some knowledge developed in Europe on which to rely on. Measures to encourage EU organisations to innovate should be put in place to avoid future technology dependency.
Molybdenum disulfide quantum dots		Top Countries (Publications) China (82), India (11), US (8), South Korea (5), EU (5/4) Patents Cont. Europe/World 0/28 Fragmentation 2,5	China clearly leads in this technology with 58 scientific publications and all of the 28 patents belonging to Chinese organisations. Europe lags behind with other countries, and after Brexit only 5 actors in Europe have been spotted. Should this WS be deemed important, significant measures to support R&D in Europe should be put in place (very little knowledge in Europe on which to rely on). Measures to encourage EU organisations to innovate should be put in place to avoid future technology dependency.
Perovskite quantum dots		Top Countries (Publications) China (389), US (66) EU (43/27) South Korea (37) Patents Cont. Europe/World 0/133 Fragmentation 2,72	China clearly leads in this technology with 291 scientific publications (far more than the US or EU) and with most of the patents belonging to Chinese organisations. Europe comes third in terms of scientific publications (4th if Brexit is taken into account) and the collaboration landscape appears to be fragmented. None of the 133 patents retrieved turns out to be owned by a European organisation. Chinese organisations or individuals own 128 of the patents Should this WS be deemed important, measures to support R&D in Europe should be put in place (there is some knowledge in Europe on which to rely on). Europe lags behind in terms of patenting and measures to encourage EU organisations to innovate should be put in place to avoid future technology dependency.
Perovskite nanowires		Top Countries (Publications) China (103) US (46) EU (20/15) Patents Cont. Europe/World 0/18 Fragmentation 1	China clearly leads in this technology with 92 scientific publications (twice as more than the US and four times more than EU) and with 17 out of the 18 patents belonging to Chinese organisations. Europe comes third in terms of scientific publications with a fairly well connected collaborative landscape in Europe. None of patents retrieved is owned by a European organisation. Ownership of the patents: China 15, US 2, South Korea 1. Should this WS be deemed important, measures to support R&D in Europe should be put in place. Europe lags behind in terms of patenting and measures to encourage EU organisations to innovate should be put in place to avoid future technology dependency.

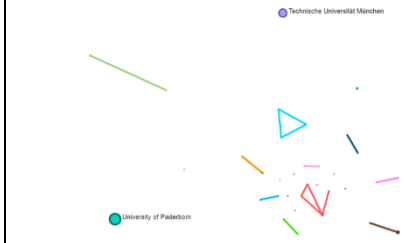
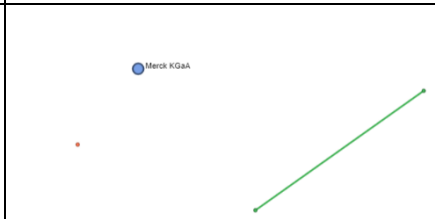
Wearable energy storage		Top Countries (Publications) China (203), US (75) EU (47/26) South Korea (36) Patents Cont. Europe/World 2/68 Fragmentation 1	China clearly leads in this technology with 181 scientific publications (significantly more than the US and EU). If Brexit is taken into account, Europe is fourth in terms of scientific publications. 42 research organisations are active in Europe and collaborate together (fragmentation=1). 3 patents retrieved were filed by a European organisations or individuals (Philips 2). US: 19 patents, China: 28, South Korea: 10. Should this WS be deemed important, measures to support R&D in Europe should be put in place. Europe lags behind in terms of patenting and measures to encourage EU organisations to innovate should be put in place to avoid future technology dependency.
Titanium carbides		Top Countries (Publications) China (421) US (184) EU (84/66) Patents Cont. Europe/World 0/44 Fragmentation 1,81	China clearly leads in this technology in terms of scientific publications (significantly more than the US and EU). 49 research organisations are active in Europe and could collaborate more together. None of the patents retrieved is owned by an organisation in Europe (43 of the patents are owned by Chinese organisations, 1 by a US entity). Europe is behind in knowledge production and patenting for this WS. Should it be deemed important, significant measures will have to be put in place to support R&D actors and encourage them to innovate and patent to avoid future technology dependency.
Planar perovskites		Top Countries (Publications) China (722) US (205) EU (191/136) Patents Cont. Europe/World 0/23 Fragmentation 1,15	China leads in this technology in terms of scientific publications (significantly more than the US and EU). Even if there will a significant loss of knowledge due to Brexit, Europe remains third in knowledge production. 113 organisations in Europe are engaged in research on this topic and they fairly well collaborate together (fragmentation close to 1). China owns more than half of the 23 patents retrieved (15), followed by South Korea (5), US (2) and Canada (1). There is production of knowledge in Europe for this WS. Other countries have started to apply for patents and there is a risk of technology dependency should European organisations not engage in transforming their knowledge into innovations. Measures should be put in place to encourage patenting.
Borophene		Top Countries (Publications) China (150) US (57) EU (44/37) Patents Cont. Europe/World 0/6 Fragmentation 1,74	China leads in this technology in terms of scientific publications (3 times more than EU and the US). Europe is at the third position behind the US. Only 33 organisations in Europe are engaged in research on this topic, in a fragmented collaboration landscape (fragmentation at 1,74). Four of the six patents retrieved are owned by US organisations, one by a Japanese entity, and one by a Chinese organisation. There is a risk for future technology dependence in this WS. There is indeed less production of knowledge in Europe and although patenting has recently started for this WS, Europe does not own any patents. Should this WS be deemed important for EU, significant measures will have to be put in place to support research and patenting.

Phosphorene		Top Countries (Publications) China (699) US (421) EU (274/226) Patents Cont. Europe/World 0/77 Fragmentation 0,93	Europe is third in terms of scientific publications for this material, behind China and the US. 164 organisations in Europe are engaged in research on this topic and they fairly well collaborate together (fragmentation close to 1). China leads in patenting (57 patents out of 77), Japan is second (10) and South Korea third (6). None of the patents is owned by an organisation based in Europe. There is production of knowledge in Europe for this WS. Other countries have started to apply for patents and there is a risk of technology dependency should European organisations not engage in transforming their knowledge into innovations. Measures should be put in place to encourage patenting.
Cesium lead halide perovskite		Top Countries (Publications) China (861) US (312) EU (283/212) Patents Cont. Europe/World 0/111 Fragmentation 0,86	Europe is third in terms of scientific publications in this weak signal, behind the US and China (which clearly leads). 150 organisations in Europe are engaged in research on this topic and they fairly well collaborate together (fragmentation < 1). China also leads in patenting, with 108 out of the 111 patents detected owned by Chinese organisations or individuals. None of the patents is owned by an organisation based in Europe. There is production of knowledge in Europe for this WS. China owns most of the patents on this topic so far and there is a risk of technology dependency should European organisations not engage in transforming their knowledge into innovations. Measures could be put in place to encourage patenting.
Antimonene		Top Countries (Publications) China (139) EU (40/38) US (21) Patents Cont. Europe/World 0/14 Fragmentation 1,06	China leads in this technology in terms of scientific publications. Europe occupies the second position. Only 34 organisations in Europe are engaged in research on this topic, in a slightly fragmented collaboration landscape (fragmentation at 1,06). All of the 14 patents detected are owned by Chinese organisations. There is a risk for future technology dependence in this WS. There is relatively little production of knowledge in Europe and although patenting has recently started for this WS, Europe does not own any patents. Should this WS be deemed important for EU, significant measures will have to be put in place to support research and patenting.
Perovskite LEDs		Top Countries (Publications) China (225) EU (96/56) US (70) Patents Cont. Europe/World 0/46 Fragmentation 1,53	Europe is second in terms of scientific publications in this WS, behind China. 19 Organisations from the UK are involved in more than 50% of the publications from Europe. 49 organisations engaged in research will remain in in a slightly fragmented landscape (fragmentation > 1). China also leads in patenting, with 38 out of the 46 patents detected owned by Chinese organisations (South Korea: 6, US: 1; UK:1). None of the patents is owned by an organisation based in Europe. Brexit will impact research in Europe in this topic but some knowledge in Europe will remain (49 active organisations). China owns most of the patents on this topic so far and there is a risk of technology dependency should European organisations not engage in transforming their knowledge into innovations. Measures could be put in place to encourage patenting and support research.

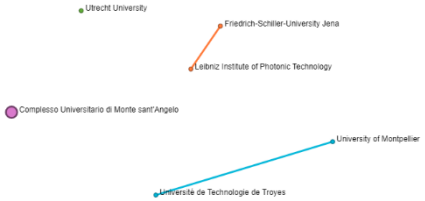
Perovskite nanocrystals		Top Countries (Publications) China (365) EU (181/141) US (170) Patents Cont. Europe/World 0/34 Fragmentation 0,78	Europe is second in terms of scientific publications in this WS, well behind China and close to the US. 102 Organisations from Europe actively engaged in research and are well connected together through scientific collaborations (fragmentation < 1). China and South Korea lead in patenting with respectively 17 and 11 patents registered. None of the patents is owned by an organisation based in Europe. Europe develops knowledge on this topic but lags behind in patenting. To avoid future technology dependency, European organisations should be encouraged to transform their knowledge into innovations protected by patents.
Lead free perovskite		Top Countries (Publications) China (253) EU (141/96) US (118) Patents Cont. Europe/World 1/31 Fragmentation 1,57	Europe is second in terms of scientific publications for this material, but falls behind the US hen Brexit is taken into account. Both the US and Europe are well behind China with 242 publications. 107 organisations are active in Europe, but with Brexit leading 24 UK based organisations to leave the European networks, only 83 Organisations from Europe will remain in a slightly fragmented research environment. China and Japan lead in patenting with respectively 15 and 11 patents registered. 1 patent is owned by an organisation based in Europe (University of Madrid). Europe develops knowledge on this topic but lags behind in patenting. To avoid future technology dependency, European organisations should be encouraged to transform their knowledge into innovations protected by patents.
Metasurface lens		Top Countries (Publications) China (210) US (139) EU (103/74) Patents Cont. Europe/World 1/23 Fragmentation 2,23	China leads in this technology in terms of scientific publications. Europe occupies the third position with 102 publications. After Brexit, 58 organisations in Europe ill remain engaged in research on this topic, in a fragmented collaboration landscape (fragmentation = 2). US is first in patenting (13 patents out of 23), followed by China with 6 patents. One patent is owned by a European organisation (CEA, France). There is a risk for future technology dependence in this WS. There is some knowledge to rely on in Europe, but EU lags behind in patenting. If this weak signal appears to be of strategic importance, strong measures will have to be put in place to support research and patenting by EU organisations.
Wearable flexible electronic		Top Countries (Publications) China (300) EU (236/152) US (176) Patents Cont. Europe/World 4/59 Fragmentation 1,575	Europe is second in terms of scientific publications, and Europe third behind the US after Brexit. 126 organisations in Europe are performing research on this technology. The landscape of collaboration is slightly fragmented. China leads in patenting with 29 patents registered so far. The US is second in patenting with 11 patents and é patents has been filed by the Siemens and Nokia. It should be noted that the two patents retrieved from Nokia and Siemens both date back to 2001 and will soon fall in the public domain. Europe develops knowledge on this topic but lags behind in patenting. To avoid future technology dependency, European organisations should be encouraged to continue R&D activities and to transform their knowledge into innovations protected by patents.

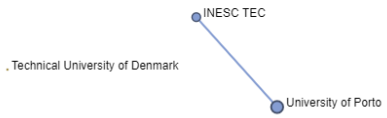
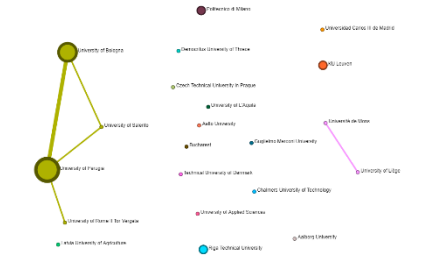
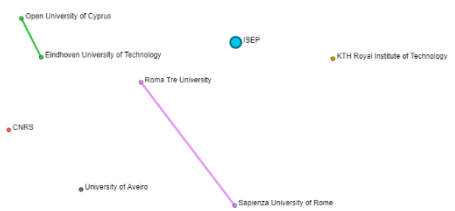
EU is weak in patenting			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Wearable IoT		Top Countries (Publications) US (125) EU (96/72) South Korea (39), China (36) Patents Cont. Europe/World 0/26 Fragmentation 1,76	Europe is second to the US in terms of scientific publications. 81 organisations in Europe are performing research on this technology. As can be seen on the graphic, some degree of collaboration is ongoing between R&D organisations but the landscape is slightly fragmented (fragmentation > 1). Patenting is led by the US (10 patents), followed by South Korea (8 patents) and China (7). None of the patents retrieved is owned by an organisation based in Europe. Europe develops knowledge on this topic but lags behind in patenting. To avoid future technology dependency, European organisations should be encouraged to transform their knowledge into innovations protected by patents.
MoTe2		Top Countries (Publications) China (193) US (149) EU (142/121) Patents Cont. Europe/World 0/14 Fragmentation 1,11	Europe is third in terms of publishing of scientific publications. 108 organisations in Europe are performing research on this technology. As can be seen on the graphic, some degree of collaboration is ongoing between R&D organisations (fragmentation ~ 1). China leads in patenting as well, with 8 of the 14 patents retrieved, while the US owns 3 and South Korea, Japan and the UK own 1 patent each. None of the patents retrieved is owned by an organisation based in Europe. Europe develops knowledge on this topic but lags behind in patenting. To avoid future technology dependency, European organisations should be encouraged to transform their knowledge into innovations protected by patents.
FAPbI3 perovskite		Top Countries (Publications) China (158) EU (121/93) US (84) Patents Cont. Europe/World 0/10 Fragmentation 1,12	Europe occupies the second position in terms of publishing of scientific publications. 86 organisations in Europe are performing research on this technology. As can be seen on the graphic, some degree of collaboration is ongoing between R&D organisations (fragmentation ~ 1). China leads in patenting with 6 patents out of the 10 patents retrieved. None of the patents retrieved is owned by an organisation based in Europe. Europe develops knowledge on this topic but lags behind in patenting. To avoid future technology dependency, European organisations should be encouraged to transform their knowledge into innovations protected by patents.
Adaptative metasurface		Top Countries (Publications) China (90) EU (72/54) US (68) Patents Cont. Europe/World 0/24 Fragmentation 1,15	225 publications and 24 patents were retrieved for this weak signal. Europe is second to China in terms of publications in the field. R&D actors in Europe could be slightly more connected (fragmentation ~ 1). Despite ongoing R&D activities, none of the patents retrieved for this technology have been registered by an organisation from Europe. US leads in patenting with 15 patents, followed by china (8) and South Korea (1). Europe develops some knowledge on this topic but lags behind in patenting. To avoid future technology dependency, European organisations should be encouraged to transform their knowledge into innovations protected by patents.

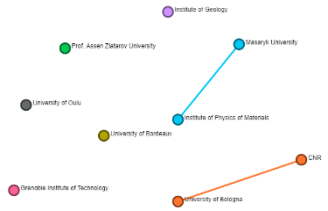
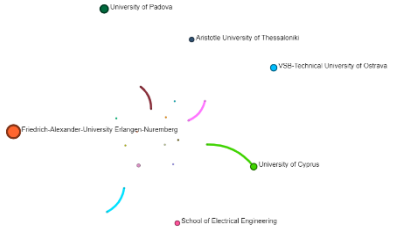
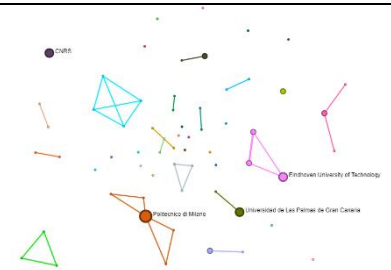
Natural deep eutectic solvents		Top Countries (Publications) EU (97/84) China (31) US (15) Patents Cont. Europe/World 1/7 Fragmentation 1,2	185 publications were retrieved for this technology. Europe leads in terms of scientific publications. R&D actors in Europe could be slightly more connected (fragmentation ~ 1). One patent was filed by an organisation in Europe (TU Eindhoven). China owns four patents, the US and South Korean one patent each. Europe develops some knowledge on this topic but lags behind in patenting. To avoid future technology dependency, European organisations should be encouraged to transform their knowledge into innovations protected by patents.

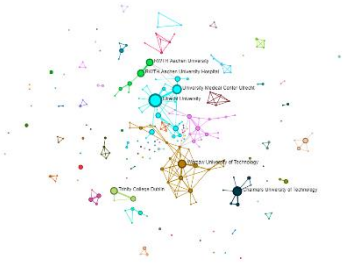
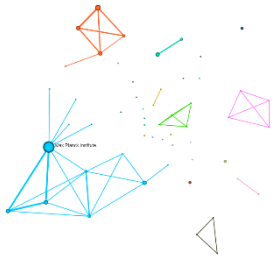
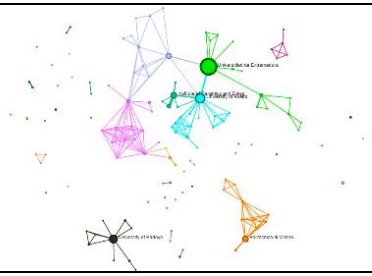
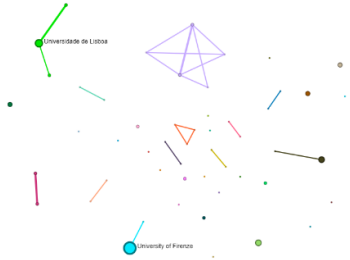
Weak signals with Brexit-risk			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Nonlinear metasurface		Top Countries (Publications) US (87) EU (57/43) China (37) Patents Cont. Europe/World 0/2 Fragmentation 2,27	Europe is second in knowledge production for this technology, but organisations from UK are involved in more than 40% of the publications from Europe. 8 actors will leave the EU after the Brexit, which will disturb the ongoing R&D activities in Europe. Brexit might impact R&D activities in this technology in Europe and measures to accompany the transition should be considered.
Dihydrolevoglucosenone		Top Countries (Publications) EU (13/4) Australia (8) US (5) Patents Cont. Europe/World 1/2 Fragmentation 4	Europe leads in number of scientific publications in this technology, but 8 out of the 13 publications retrieved have been published solely by UK organisations. R&D activities in Europe will be disturb by Brexit (e.g. Merck was collaborating with UK). Brexit will impact R&D activities in this technology in Europe and measures to accompany the transition should be considered.

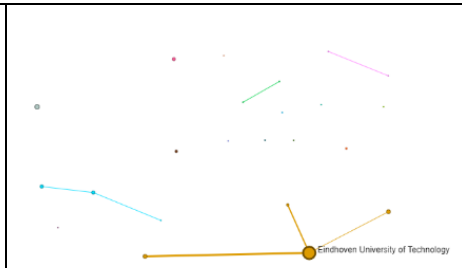
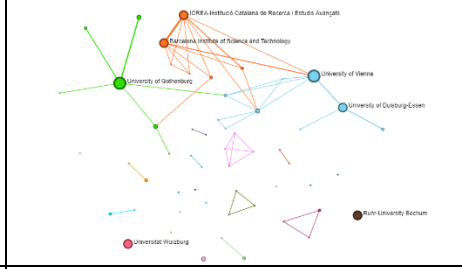
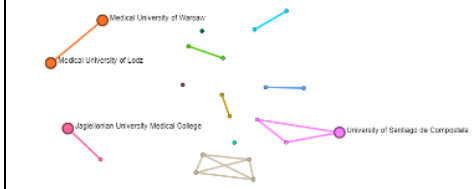
7.7 Physics and Engineering

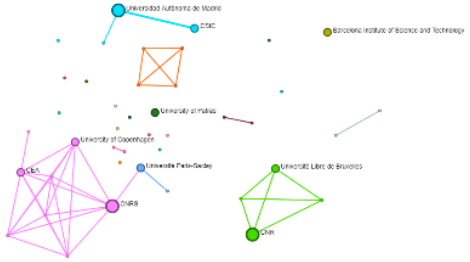
EU is weak in knowledge production			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Photoelectrochemical aptasensors		Top Countries (Publications) China (72) EU (2) Patents Cont. Europe/World 0/0 Fragmentation -	Chinese organisations are responsible for 72 out of the 76 publications retrieved. In Europe, only two French organisations have published about this technology. No patents were retrieved. Should this WS be deemed important, significant efforts will have to be made to create R&D and push innovation in Europe. There is almost zero knowledge in EU and the possibility of a future technological dependency should not be underestimated.
Photoelectrochemical immunosensors		Top Countries (Publications) China (84) US (5) EU (4) Patents Cont. Europe/World 0/5 Fragmentation -	Chinese organisations are responsible for 84 out of the 91 publications retrieved. In Europe, only two French organisations have published 4 scientific articles about this technology. The five patents retrieved are all owned by Chinese organisations. Should this WS be deemed important, significant efforts will have to be made to create R&D and push innovation in Europe. There is almost zero knowledge in EU and the possibility of a future technological dependency should not be underestimated.
Photoinduced force microscopy		Top Countries (Publications) US (32) South Korea (6) EU (5), China (4) Patents Cont. Europe/World 0/0 Fragmentation 3	With only 5 publications retrieved, Europe is lagging behind in this technology. The US are leading the R&D. Only 6 organisations from Europe have published. No patents was retrieved. Should this WS be deemed important, massive efforts will have to be made to start R&D activities in Europe. There is almost zero knowledge in EU and the possibility of a future technological dependency should not be underestimated.
Spatial heterodyne raman spectrometer		Top Countries (Publications) US (20) China (10) EU (4/1) Patents Cont. Europe/World 0/4 Fragmentation -	Chinese and US organisations lead in this technology in terms of publications. Europe comes third with 4 publications, out of which 3 are from the UK. After Brexit, the landscape of R&D activities will consist in one organisation. None of the patents retrieved was filed by an organisation from Europe (China: 3, US: 1). Should this WS be deemed important, strong measures will have to be implemented to create R&D in Europe and to foster innovation. There is almost no knowledge in EU and the possibility of a future technological dependency should not be underestimated.

Underwater wireless power transfer		Top Countries (Publications) China (13) Japan (9), US (8) EU (6) Patents Cont. Europe/World 0/2 Fragmentation -	Only 34 scientific publications and 2 patents have been retrieved. In Europe, publications from only three organisations have been retrieved (EU occupies the fourth place). The two patents retrieved belong to a Japanese (1) and a South Korean organisations (1). Should this WS be deemed important, massive efforts will have to be made to induce R&D in Europe and create a network of knowledgeable organisations. Measures to ensure that knowledge is transformed into innovations and patents should also be considered.
Stretchable strain sensor		Top Countries (Publications) China (59) South Korea (36) US (17) EU (14/8) Patents Cont. Europe/World 0/7 Fragmentation 5	China and South Korea have taken the lead in this weak signal. 14 publications have been retrieved for Europe, out of which 6 are from UK organisations. 5 actors are active in R&D in Europe. None of the patents retrieved belongs to an organisation from Europe (US: 4, China: 2, South Korea: 1). Should this WS be deemed important, strong measures will have to be implemented to create R&D in Europe and to foster innovation. There is almost no knowledge in EU and the possibility of a future technological dependency should not be underestimated.
Capacitive wireless power transfer		Top Countries (Publications) US (63) China (57) EU (35/28) Patents Cont. Europe/World 1/16 Fragmentation 4,6	China and the US have taken the lead in this weak signal. Europe is third in publications (35). 5 actors are active in R&D in Europe and the degree of collaboration is very low (high fragmentation). One patents out of the 16 retrieved has been registered by an organisation from Europe (Phillips). (China: 7, US: 5). Should this WS be deemed important, strong measures will have to be implemented to further develop R&D activities in Europe and to foster innovation. There is little knowledge in EU and the possibility of a future technological dependency should not be underestimated.
Visible light positioning		Top Countries (Publications) China (113) EU (30/12) US (21) Patents Cont. Europe/World 0/0 Fragmentation 2	China leads in this weak signal, well in front of EU and the US. Out of the 30 publications retrieved for EU, 13 are made by or in collaboration with UK organisations (with one big actor, Northumbria University, involved in 8 publications). Brexit will therefore perturb the knowledge production landscape for this technology in Europe, leaving only 8 organisations engaged in R&D and not collaborating together. No patents have been retrieved. If this technology is deemed of some importance, strong measures will be needed to accompany R&D actors in Europe during the Brexit-transition, to increase the number of R&D actors and reinforce collaborations, and to encourage the development of innovations.

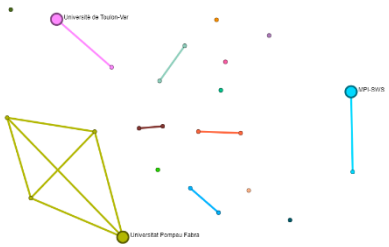
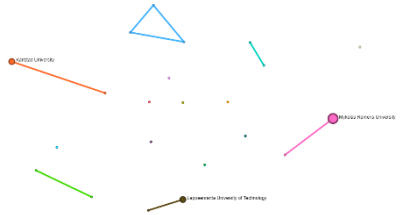
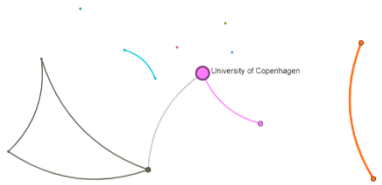
Cold sintering process		Top Countries (Publications) US (44) EU (29/15) China (27) Patents Cont. Europe/World 1 (expired)/20 Fragmentation 4,5	The US leads in this weak signal and EU occupies the second position close to China. Out of the 29 publications retrieved for EU, 12 are made by or in collaboration with UK organisations. Brexit will therefore perturb the knowledge production landscape for this technology in Europe, leaving only 9 organisations engaged in R&D and not collaborating together. Out of the 20 patents retrieved, 10 are owned by Chinese entities. One patent from 1996 from Sweden has been retrieved and is therefore no in the public domain. If this technology is deemed of some importance, strong measures will be needed to accompany R&D actors in Europe during the Brexit-transition, to increase the number of R&D actors and reinforce collaborations, and to encourage the development of innovations to avoid future technological dependency.
Wireless powered communication networks		Top Countries (Publications) China (155), South Korea (63) EU (68/40) Singapore (41), US (35) Patents Cont. Europe/World 2/60 Fragmentation 5,5	China leads in this weak signal, both in terms of scientific publications (155) and patents (34 out of 60). After Brexit, Europe will rank 4th in number of publications behind Singapore but in front of the US. There is some knowledge about this technology in Europe, but the research ecosystem is very fragmented. 2 out of the 60 patents are owned by European organisations. Measures to reinforce R&D in Europe, to encourage collaboration between European organisations and to foster innovation and patenting should be considered. There is a risk of technology dependency should European organisations not transform their knowledge into patents.
Hybrid modular multilevel converter		Top Countries (Publications) China (79) EU (37/13) US (19) Patents Cont. Europe/World 0/22 Fragmentation -	China leads in this weak signal and EU occupies the second position. But out of the 37 publications retrieved for EU, 24 are made by or in collaboration with UK organisations. Brexit will therefore perturb significantly the knowledge production landscape for this technology in Europe, leaving behind only 8 organisations engaged in R&D with no interaction through co-publications. Out of the 22 patents retrieved, 19 are owned by Chinese entities, 2 by General Electric (US), and 1 by ABB (Switzerland). If this technology is deemed of some importance, strong measures will be needed to accompany R&D actors in Europe during the Brexit-transition, to increase the number of R&D actors and reinforce collaborations, and to encourage the development of innovations.
4D printing		Top Countries (Publications) US (94) EU (64/48) China (59) Patents Cont. Europe/World 0/34 Fragmentation 1,88	US leads in terms of scientific publications and China leads in patenting. Europe occupies the second position in knowledge production with 64 publications. UK organisations are involved in a third of these publications. Brexit will slightly impact R&D in Europe, leaving behind 62 organisations engaged in research in a fragmented collaborative landscape. China owns 22 of the 34 patents retrieved (US: 5, South Korea: 5). No patents has been registered by a European organisation. If this technology is deemed of some importance, measures will be needed to strengthen R&D in Europe. As EU in lagging behind in patenting, strong measures should also be put in place to encourage the development of innovations and avoid technology dependency.

EU is weak in patenting			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
3D Bioprinting		Top Countries (Publications) US (412) EU (277/203) China (220) Patents Cont. Europe/World 11/558 Fragmentation 0,94	1043 publications and 558 patents were retrieved for this weak signal. Europe is strong in knowledge production and is second in terms of publications, behind the US but in front of China. A significant number of actors operate R&D in Europe, in a fairly well connected collaboration landscape. Europe is clearly lagging behind in patenting, with only 11 patents owned by organisations in Europe. China, the US, and South Korea own respectively 429 and 54, and 27 of the 558 patents. Europe is lagging behind in patenting and strong measures to encourage the transformation of European knowledge should be considered to ensure Europe can be competitive in this field. There is a likely risk of technology dependency.
Quantum machine learning		Top Countries (Publications) US (53) EU (48/41) China (32) Patents Cont. Europe/World 1/7 Fragmentation 1,24	EU is second in knowledge production for this WS with 28% of the publications (48), close to the US (53). 40% of the scientific articles in EU involve an organisation form the UK, and Brexit will therefore have some impact on the research ecosystem for this technology. Europe is clearly lagging behind in patenting, with only 1 patents owned by a German organisation (Siemens). The other six patents retrieved are owned by US based entities. Europe is lagging behind in patenting and measures to encourage the transformation of European knowledge should be considered to ensure Europe can be competitive in this field.
Robocasting		Top Countries (Publications) US (228) EU (174/143) China (79) Patents Cont. Europe/World 0/15 Fragmentation 0,67	EU is second in knowledge production for this WS with 35% of the publications (26% if UK organisations are not taken into account). The US lead in terms of scientific publications. 133 organisations are engaged in R&D in Europe for this technology, in a well-connected collaboration landscape. None of the 15 patents retrieved belong to an EU based organisation (US: 7, China: 6). Europe is lagging behind in patenting and measures to encourage the transformation of European knowledge should be considered to ensure Europe can be competitive in this field.
Wire arc additive printing		Top Countries (Publications) EU (136/64) China (129) Australia (43), US (39) Patents Cont. Europe/World 1/27 Fragmentation 2,36	Europe is first in knowledge production in this technology. But 72 of the publications retrieved for EU involve UK organisations. R&D actors in Europe do not exhibit a strong appetite for collaboration (high fragmentation) and are only involved in 64 of the publications. Brexit will therefore have a significant impact. In patenting, one patent comes from Germany. China leads with 24 patents out of the 27. Europe is lagging behind in patenting and measures to encourage the transformation of European knowledge should be considered to ensure Europe can be competitive in this field. Support should also be considered to accompany the research community in Europe during the Brexit transition.

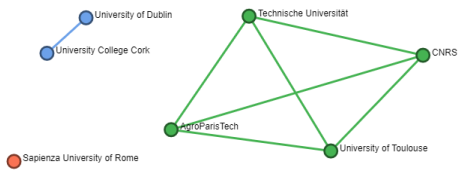
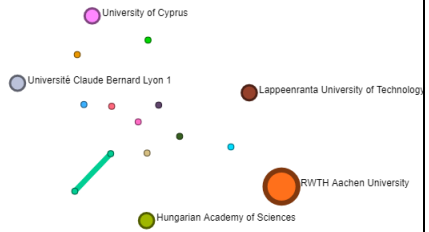
3D Concrete printing		Top Countries (Publications) EU (53/53) Australia (26) Singapore (21) China (17), US (10) Patents Cont. Europe/World 0/36 Fragmentation 3,28	Europe is first in knowledge production in this technology. Only 23 actors have been spotted in Europe, and they evolve in a fragmented collaboration landscape (high fragmentation) and are only involved in 64 of the publications. Brexit will therefore have a significant impact. None of the 36 patents retrieved belong to an EU based organisation, most of them originate from China (27) and South Korea (8). Europe is lagging behind in patenting and measures to encourage the transformation of European knowledge should be considered to avoid future technology dependency.
Levitated optomechanics		Top Countries (Publications) EU (87/63) US (53) China (25) Patents Cont. Europe/World 1/6 Fragmentation 1,08	Europe is first in knowledge production in this technology. 55 actors are engaged in R&D in Europe (UK excluded). They evolve in a fairly well collaborative environment (fragmentation~1). One of the six patents retrieved is owned by a European organisation (University of Vienna). 3 patents are from South Korea, 1 from Taiwan, and 1 from the US. Patenting activity is low for this technology, and Europe is not (yet) lagging behind. To avoid future technology dependency, measures should be put in place to ensure that the leading role in knowledge production translates into concrete innovations.
3D printing of tablets		Top Countries (Publications) EU (32/15) US (11) China (8) Patents Cont. Europe/World 0/8 Fragmentation 1,46	Europe is first in knowledge production in this technology. But out the 32 publications from EU, 17 have been published solely by UK organisations. Brexit will therefore have a significant impact in this technology. 22 actors will remain in Europe, in a fragmented collaborative environment (fragmentation > 1). 5 of the 8 patents retrieved are owned by Chinese organisations, 2 by US organisations, 1 in Japan. Despite a leading role in knowledge production, Europe is lagging behind in patenting and measures to encourage the transformation of European knowledge should be considered to avoid future technology dependency. Transition measures should also be considered to allow organisations in Europe to absorb the Brexit chock.

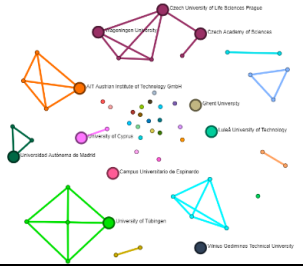
Weak signals with Brexit-risk			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Topological photonics		Top Countries (Publications) US (85) China (75) EU (53/31) Patents Cont. Europe/World 0/2 Fragmentation 1,02	Europe is third in terms of scientific publications. 8 organisations from UK are involved in 23 of the 53 EU publications and are connected to other organisations in Europe. Brexit will therefore impact this R&D environment. Brexit will have some impact on the R&D activities in this technology if measures to support the transition phase are not put in place.

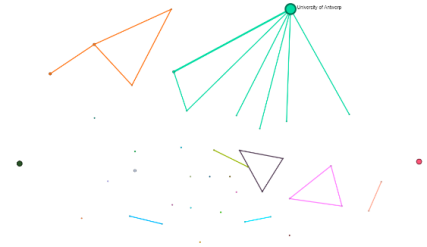
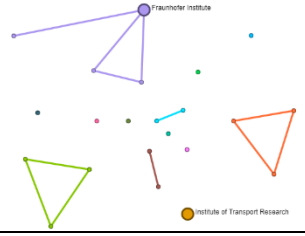
7.8 Social Sciences

Weak signals with Brexit-risk			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Algorithmic fairness		Top Countries (Publications) US (35) EU (27/16) China (17) Patents Cont. Europe/World 0/0 Fragmentation 2	8 UK organisations are involved in more than 40 % of publications in this technology. Brexit will impact the research activities in Europe by reducing the available knowledge and weakening the collaborative landscape. 24 organisations in Europe are active but they do not collaborate much together. Brexit will have significant impact in this weak signal if measures to reinforce research activities and patenting are not put in place.
Civic technologies		Top Countries (Publications) EU (34/19) US (25) Patents Cont. Europe/World 0/0 Fragmentation 2,75	16 UK organisations are involved in more than 40 % of publications in this technology. Brexit will impact the research activities in Europe by reducing the available knowledge (16 UK actors will leave Europe) and weakening the collaborative landscape (22 actors for a fragmentation~3). Brexit will have significant impact in this weak signal if measures to reinforce research activities and patenting are not put in place.
Digital humanitarism		Top Countries (Publications) EU (15/6) US (10) UK (9) Canada (6) Patents Cont. Europe/World 0/0 Fragmentation 1,5	9 organisations from the UK are involved in 9 of the 15 publications produced in Europe. Brexit will impact the research activities in Europe by reducing the number of actors in Europe to a few. Should this WS be deemed of importance, measure to create R&D activities could be considered.
Drug cryptomarkets		Top Countries (Publications) UK (20) Australia (17), Canada (17) EU (34/14) Patents Cont. Europe/World 0/0 Fragmentation 1,88	Half of the organisations active in this weak signal are from the UK and are involved in 20 of the 34 publications from Europe. Brexit will impact the research activities in Europe by reducing the number of actors in Europe. Should this WS be deemed of importance, measure to support R&D activities in Europe could be considered.

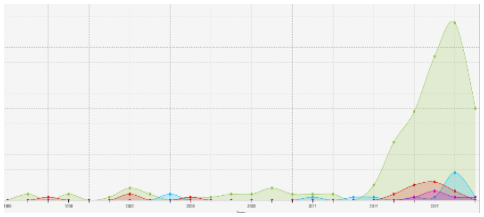
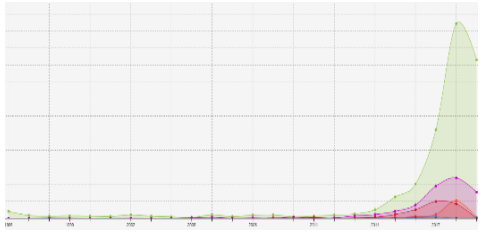
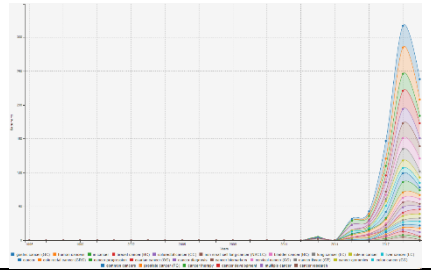
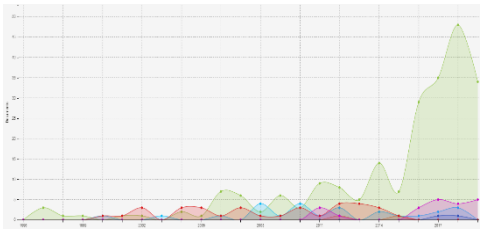
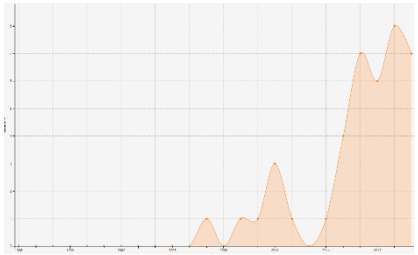
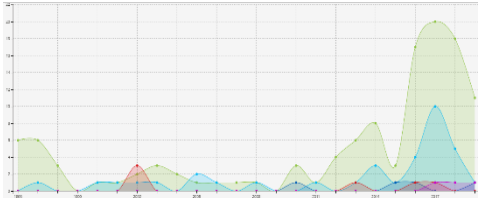
7.9 Environment

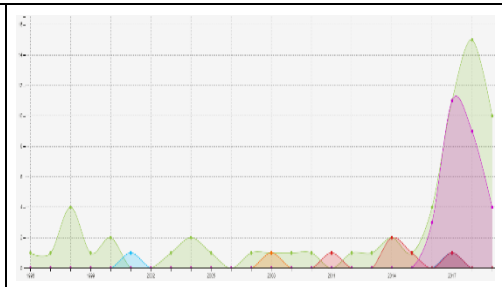
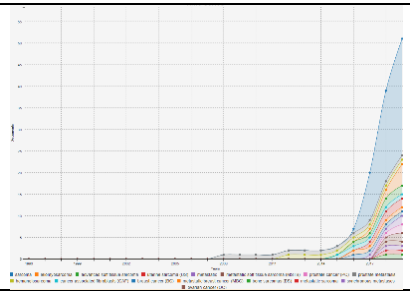
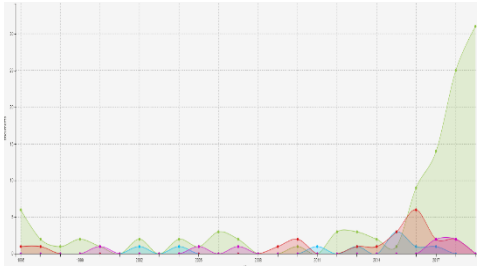
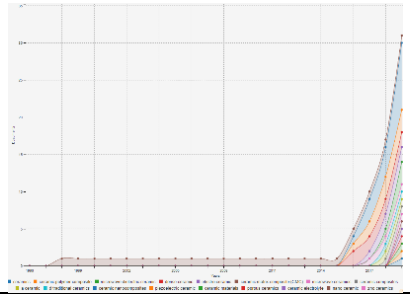
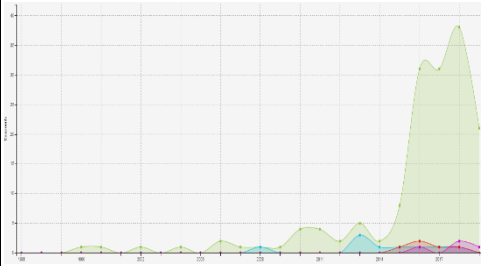
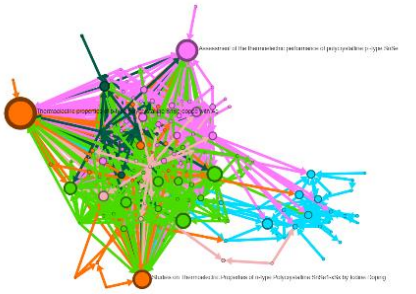
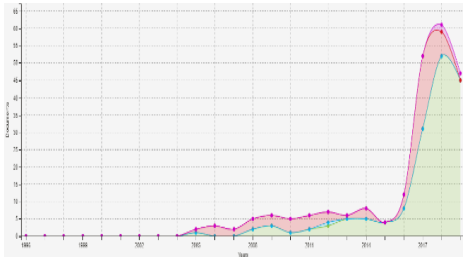
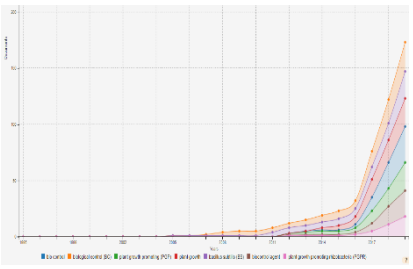
EU is weak in knowledge production			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Coastal blue carbon		Top Countries (Publications) US (17) Australia (7) EU (6/3) Patents Cont. Europe/World 0/0 Fragmentation 1	Only 29 publications have been retrieved for this weak signal. Organisations from the US lead in knowledge production; EU is second with 6 publications. If Brexit is taken into account, only 3 publications have been produced so far in Europe, by 7 organisations. No patents has been retrieved. Should this WS be deemed important, significant efforts will have to be made to create R&D and push innovation in Europe. There is almost no knowledge in EU and the possibility of a future dependency should not be underestimated.
Marine heatwave		Top Countries (Publications) Australia (43) US (30) EU (22/16) Patents Cont. Europe/World 0/0 Fragmentation 3,2	43 out of the 74 publications retrieved originate from Australia, placing this country at the top position in terms of knowledge production. Research in Europe is rather weak, with 15 actors having produced 14 publications. No patents has been retrieved. Should this WS be deemed important, significant efforts will have to be made to create R&D and push innovation in Europe. There is almost no knowledge in EU and the possibility of a future dependency should not be underestimated.
Black soldier fly larvae biodiesel		Top Countries (Publications) China (11) Malaysia (7) US (5), EU (3/3) Patents Cont. Europe/World 0/1 Fragmentation 2,5	Only 33 publications have been retrieved for this technology. The level of research activity in Europe is quite low, with only 5 actors and 3 publications. The patent retrieved belongs to a Chinese University. Should this technology become essential, significant efforts will have to be made to create R&D and push innovation in Europe. There is almost no knowledge in EU and the possibility of a future technology dependency should not be underestimated.
Peroxymonosulfate activation		Top Countries (Publications) China (331) Australia (42) US (40) EU (24/23) Patents Cont. Europe/World 0/13 Fragmentation 17	Chinese organisations have clearly take the lead in knowledge production. European organisations are only involved in 20 scientific publications (a mere 5% of the total number of publications). In addition to this low research activity, the landscape of R&D activities in Europe is fragmented. All of the 13 patents retrieved for this technology have been registered by Chinese organisations. Should this technology become important, significant efforts will have to be made to reinforce R&D activities and push innovation in Europe. There is little knowledge in EU and the possibility of a future technology dependency should not be underestimated.

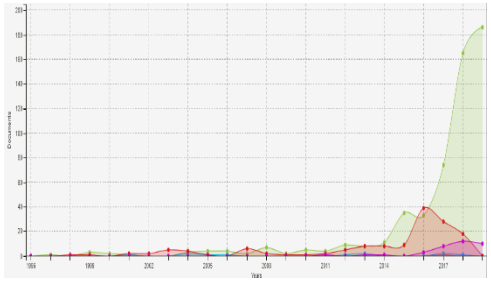
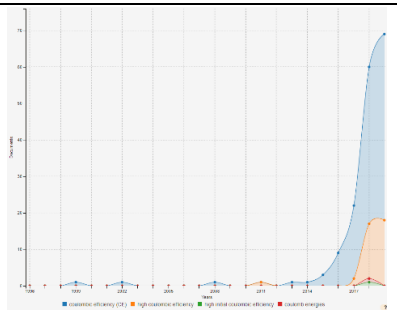
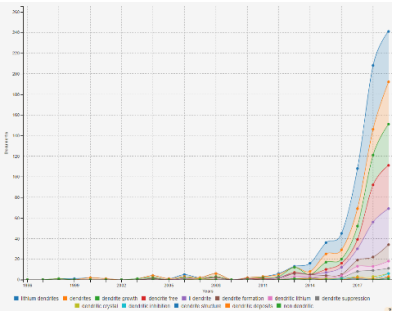
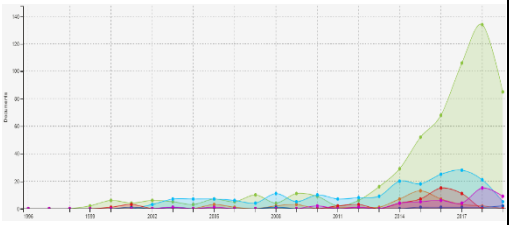
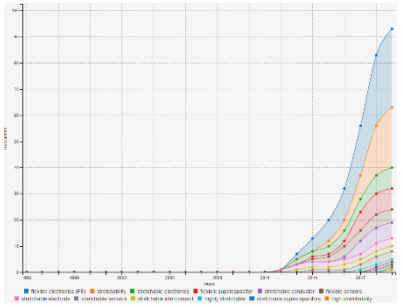
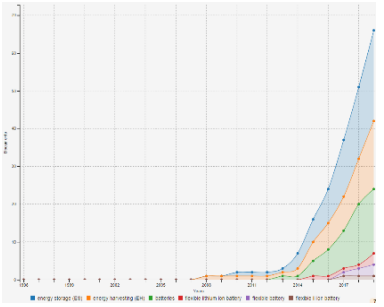
Functionalised Biochar		Top Countries (Publications) China (186) US (70) EU (61/46) Patents Cont. Europe/World 0/16 Fragmentation 1,45	Chinese organisations are leading in knowledge production. Europe is third with 61 publications but if Brexit is taken into consideration, only 46 publications made by 56 actors originated in Europe. The landscape of collaboration is slightly fragmented. 14 of the patents retrieved are owned by Chinese organisations, 2 by an US company. Should this technology appear to be essential, significant efforts will have to be made to reinforce R&D activities and push innovation in Europe. There is little knowledge in EU to rely on and the possibility of a future technology dependency should not be underestimated.

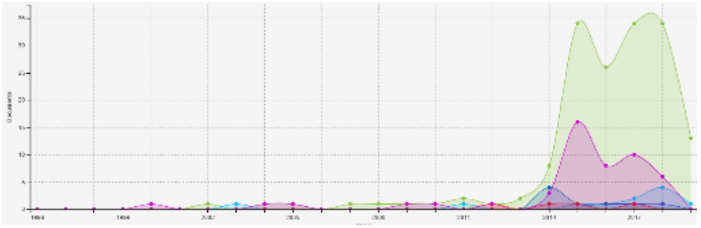
EU is weak in patenting			
Weak signal	**Actors in Europe (not UK)**	**Indicators**	**Analysis and recommendations**
Organophosphorus flame retardant		Top Countries (Publications) EU (43/41) China (30) US (19) Patents Cont. Europe/World 0/6 Fragmentation 2	Even if Brexit is taken into account, Europe leads in publications in this technology. 42 research organisations are engage in R&D activities and the landscape of research is slightly fragmented. But in terms of patenting, China leads, owning all of the six patents retrieved. Patenting activity is still low for this technology but Europe is already lagging behind. To avoid future technology dependency, measures should be put in place to ensure that the leading role in knowledge production of organisations in Europe translates into concrete innovations.
Cargo bikes		Top Countries (Publications) EU (37/29) US (3) Patents Cont. Europe/World 4/15 Fragmentation 1,83	37 publications have been made by European organisations, almost all from Europe. This puts Europe at the first position in knowledge production for this weak signal. 22 research organisations are engage in R&D activities and the landscape of research is slightly fragmented. 5 of the patents are owned by European entities (US: 6). Despite its leading role in knowledge production, Europe is not leading in patenting. To avoid future technology dependency, measures should be put in place to ensure that the leading role in knowledge production of organisations in Europe translates into concrete innovations.

7.10 Persistent weak signals

Weak signal	Documents profile	New application
ReS2 (Rhenium Disulfide)		Rhenium disulphide is a material that is known since a long time. The weak signal corresponds to the discovery of its unique semiconducting properties that is of interest for electronic and optoelectronic devices, for energy storage, and photocatalytic and electro-catalytic applications.
Circular RNA		For many years, circular RNAs have been thought to be non-coding metabolites. It appears now that under some conditions they can code for proteins and also have a regulatory role in come cancers and diseases. The graphic to the left shows that the weak signal is most likely related to the study of circular RNA in the context of cancer detection and therapy (most frequent cancer-related keywords in documents retrieved for circular RNA). 
Platinium free catalyst		Platinum is an expensive material that is used in the composition of many catalysts. The quest to reduce its amount or to find alternative materials is going on for many years. The weak signal relates to the need to find cheaper materials for catalyst inside fuel cells, which is key in the large scale commercialisation of this new technology. The graphic to the right shows the number of occurrence of the keyword “fuel cell” in the documents retrieved. 
Levitated optomechanics		Levitated optomechanics is a technique used for more than 20 years to analyse the characteristics of micro sized molecule assemblies. Since a few years, it is used to explore nanosized particulates and explore phenomenon at the boundary between the classical and quantum worlds

Anti-PDGFR monoclonal antibodies		Platelet-derived growth factor is known for many years. The weak signal is related to its potential use in the fight against cancers (as can be seen on the graphic to the right, showing that the use of the keywords related to cancer correspond to the peak of documents over the last four years.	
Cold sintering process		Cold sintering is a well-known process to make solid masses more compact at low temperature. The weak signal is related to the use of this technique for the production of ceramic materials at low temperature (as can be seen in the graphic to the right showing the occurrence of keywords related to ceramic materials).	
SnSe (Tin selenide)		Three articles in 2014 and 2015 reported unique thermoelectric properties for the polycristalline structure of Tin selenide. These articles triggered the increase of research on this new form and applications of this known material. The graphic to the right shows the publications citations landscape (the three founding articles have their title).	
Bacillus velenzis		Bacillus velenzis is a known bacterium which has been recently the subject of increasing R&D for its application as suppressor of microbial pathogens and promoter of plant growth. The graphic to the right shows the increasing use of keyords related to biocontrol and plant growth.	

Weak signal	Documents profile	Technological barrier
Li-Metal batteries		The sluggish progress of battery technologies has drastically hindered the rapid development of electric vehicles and next-generation portable electronics. One alternative to Li-ion batteries is to use Lithium metal anodes. Research on the Li-metal field has increased over recent years to break two technogical barriers preventing Li-Metal batteries to become commercially available : Li-dendrite growth and low Coulombic efficiency. Unprecedent progresses have been made recently, explaining the renewed interested for research in that field. The two graphics below show the increase in keywrods related to Coulombic efficiency (left) and Lithium dendritic growth (right).  
Wearable electronics		Wearable electonics have been on the radar for many years, but it is only recently that the conjonction of R&D in new powering mechanisms and of the development in printed flexible electronics has brought wearable electronics closer to becomling a reality. The graphics below illustrate the increase in research papers in flexible electronics (left) and on new powering means (right).  

Weak signal	Documents profile	Policy decision
Ebola vaccine		The increase in research and development for this weak signal is related to a policy decision made in 2014 by the World Health Organisation, which declared that year a Public Health Emergency of International Concern (PHEIC) alerting the world that Ebola was out of control in West Africa. An international platform was mobilized to accelerate testing of existing experimental Ebola vaccines, resulting in a steep increase in the production of scientific publications and patents realted to Ebola vaccines.

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