European Commission

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Weak signals in Science and Technologies

2019 Report

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 scientometrics indicators, 256 of these weak signals have been identified on the basis of scientific literature and are reported in the present report.

Executive summary

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 capacity mostly based on technology monitoring and assessment, JRC is currently developing further its technology foresight capability. In that context, a quantitative methodology relying on text mining algorithms was conceived to identify early signals of new technological developments, as well as new applications of existing technologies.

This report presents the weak signals in technological development detected by applying JRC's new method to a corpus of scientific publications from 1996 to 2018. Weak signals of emerging technologies have been generated by a text mining algorithm which, after selection using indicators and domain knowledge, has led to a list of 256 relevant weak signals. Most of them are related to the fields of energy, environment, health, biotechnology, and ICT. Each signal has been rebuilt in the TIM Technology system (a technology monitoring system developed by JRC 'see link below), and can be analysed further to understand e.g. who are the leading countries, the main industrial and academic actors, the stage of development or the current trends, or what the potential future applications are.

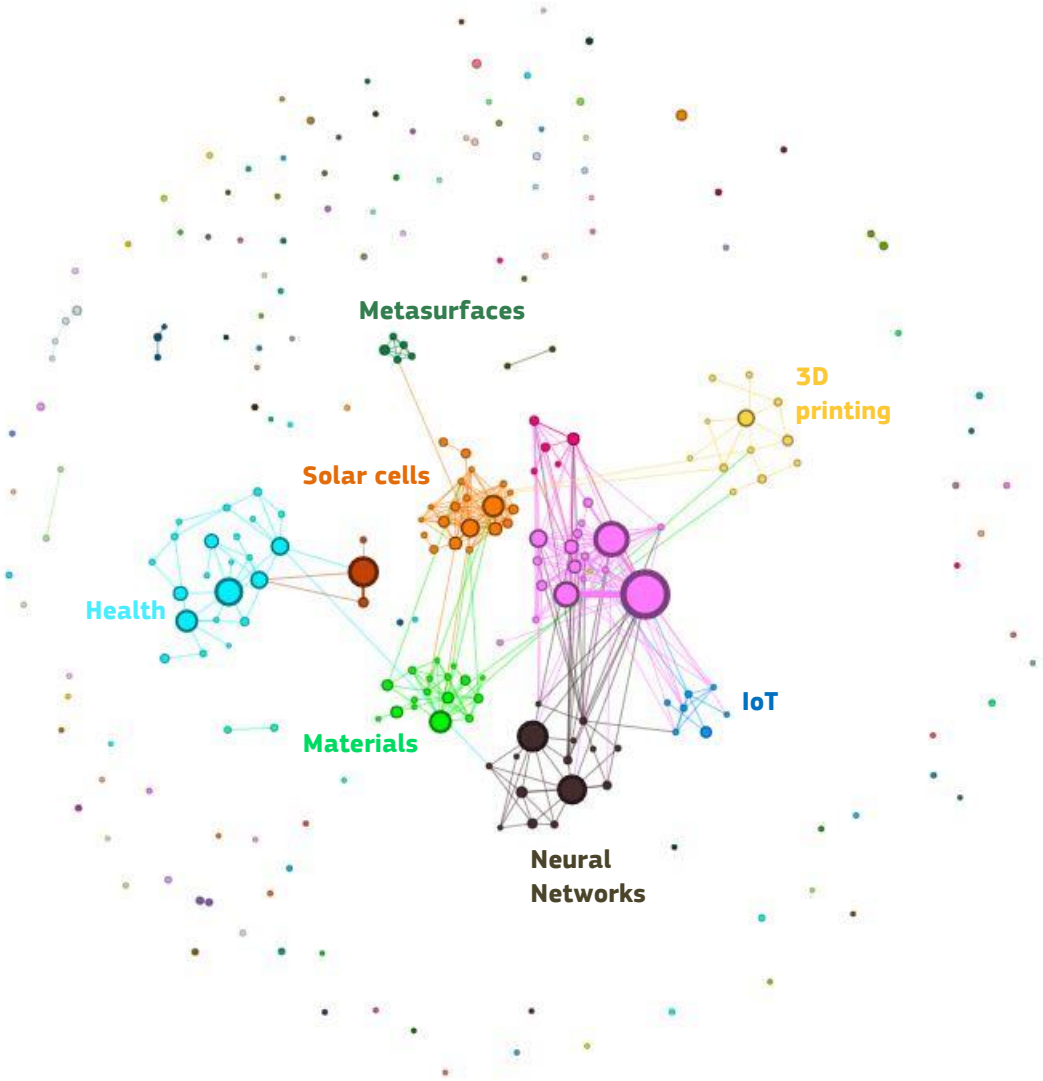
In the next months the JRC will also perform a meta-analysis of the weak signals to identify points of focus for policy-makers, the research community, and stakeholders of technological development. In addition, the results of the present report will be compiled and submitted to experts in Europe and more widely in other regions of the world. Through an iterative and structured process (i.e. with the use of Delphi to collect both qualitative and quantitative insights, and workshops to validate and further deepen the implications of these insights), 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 quantitative methodology for detecting 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 policy recommendations and legislative opportunities for European stakeholders and policymakers to act upon.

The methodology used to detect weak signals will be further validated through conferences and peer-reviewed publications in scientific journals, as well as further developed and applied to other types of data (e.g. patents) or specific policy or technology fields. Finally, the detection of weak signals will be integrated to existing foresight and anticipation mechanisms to support JRC services and policy Directorate Generals of the European Commission in designing European policies.

The 256 weak signals can be examined in detail here:

https://www.timanalytics.eu/TimTechPublic/main.jsp?dataset=s_1231

Figure 1: Network graph of the 256 weak signals. The size of the nodes is the number of documents retrieved, while edges link two nodes when they have documents in common. Some technologies have been regrouped into communities of different colours. These communities were calculated with the Louvain modularity algorithm[1]. Some clusters of weak signals pertaining to the same field are indicated on the graph.



[1] "Fast unfolding of communities in large networks", Blondel et al., arXiv:0803.0476 [physics.soc-ph].

1 Introduction

The design of new policies entails policy-makers to stay abreast of technological developments that may bring paradigm shifts to society. In a time of accelerating technological change and hyperconnectivity, early awareness of possible disrupting innovations, technologies, or scientific development allows more time for the design of well-fitted policies that secure both a stable business environment for industrial actors and a safe society for citizens to live in.

Foresight is the discipline that, through a series of well-established tools and methods, develops anticipatory knowledge by bringing together relevant experts and stakeholders to collect insights on possible alternative futures. The generated insights can be used to support policy-makers with long-term implications and opportunities on technological development. As many policy fields have a technological component, foresight methods have been developed to gather knowledge from scientists, experts and other stakeholders about the trajectories that scientific or technological fields are taking. For many years, qualitative and semi-quantitative methods were devised for this purpose and it is only recently that attempts at developing more quantitative methods have been undertaken. These quantitative methods usually apply AI techniques (e.g. text mining, neural networks) to large corpora of data in an attempt to extract early signals of new scientific developments or technologies. These so-called weak signals have specific characteristics that allow them to be detected, analysed (to assess their disrupting potential) and monitored (to follow their evolution in time). Therefore, these quantitative methods provide added value and can strengthen foresight methods by 1) complementing them by flagging new emerging topics or challenges that should be explored by means of qualitative processes or 2) being used to validate/reinforce the results of a qualitative exercise.

The analysis presented here is the result of a quantitative forward-looking exercise ran by the JRC between May and August 2019 using the TIM Trends software. This software combines text mining techniques with computation and data visualisation means and has been designed by JRC to detect weak signals of emerging technologies or scientific topics. Using TIM Trends on scientific literature covering 1996 to 2018 inclusive (Scopus data set) and the methodology described below, we were able to report 256 weak signals in various fields. This report presents all these weak signals and gives some indications of their level of technological maturity, according to indicators described herein. The present report does not analyse for each weak signal what are the main actors, where they are located, or if Europe is strong. To allow for deeper investigation of the signals, JRC has created a specific space on its TIM platform where all of the identified signals have been reconstructed. This space is accessible here: https://www.timanalytics.eu/TimTechPublic/main.jsp?dataset=s_1231.

This report demonstrates that quantitative forward-looking methods could bring additional elements to the design of policy-making by identifying new emerging trends. The quantitative methodology developed by JRC allows for a high granularity in the detection of the weak signals, which can be done at the level of a technology or just from mere issues that only few articles have reported. TIM Trends offers many features for its users to build data corpora for analysis, identify the weak signals using customisable indicators and visualise the results.

2 Methodology

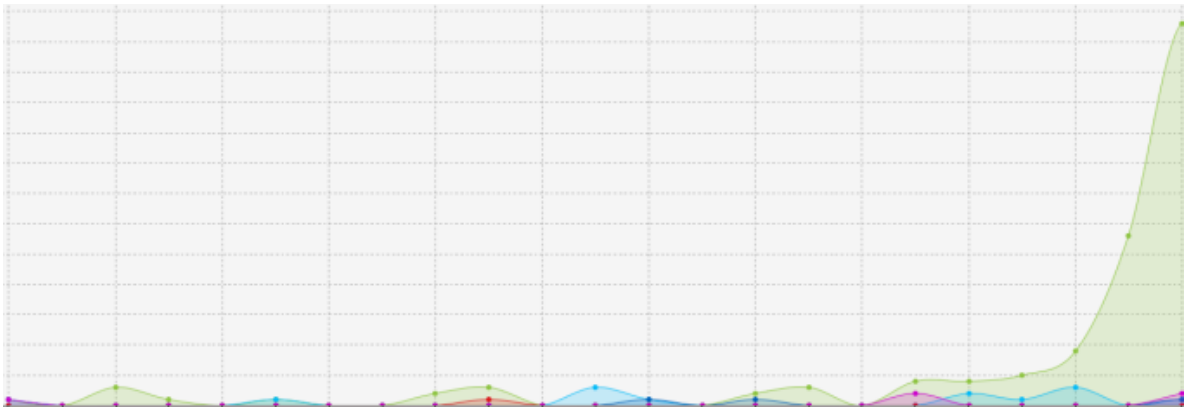
2.1 Building datasets

A dictionary of multi-word concepts is generated from a corpus of documents using text mining techniques. To capture the recent vocabulary used in scientific publications, the last five years of scientific publications (2014-2018) from the Scopus database, which counts 2.15 million publications, is used as corpus. Single words, multi-word terms and acronyms are extracted from the title, abstract or author keywords of the publications. The TF*IDF[2] method is then used to select the most relevant keywords, and stemming is applied to group words with similar basic meaning. The resulting dictionary is composed of more than four million relevant concepts, each of them subsequently used in a search query to build an equivalent number of datasets, each containing the documents retrieved by the search from scientific publications dating from 1996 to 2018[3].

2.2 Detection of raw weak signals

A custom-built indicator called "activeness" is used to sort the datasets obtained by the text mining process. This indicator is defined as the ratio between the number of documents retrieved for a certain period and the total number of documents retrieved for the period 1996-2018. For example, the indicator activeness[2016-2018] is the [#documents published during the period 2016-2018] / [#documents published during the period 1996-2018]. A high activeness score means that a higher percentage of documents have been published during the selected period. Several activeness indicators for different periods have been used to detect the weak signals in the Scopus database.

Figure 2: Typical shape of a weak signal on a graph #documents (Y-axis) Vs years (X-axis).



2.3 Selection of relevant weak signals

Various filters are used to refine the list of raw weak signals, which inevitably also contains false positives. First, a simple filter is applied to reject datasets that do not reach a certain minimum number of documents. Then, a more elaborate filter relying on "semantic compactness"[4] is used to reject weak signals containing documents that are not similar from

[2] Term frequency–inverse document frequency (TF-IDF) is a numerical statistic method that calculates how important a word is to a document in a collection or in a corpus.

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

[4] The semantic compactness indicator allows evaluating the semantic proximity of a collection of documents. It relies on the cosine similarity matrix, calculated for the collection of documents. To build the matrix, a

a semantic perspective. Weak signals pertaining to different conceptual areas but with one or two semantic concepts in common are not considered (e.g. documents related to a conference where the only common term between the documents is the name of said conference). Manual filtering is also used to reject datasets resulting from errors in the original corpus (e.g. spelling mistakes). Finally, custom-made indicators are used to further refine the list of weak signals. To complete the selection, the remaining weak signals are reconstructed in the TIM Technology system, which, in addition to scientific publications, also contains patents and EU R&D grants. The search queries are optimised to improve the recall of documents and to confirm the list of weak signals.

2.4 Description of the weak signals

The 256 weak signals are all listed in chapters 3 and 4. Chapter 3 gives an overview of all weak signals manually classified into nine categories (and sub-categories) to facilitate reading. Each (sub-)category was selected on the basis of the most prominent field appearing in the scientific publications. Chapter 4 briefly describes each signal and puts it on a comparative graph that uses three complementary indicators (Table 1).

Table 1: Complementary indicators used for analysis of the weak signals

Indicator	Calculation	Function
Activeness score	(act1*act2*act3)/10,000	This indicator gives more weight to weak signals whose publications are mostly in the last year. The higher the activeness score, the more recent the WS.
% Patents	#patents / #documents	This indicator gives an indication of the potential commercial interest related to the WS. The higher the number of patents, the higher the commercial potential.
Hotness	(% conference proc. + 1) x (#journals/#publications)	This indicator gives more weight to weak signals that are debated during scientific conferences (high % of conference proceedings) and/or are discussed in scientific publications of different fields (high number of different journal titles).

These three indicators are used for visualising the results and help locate weak signals of different types, as can be seen on Figure 3. Five weak signals have been highlighted as an example: Internet of Vehicles, MK-8591 for HIV, 5G Security, Underwater wireless power transfer and Zika vaccine. A node representing the average values for the three indicators is also displayed in the graph.

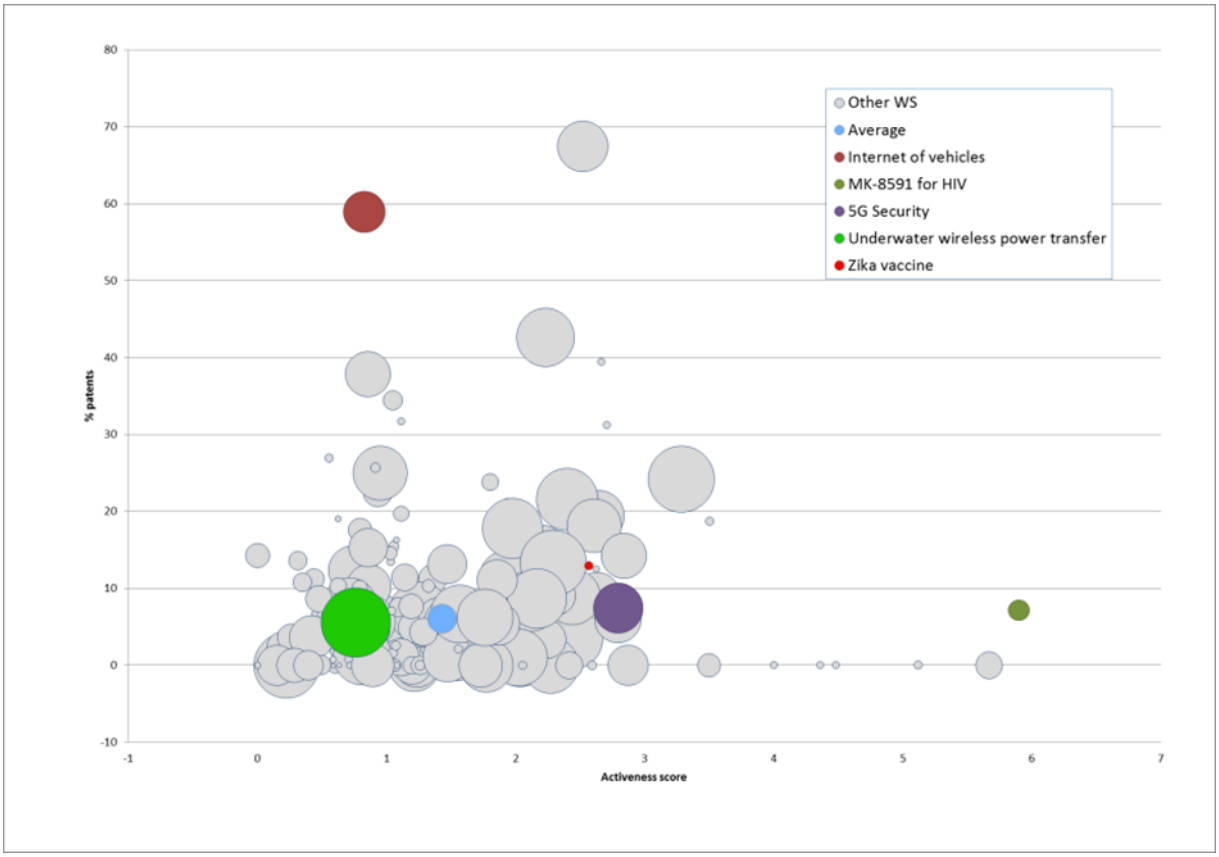
Internet of Vehicles: located on the top left, this weak signal exhibits a high proportion of patents (more than 50% of the total number of documents retrieved) and a relatively quite modest activeness score. For a weak signal, a high proportion of patents can be seen as a proxy to strong anticipated market potential, while modest activeness reflects persistence of the weak signal in time (the number of documents on the topic has been growing for several years). These two indicators combined could indicate that this weak signal is about to become an emerging commercial technology.

vector of relevant semantic concepts is built for each document; these vectors are then used to calculate the cosine similarity of each document to the others. The indicator then displays the compactness of the set of documents from a semantic perspective.

5G Security: has a relatively high activeness score but an average hotness score. This reflects that 5G security is recent but does not generate fierce debate in the scientific community.

MK-8591: located on the very far right of the graph, this WS has a very high activeness score but a medium hotness score, indicating that this is a very recent issue. The low patent proportion is typical for this class of weak signals, where only a few patents are needed to protect the technology.

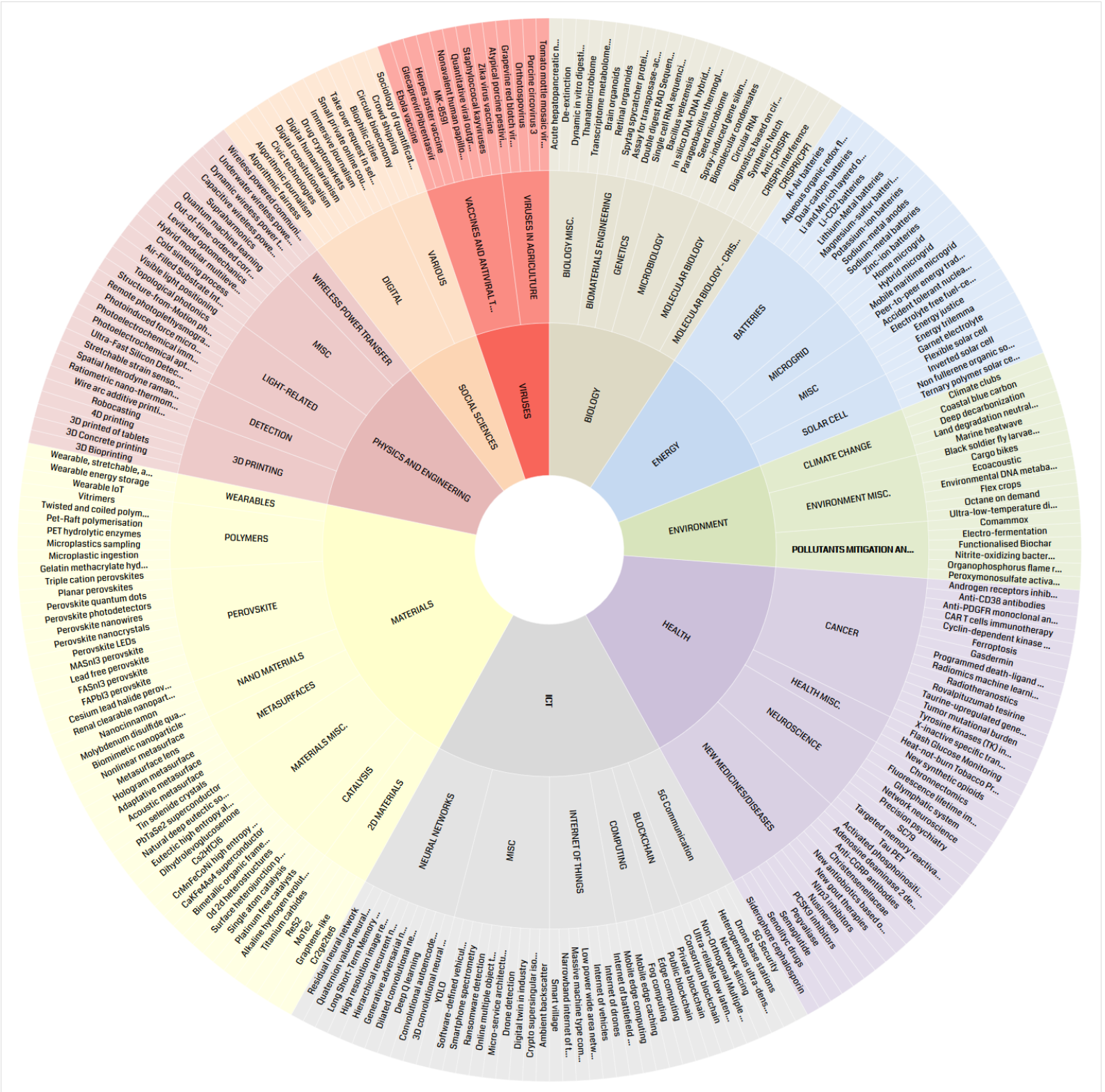
Figure 3: Visualisation of weak signals using three indicators. X-axis: activeness score, Y-axis: %patents, node size: hotness score. Some examples of weak signals are highlighted.



Underwater wireless power transfer: located on the bottom left of the graph, has a rather low patent proportion with a high hotness score (70% of the Scopus documents retrieved are conference proceedings). This indicates a technological weak signal with intense research activity, but for which industrial potential is not yet well-defined due -for example- to technological blockage, conceptual flaws, etc.

Zika virus vaccine: located in the middle of the graph with a low hotness score (no conference proceedings, a fair proportion of journal titles), a medium activeness score and an average patent proportion. This indicates a weak signal, which is mainly being reported in scientific literature. The low number of patents may reflect a rather moderate interest from industry but is also linked to the fact that only few patents are needed to obtain IP rights on vaccines.

3 List of weak signals



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/PF1
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
New antiobiotics based on octapeptins
Nlrp3 inhibitors
Nusinersen
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, stretchable, and flexible electronic textiles
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

4 Description of the weak signals

4.1 Energy

In the context of climate change, the world faces significant challenges in energy production and demand. The transition from exclusive dependence on fossil fuels towards a sustainable energy mix is a complex ongoing process and there is strong pressure on policy makers for a quick transition.

Batteries

The increasing global demand for energy and the potential environmental impact of increased energy consumption requires greener, safer, and more cost-efficient energy storage technologies. Traditional Lithium-ion batteries have been successful in meeting much of today's energy storage demand, but they have reached a peak in performance. Additionally, Lithium is a costly metal that is distributed geographically in an uneven manner and bears safety and environmental concerns.

▶ Aqueous organic redox flow batteries are using water as solvent and organic materials for the anode/cathode. They are expected to overcome major drawbacks preventing economical and extensive deployment of traditional inorganic redox flow batteries. Their primary merit lies in the tuneable redox properties of the redox-active components.

▶ Al-air batteries is not a new concept but has recently received a lot of attention from the scientific community. This type of battery has one of the better energy density/weight ratios, which makes it a very promising candidate for powering up electric cars. Technical issues related to the composition of the anode and the cleaning of the reaction by-products remain to be solved before its widespread use in the car industry.

▶ Dual-carbon batteries are considered very promising for stationary applications like smart grid intermediary storage. These batteries would have higher energy density and they would charge much faster than lithium ones. In addition, dual-carbon batteries do not heat up during operation, dispensing the need for cooling systems.

▶ Li and Mn rich layered oxides. Tremendous research efforts are made to develop new Li-ion batteries with enhanced electrochemical performance. One area of research looks at new materials for cathodes, such as Lithium and Manganese rich layered oxides.

▶ Li-CO2 batteries consume pure CO2 gas at the cathode, which could contribute to capturing CO2 from the atmosphere while producing electricity.

▶ Lithium-Metal batteries are one of the candidates to break the energy-density bottleneck of the current Li-ion chemistry. Some major issues are still to be resolved e.g. preventing the growth of Lithium dendrites and improving their efficiency.

▶ Magnesium-Sulphur batteries are expected to compete with and possibly surpass the traditional Li-ion batteries. On paper the Mg/S chemistry can provide higher energy density and voltage. In addition, magnesium is abundant, non-toxic, doesn't degrade in air and does not form dendrites during deposition/stripping process, which is one of the main safety issue in lithium ion battery.

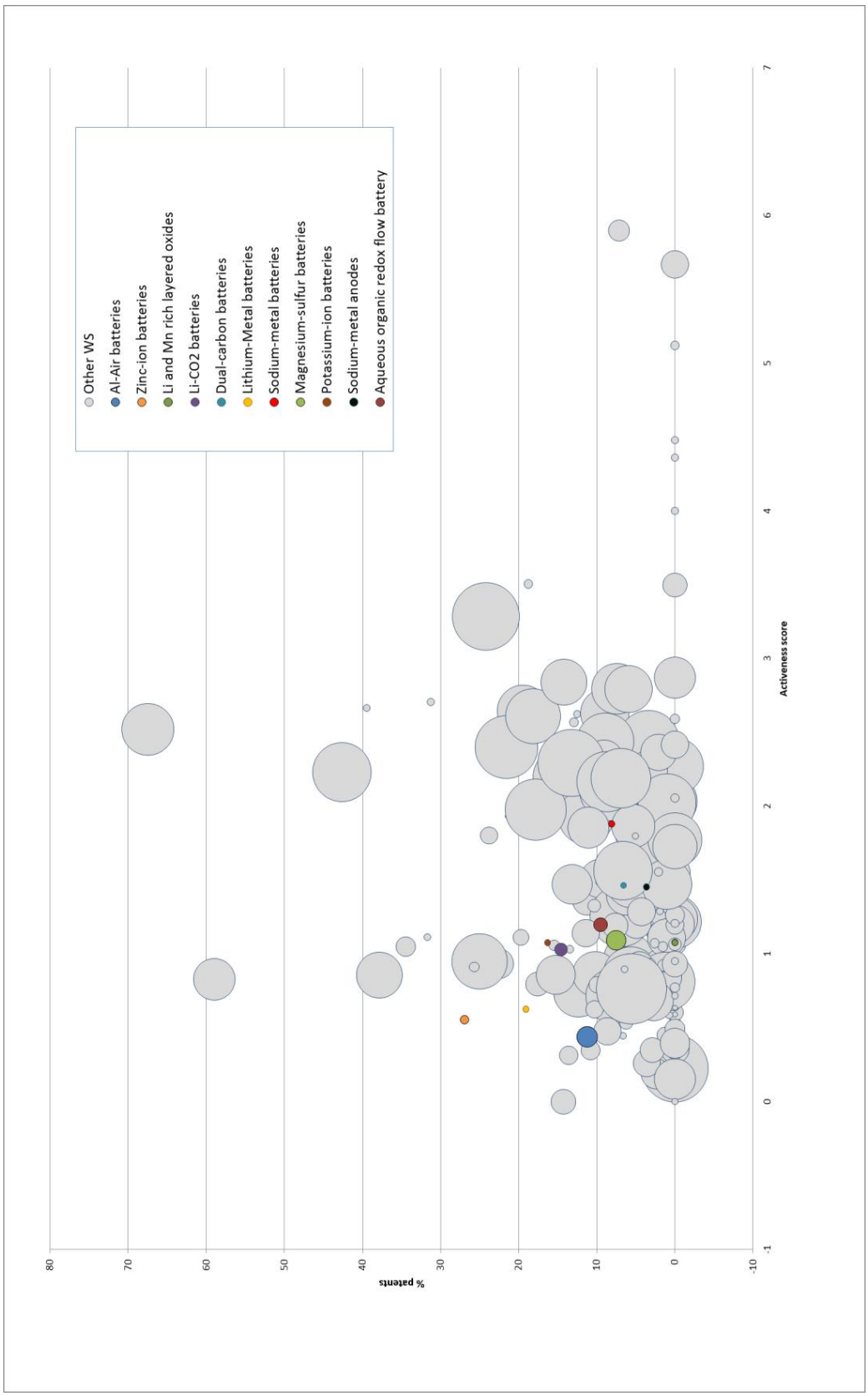
▶ Potassium-ion batteries are one of the prime candidates to replace lithium-ion batteries. Their design is simpler, materials are much cheaper (abundance of K on Earth) and the manufacturing process less complex. This makes potassium batteries a promising candidate for large-scale applications such as energy storage for households and vehicles. K-ion batteries should also be rechargeable much faster than their Lithium counterpart, with estimated charging times e.g. for smartphone applications in the range of only a few minutes.

▶ Sodium-metal batteries are a candidate for the next-generation of low-cost and practical energy storage. Rechargeable sodium metal batteries with high energy density could be important to a wide range of energy applications in modern society.

▶ Sodium-metal anodes have a high theoretical specific capacity and a low electrochemical potential, and are considered as the ultimate anode material for Na-based batteries. Research is ongoing to solve the technical challenges (dendrites growth, unstable solid electrolyte interphase) that are hindering its commercialisation.

▶ Zinc-ion batteries are one viable alternative to Li-ion batteries due to their low cost, the use of water as solvent, their increased safety and lower environmental impact. A lot of research has been ongoing lately to overcome the practical challenges for these batteries to become mass products.

Figure 4: Weak Signals for Energy - Batteries.



Microgrids

Microgrids are localized groups of electricity production and consumption systems that are connected to the traditional electricity grid but can also autonomously operate in isolated mode.

▶ Home microgrids are local electric grids at the level of individual houses. A paradigm shift in the way electricity is produced and consumed is slowly taking place. Microgrids present technical challenges in synchronising with other local grids and with the traditional macrogrid.

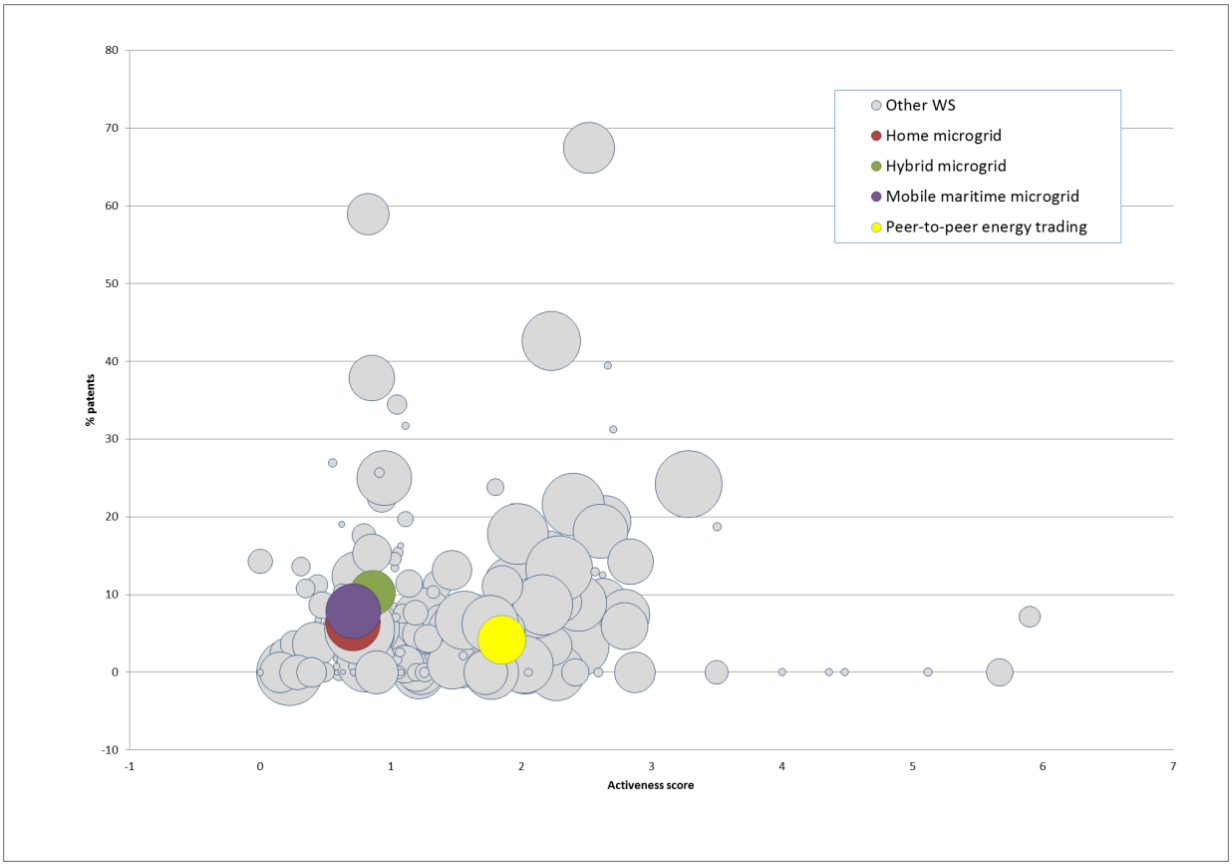
▶ Hybrid microgrids combine various sources of electricity production, conversion, distribution and storage at local level: photovoltaic, diesel generators, wind turbines, batteries, converters, etc. Optimization of hybrid microgrids is currently a very active research area.

▶ Mobile maritime microgrids are complex systems on board of ships, connecting various production and storage means to different loads (propulsion, command and control, communications, etc.), while acting as a controllable entity. This is not a new concept, but it recently gained importance with the increasing electrification and computerized control of naval and merchant marine ships.

▶ Peer-to-peer energy trading

The energy market is undergoing profound transformation with the multiplication of local grids and the growing proportion of renewable energy in the energy mix. This calls for an efficient peer-to-peer (grid-to-grid) trading mechanism for energy. Blockchain technology is one of the candidate technologies that could enable this new peer-to-peer market, by ensuring secure trading and traceability.

Figure 5: Weak Signals Energy - Microgrids.



Solar Cell

Solar cells are photovoltaic devices converting energy carried by light directly into electricity. They are a key component of a sustainable energy production system.

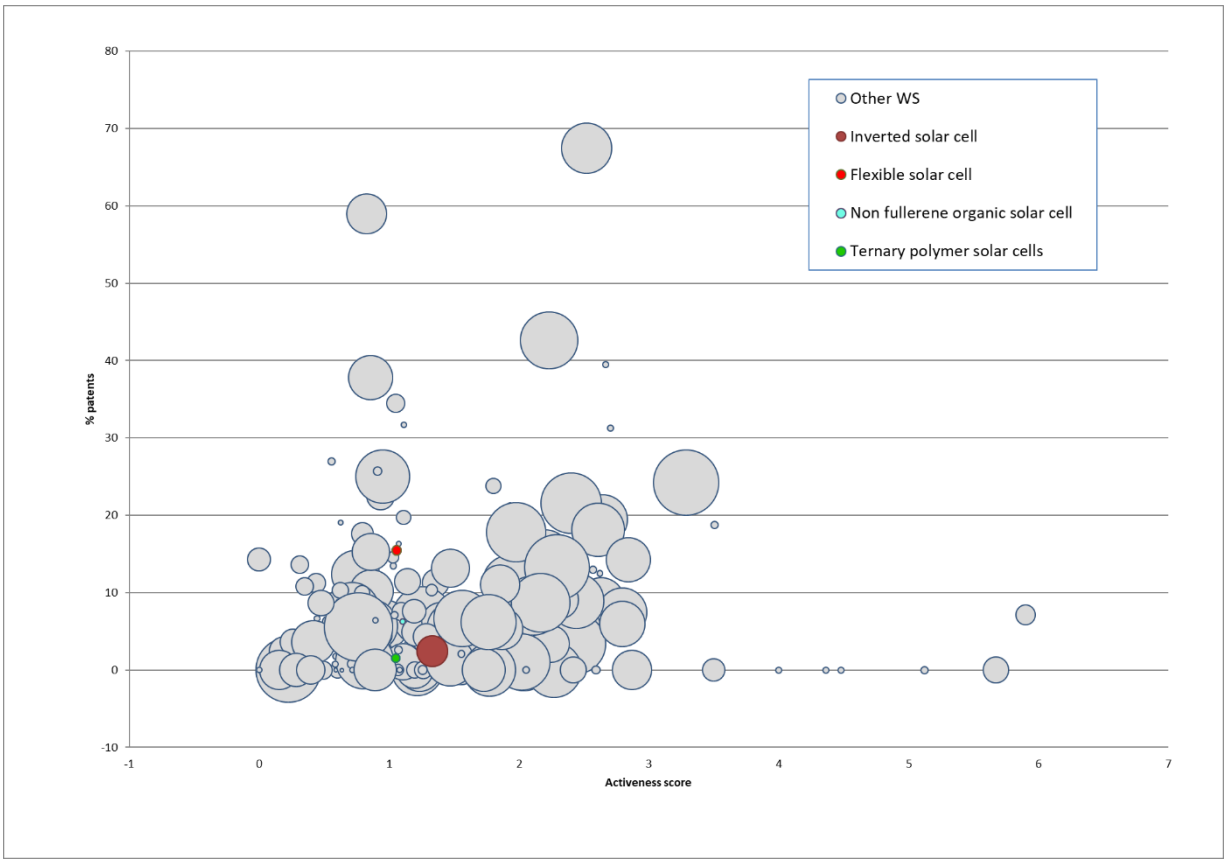
▶ Flexible solar cells are good candidates for powering the next generation of wearable electronics, which must simultaneously have high power efficiency, low weight, environmental stability, flexibility, stretchability, and twistability.

▶ Inverted solar cells have the positive and negative electrodes switched to reverse the flow of electric charges, compared to a normal device. Advantages of this design: longer lifetime and resistance, but mainly a cheaper and easier mass production manufacturing process. Research is being performed to bring inverted cells to similar light conversion efficiency as traditional solar cells.

▶ Non-fullerene organic solar cells are being developed to overcome the limitations of fullerene organic solar cells, which are flexible, semi-transparent and environmentally friendly, but only achieve modest light conversion efficiency of a maximum of 12%. Their properties make them promising materials for photovoltaic applications where silicon panels cannot be used (e.g. glass windows on buildings).

▶ Ternary polymer solar cells have attracted interest lately due to their potential for high light conversion efficiency. The increasing demand for photovoltaic devices is triggering research geared at improving the overall cost-effectiveness of solar cells.

Figure 6: Weak Signals Energy - Solar Cells.



Miscellaneous

▶ Accident-tolerant nuclear fuels are new nuclear fuels that have been developed in response to the accident at the Fukushima power station in March 2011. Although the increase in R&D for these materials has been triggered by a catastrophic event, it can be considered as a weak signal. The impact of these new nuclear fuel materials on society will be to limit the exposure of populations, fauna and flora to radiation emitted in nuclear plants after serious incidents.

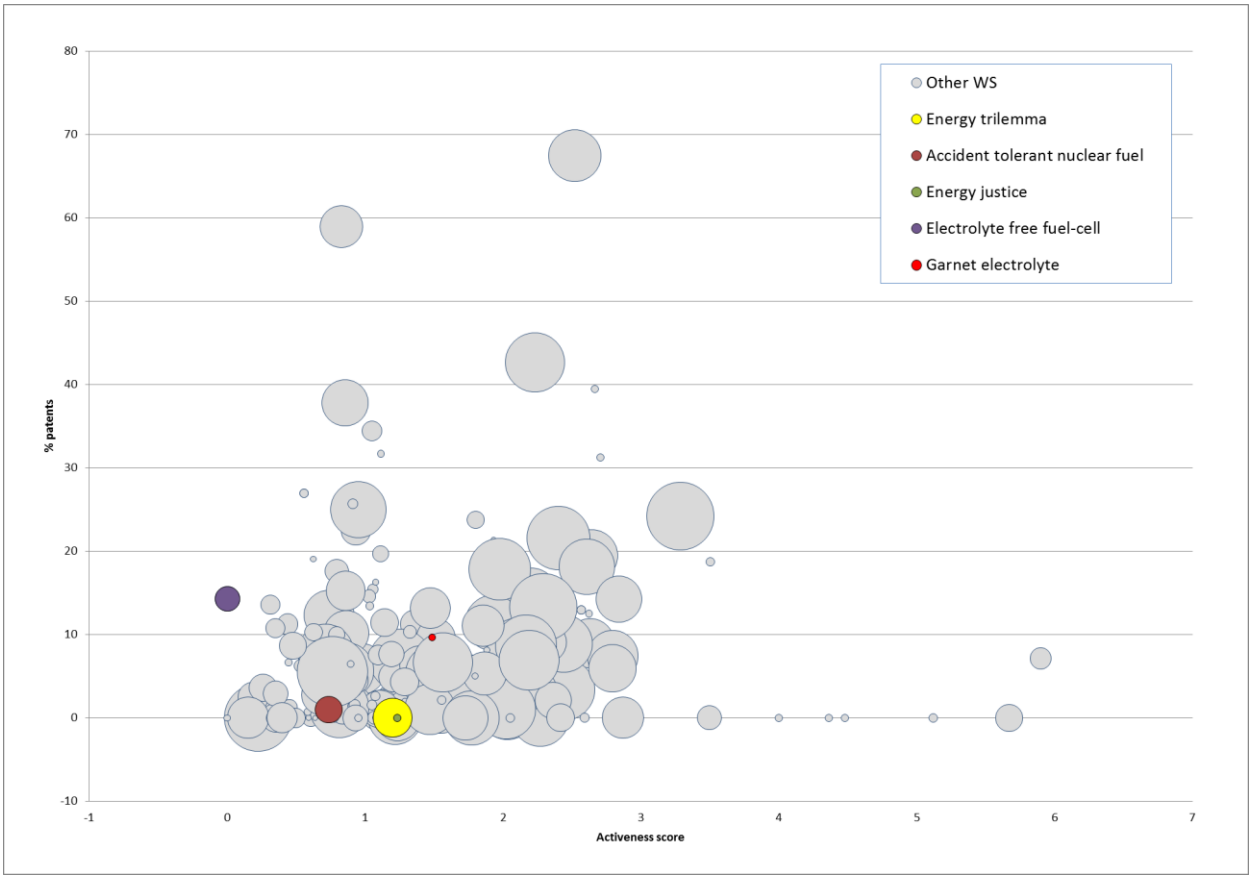
▶ Energy justice is a concept that recently emerged as a new cross-cutting issue in social sciences. It seeks to apply justice principles to energy policy at large (production, consumption, security, etc.).

▶ Electrolyte free fuel-cell is a type of fuel cell design with a radically new approach that could lead to simpler construction and improved cost-efficiency, and open up new opportunities for fuel cells.

▶Energy trilemma is a new concept in social sciences research that describes the trilemma between energy security, social impact and environmental sensitivity.

▶ Garnet electrolytes possess a garnet structure and are subject to intense research, as they are promising candidates for the achievement of all-solid-state Li-metal batteries, which is itself a promising alternative to traditional Li-ion batteries.

Figure 7: WS Energy - Miscellaneous.



4.2 Biology

Biomaterials engineering

Biomaterials are substances that have been engineered to interact with biological systems, usually for therapeutic purposes or in diagnostic procedures.

▶ Brain organoids & Retinal organoids

Organoids are tiny, self-organized three-dimensional tissue cultures that are derived from stem cells and can be crafted to replicate the complexity of organs or to express selected aspects of it like producing only certain types of cells. Organoids allow the study of biological processes, such as cell behaviour, tissue repair and response to drugs or mutations, in an environment that mimics endogenous cell organisation and organ structures. Recently, brain and retina organoids were developed to model and study the development of the human brain and the retina.

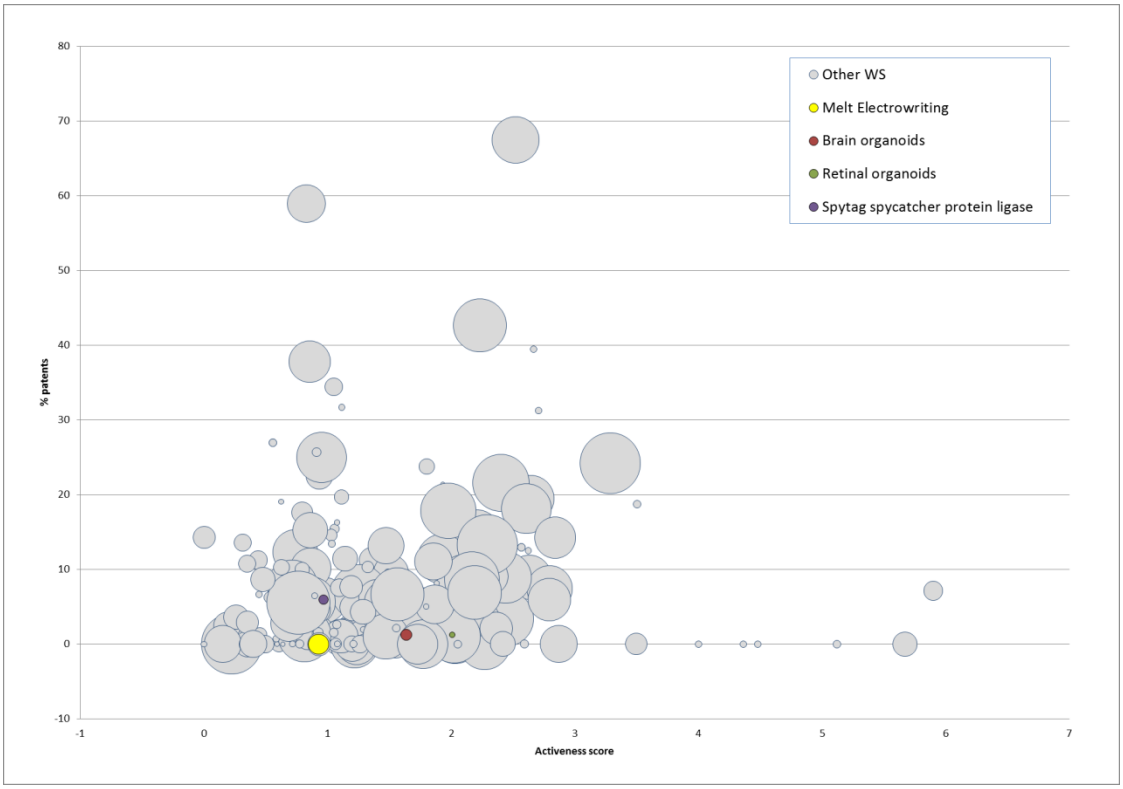
▶ Melt ElectroWriting

(MEW) is a novel additive manufacturing technique using thermoplastic polymers to produce microscale structures. MEW allows controlling and tailoring the properties of the materials produced and this is of particular interest in scaffold-guided tissue engineering, where the goal is not to replicate the physical structure of a tissue, but to guide the regeneration process by designing customized scaffold assembly. MEW scaffolds are biocompatible, biodegradable, and can be designed with different porosities, fibre diameter, spacings, and laydown patterns.

▶ Spytag-Spycatcher protein ligase

is a sort of protein superglue that can be used in synthetic biology applications. SpyTag is a short peptide that forms an isopeptide bond upon encountering its protein partner SpyCatcher. This covalent peptide interaction is a simple and powerful tool for bio-conjugation, allowing building complex multiprotein assemblies with sophisticated functions, by using protein components as building blocks. The development of new protein assemblies is booming and holds the promise for novel materials with many applications.

Figure 8: Weak Signals Biology – Biomaterials engineering.



Genetics

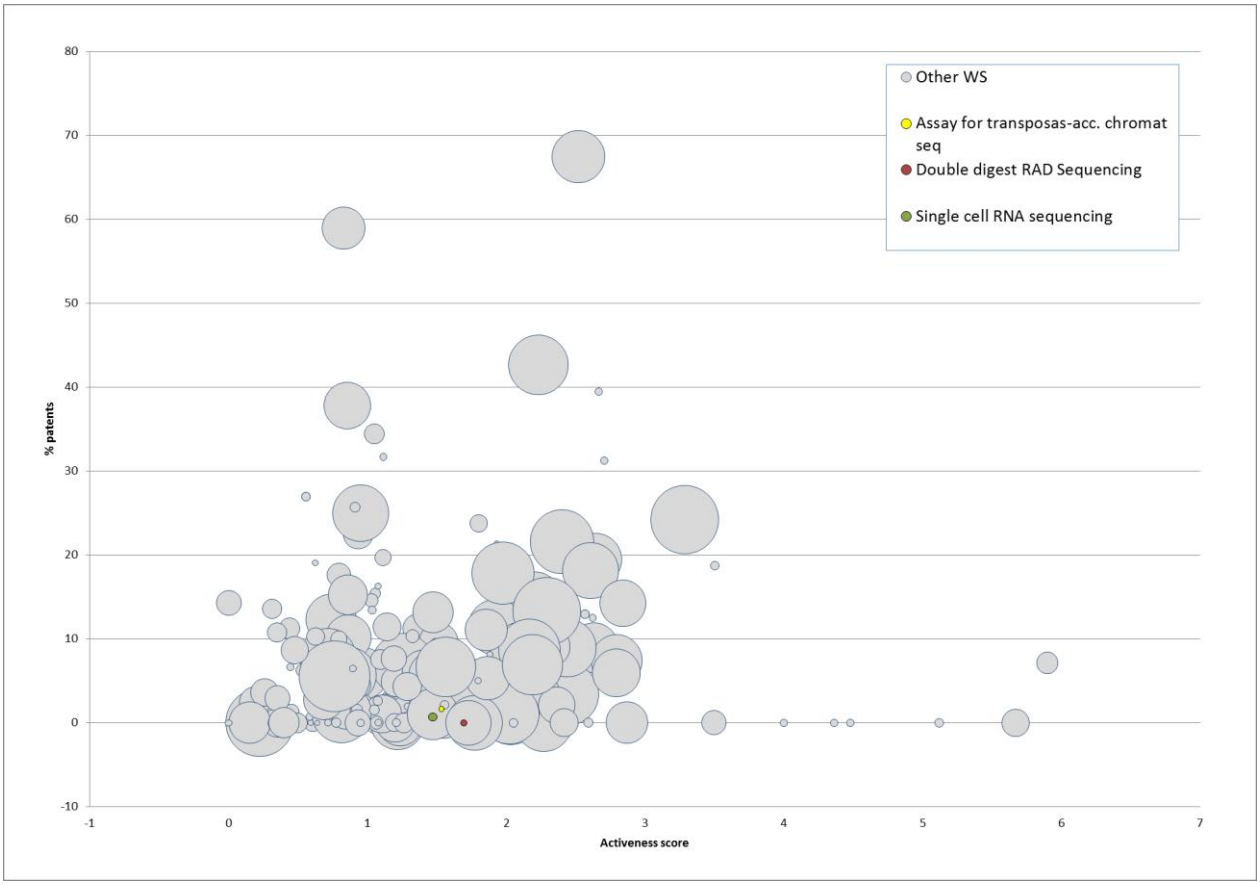
This branch of biology specifically looks into genes, genetic variation, and heredity. Ultimately, genetics aims to develop more personalised medicines and curative/preventive treatments for diseases.

▶ Assay for transposase-accessible chromatin sequencing (ATAC-seq) is a technique used in molecular biology to assess genome-wide chromatin accessibility. This method probes DNA accessibility with hyperactive Tn5 transposase, which inserts sequencing adapters into accessible regions of chromatin. ATAC-seq is becoming an essential tool in epigenetics and genome-regulation research. It has been successfully adapted to efficiently identify open chromatin and identify regulatory elements across the genome.

▶ Double digest RAD Sequencing (ddRAD-Seq), also known as Sequence-Based Genotyping (SBG), is a fractional genome sequencing strategy designed to efficiently identify and score genetic variants across any genome. It involves digesting a target genome with two restriction nucleases and then surveying the resulting fragments for single nucleotide polymorphisms (SNPs) variants using next generation DNA sequencing. With SBG technology, development of thousands of genetic markers can be accomplished quickly and effectively.

▶ Single cell RNA sequencing provides a high resolution images of cellular differences and a better understanding of the function of an individual cell in the context of its microenvironment. Sequencing RNAs expressed by individual cells can give insight into the development and behaviour of different cell types, for example in diseases like cancer.

Figure 9: Weak Signals Biology - Genetics.



Microbiology

Microbiology studies microorganisms and encompasses numerous sub-disciplines including virology, parasitology, mycology and bacteriology.

▶ Bacillus velezensis is a bacterium that has attracted a lot of attention, mainly for its potential as alternative to currently-used synthetic fertilizers and chemical pesticides. Numerous strains of this species have the potential to fight drug-resistant pathogens and some also have been shown to degrade various toxic industrial by-products.

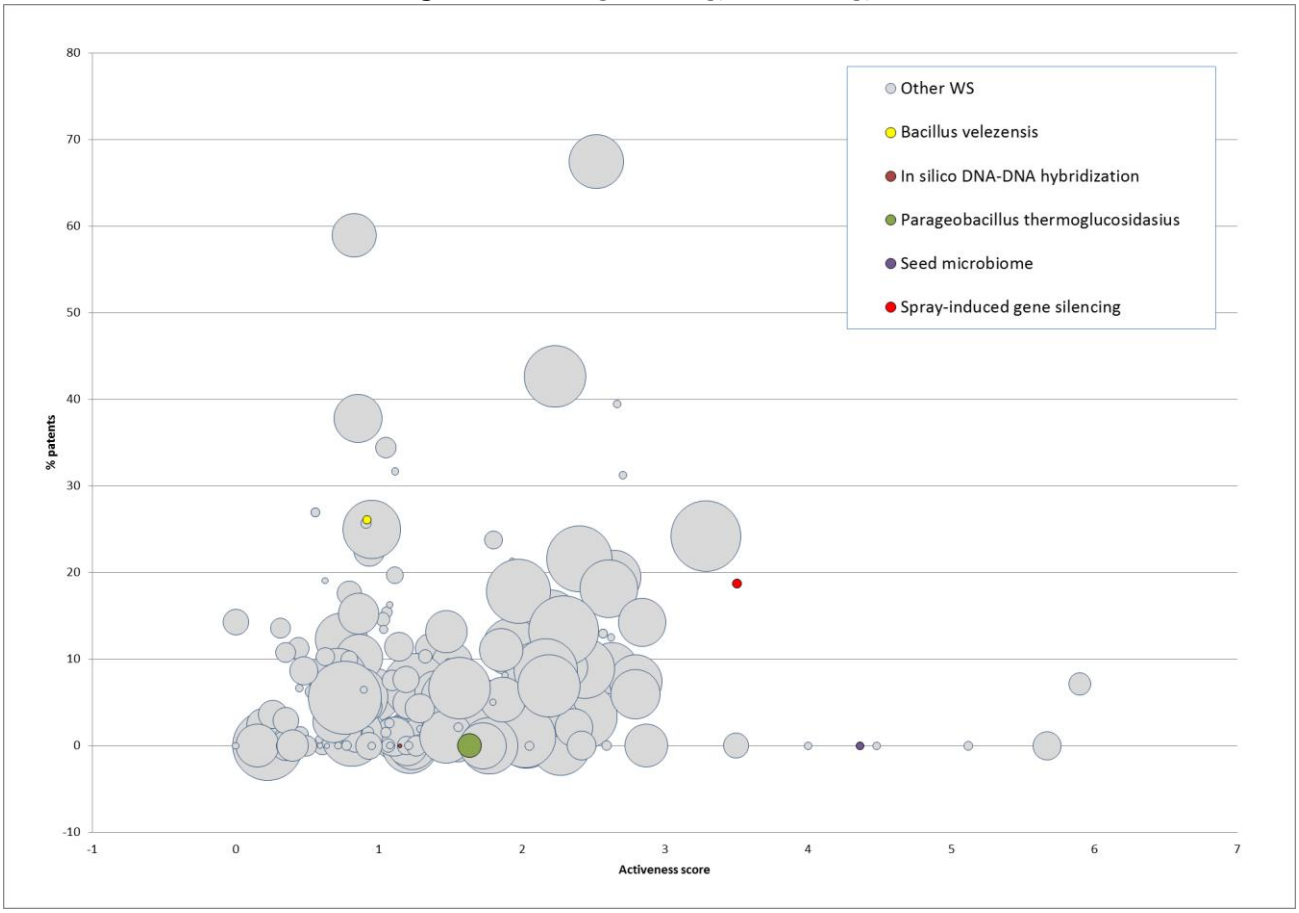
▶ In silico DNA-DNA hybridization (DDH) is a new bioinformatics method in molecular biology that measures the degree of genetic similarity between pools of DNA sequences. It has been developed to overcome the drawbacks of wet-lab DDH (mainly a lack of reproducibility). The method allows inferring whole-genome distances, to work with reduced genomes, repetitive sequence regions, and missing fractions of genomic information. In microbiology, it is used to distinguish bacterial species.

▶ Parageobacillus thermoglucosidasius is a facultative anaerobic thermophilic bacterium that produces hydrogen gas (H2) by coupling CO oxidation to proton reduction in the water-gas shift (WGS) reaction via a carbon monoxide. Parageobacillus has the potential to become a source of Hydrogen (H2), a promising alternative source to fossil fuel.

▶ Seed microbiome includes the community of bacteria, archaea and fungi found on both the surface and the inner parts of seeds. Seed-microbe interactions are studied for their role in plant ecology, health, and productivity in both natural and agricultural systems.

▶ Spray-induced gene silencing is a new method for crop protection against plant pathogens that cause significant crop losses worldwide. Recent new studies demonstrate that spraying double-stranded RNAs and small RNAs that target essential pathogen genes on plant surfaces confer efficient crop protection. This technology for disease control is potentially sustainable and environmentally friendly.

Figure 10: Weak Signals Biology - Microbiology.



Molecular Biology

This branch of biology investigates the molecular mechanisms responsible for biological activity between biomolecules in cells.

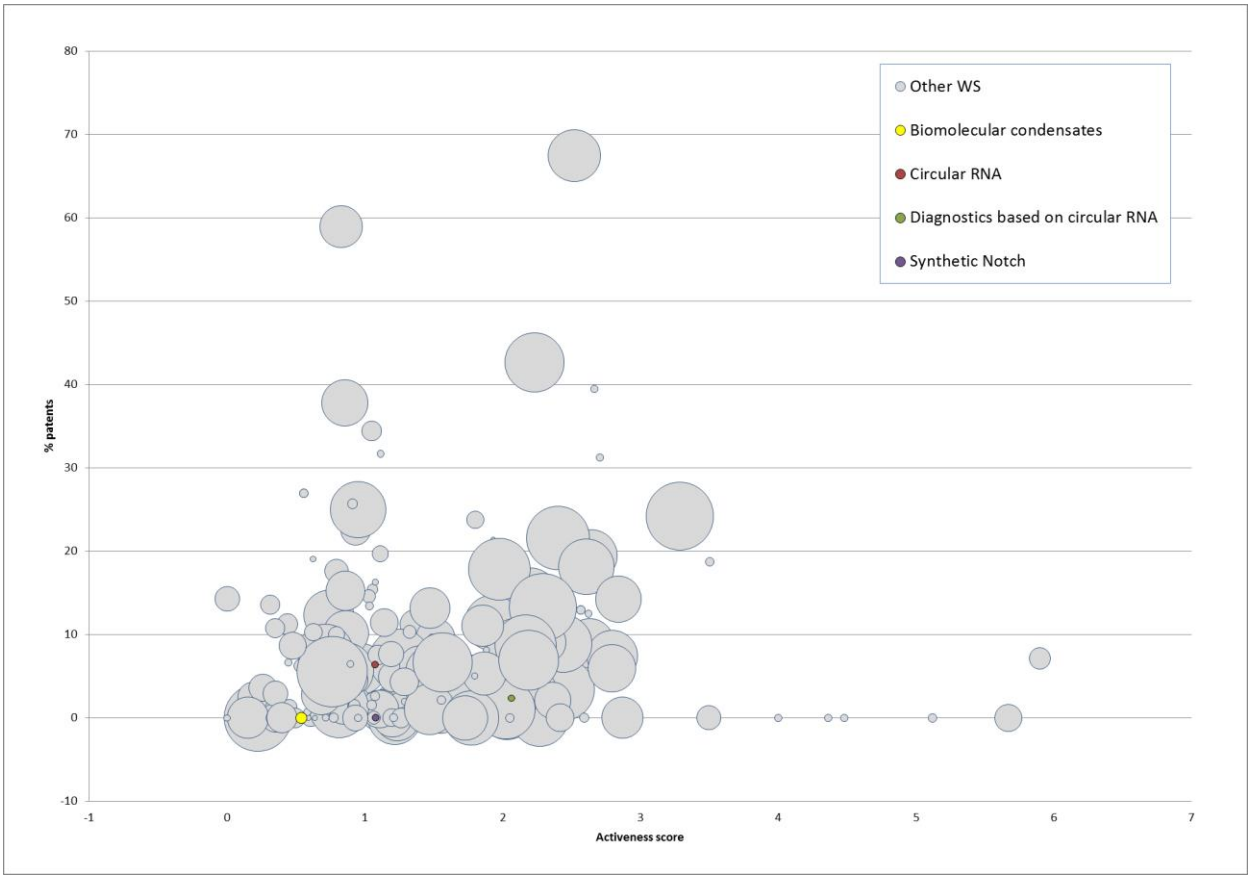
▶ Biomolecular condensates are micron-scale compartments in eukaryotic cells that lack surrounding membranes but present a concentration of proteins and nucleic acids. These condensates, also called membrane-less organelles, are involved in diverse processes, including RNA metabolism, ribosome biogenesis, DNA damage response and signal transduction. These condensates are important to the functioning of cells, but their dynamics and functions are still vastly unknown.

▶ Circular RNA is a group of endogenous non-coding RNAs characterized by covalently closed cyclic structures lacking poly-adenylated tails. Although there is still no consensus as to the function of circRNAs in cells, recent studies have suggested that they play a crucial role in regulating gene expression and be involved in developing e.g. autoimmune diseases, Alzheimer or cancer.

▶ Diagnostics based on circular RNA. An increasing number of studies have suggested that circular RNAs play a vital role in carcinogenesis and tumor progression. Furthermore, the stability, conservation and high abundance in body fluids of circRNAs make them promising biomarkers for various diseases.

▶ Synthetic Notch (synNotch) are synthetic receptors based on the cell-cell signalling receptor "Notch". SynNotch provides a potential way to flexibly design customized and inducible immune cell responses. The unprecedented programmability of synNotch cells has promising applications in the design of therapeutic cells to treat a broad range of diseases including cancer and autoimmune diseases.

Figure 11: Weak Signals Biology – Molecular biology.



Molecular Biology - CRISPR

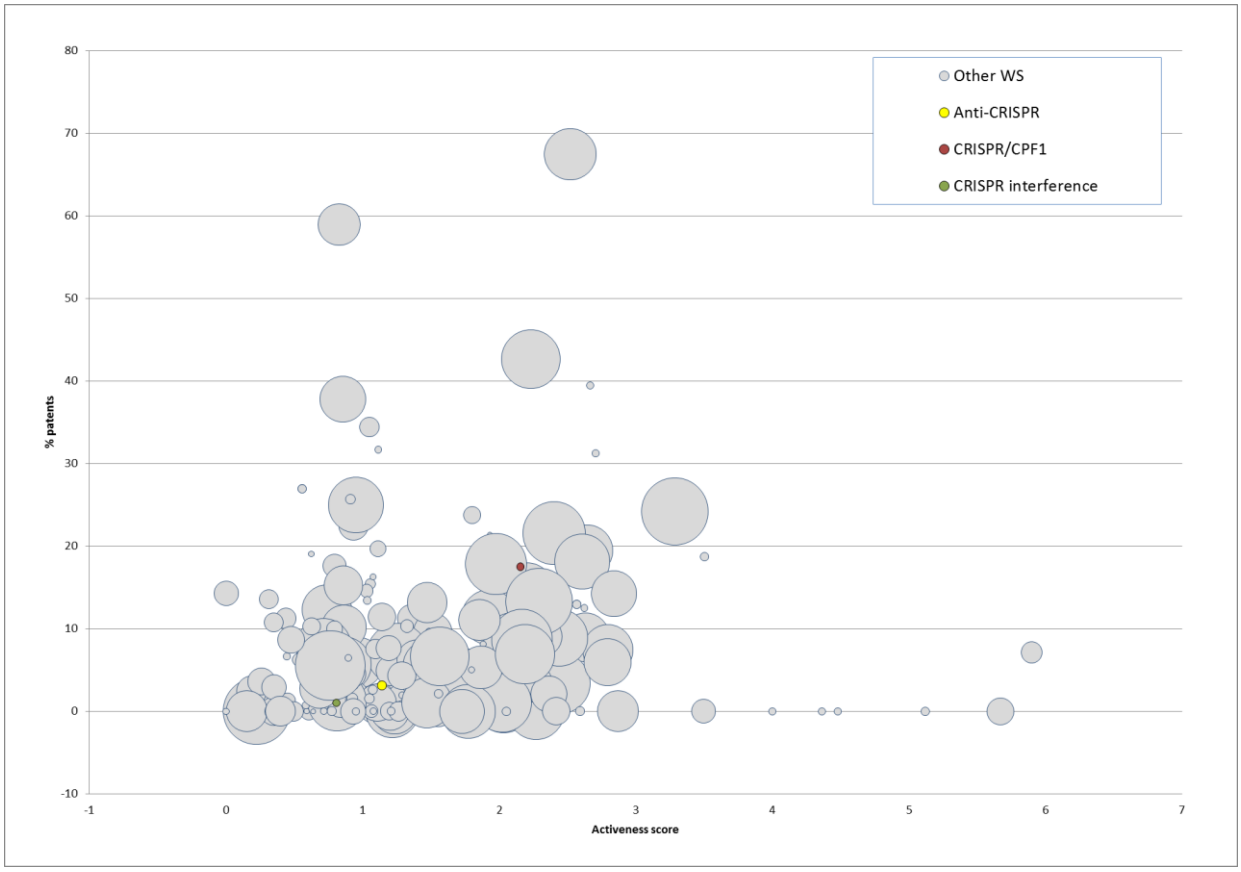
Genome editing, the ability to precisely edit the genome of a living cell, has led to many innovations in the past years. It still holds great potential for new applications in life science and biotechnology. While methods for genome editing have been around for several years, the CRISPR-Cas9 method quickly eclipsed all other genome editing techniques with its efficiency, effectiveness and precision.

▶ Anti-CRISPR Scientists have found four new anti-CRISPR proteins that are distributed across different environments. The new study suggests that some anti-CRISPR proteins are more widespread in nature than previously anticipated. These anti-CRISPRs could potentially be used to better regulate the activity of CRISPR-Cas9 systems, which have become a major tool in gene editing.

▶ CRISPR/CPF1 stands for "Clustered Regularly Interspaced Short Palindromic Repeats from Prevotella and Francisella 1" and is a DNA-editing technology analogous to the CRISPR/Cas9 system. This acquired immune mechanism is found in Prevotella and Francisella bacteria and prevents genetic damage from viruses. CRISPR/Cpf1 is an endonuclease smaller and simpler than Cas9, overcoming some of the CRISPR/Cas9 system limitations. CRISPR/Cpf1 could have multiple applications, including the treatment of genetic illnesses and degenerative conditions.

▶ CRISPR Interference (CRISPRi) is a genetic perturbation technique that allows for sequence-specific repression of gene expression (up to 99.9% repression). Based on the bacterial genetic immune system - CRISPR pathway, the technique provides a complementary approach to RNA interference (RNAi). The difference between CRISPRi and RNAi, though, is that CRISPRi regulates gene expression primarily on the transcriptional level, while RNAi controls genes on the mRNA level.

Figure 12: Weak Signals Biology – Molecular biology CRISPR.



Miscellaneous

▶ Acute hepatopancreatic necrosis disease (AHPND), also referred to as "early mortality syndrome" (EMS), is a destructive disease of cultured shrimp, mainly in Asia. It is caused by the bacterial pathogen Vibrio parahaemolyticus, whose possible spread to the Western Hemisphere is of major concern to the shrimp industry, as it would result in significant economic losses in affected areas.

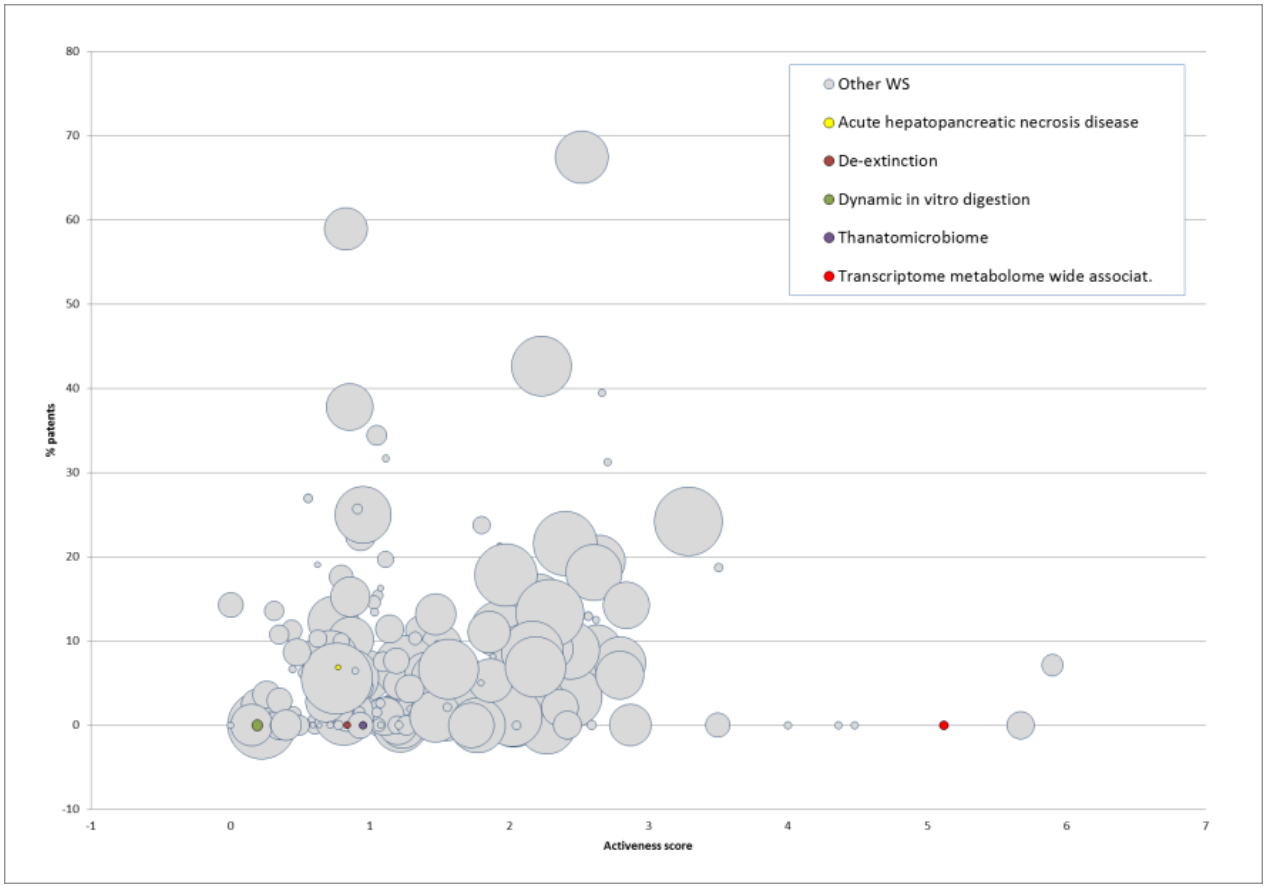
▶ De-extinction, also known as "resurrection biology" or "species revivalism", aims at re-viving extinct species. Cloning is the most widely proposed method, although selective breeding has also been proposed. Although there is significant controversy about de-extinction, this technique could play a role in conservation and restauration of the biodiversity of our planet.

▶ Dynamic in vitro digestion is a new technique that allows studying human digestion in vitro but in dynamic conditions (in vivo digestion studies face ethical and financial constraints). Compared to static in vitro digestion models that hardly recreate the complexity of the digestive tract, dynamic models are promising for understanding digestion better in humans by allowing pH regulation, food flow and injection of digestive enzymes in real time, in different compartments of the gastrointestinal tract.

▶ Thanatomicrobiome is also referred to as the post-mortem microbiome. It has been recognized as a useful microbial marker of the time and location of death individuals. Upon death, host tissues and cells decompose and cellular components are released to the surrounding tissues, resulting in significant changes in the host environment overtime. Such changes shape, and are influenced by, host microbes as well as environmental microbes, resulting in specific microbial dynamics.

▶ Transcriptome metabolome wide association is used to search for associations between the transcripts/metabolites and traits. It is similar to genome wide association studies that look for associations between phenotypes and genetic common variants. Integrating genomics and metabolomics data with disease data will bring important information about the pathways that are involved in the development of complex diseases and may lead to novel approaches in personalized health care.

Figure 13: Weak Signals Biology – Biology Misc.



4.3 Health

Neurosciences

Neuroscience is a multidisciplinary scientific field that resorts to molecular biology, medical imaging, cytology, physiology, anatomy, mathematical modelling and others to study the nervous system. Understanding the mechanisms for learning, memory, behaviour, perception, and consciousness is one of the main challenges in the sciences today.

▶ Chronnectomics aims at capturing time-varying properties of connectivity within brain regions using functional magnetic resonance imaging. The term "chronnectome" is used to describe metrics that allow a dynamic view of coupling, which refers to possibly time-varying levels of correlated or mutually informed activity between brain regions, whose spatial properties may also be temporally evolving. It is assumed that the chronnectome may vary as a function of condition (e.g., health, disease, behavior). This new approach holds great promise for the study of both the healthy and malfunctioning brain.

▶ Fluorescence lifetime imaging ophthalmoscopy is a novel technique in ophthalmology that allows fluorophores to be detected and potentially discriminated using their fluorescence lifetime. The detection and discrimination of these fluorophores is key to elucidating metabolic and functional alterations in the context of various retinal diseases.

▶ Glymphatic system is a recently discovered pseudolymphatic system in the brain that plays an important role in the drainage and removal of interstitial metabolic waste products. The glymphatic system could be involved in Alzheimer's disease and other neurodegenerative disorders, and its understanding should lead to new preventive and diagnostic tools, as well as new drugs.

▶ Network neuroscience approaches brain structure and function from an explicitly integrative perspective and pursues new ways to map, record, analyse and model the elements and interactions of neurobiological systems. It is aiming at a better understanding of the brain as a multiscale networked system.

▶ Precision Psychiatry is the new field of personalized medicine in psychiatry. The aim is to leverage the collection of "big data" to help understand how biomarkers and genetic characteristics align with certain types of responses to different medications. From there, individual patients' genetic characteristics and biomarkers would be used to better predict which psychiatric medicines might be best for them.

▶ SC79 is a recently discovered activator of the protein kinase B (PKB), which plays a key role in cellular processes such as glucose metabolism, apoptosis, cell proliferation and migration, transcription. SC79 suppresses the translocation of PKB through the cell membrane, while activating it in the cytosol. It has shown cyto-protective effects and is a promising new neuroprotective agent that could become important in treating cerebral infarction and other brain injuries.

▶ Targeted memory reactivation consists in re-exposing the brain to memory cues during non-rapid eye movement sleep. It affects the selectivity of memory storage using sound cues associated with learning and improves memory performance. Targeted memory activation has been successfully used to improve memory processes, strengthen motor skills, modify social biases, and enhance fear extinction.

▶ Tau PET is a new imaging method in positron emission tomography (PET) that allows for the assessment of neurofibrillary tangles in the brain. These tangles, made up of aggregated tau protein (abundant in the brain), are a hallmark of several neurodegenerative diseases and cognitive decline. The use of such a method could allow researchers to better distinguish between different variants of neural degeneration in living patients and guide the development of precise treatments. It will also be critical to understanding differences between individuals that are resistant to developing tau pathology and those who have tau pathology but are resilient to its effects on cognition.

Figure 14: Weak Signals Health – Neurosciences.

New drugs/diseases

▶ Activated phosphoinositide 3-kinase (PI3K) δ syndrome is a recently described primary immunodeficiency, resulting from autosomal dominant mutations in the gene encoding the regulatory subunit of PI3K. The disease deregulates the immune system, which causes airway infections, bronchiectasis and lymphoproliferation. The number of patients with this syndrome is increasing fast and has led to new research on the topic.

▶ Adenosine deaminase 2 deficiency is a recently described auto-inflammatory disorder that causes vasculitis, i.e. the destruction of blood vessels by inflammation. It is an inherited disease, caused by mutations in the ADA2 gene encoding ADA2 enzyme. This is a rare condition, reported for the first time in 2014.

▶ Anti-CGRP antibodies are new drugs designed to inhibit the calcitonin gene-related peptide (CGRP) or its receptor. CGRP is a protein that is released around the brain and is known for causing migraine. These molecules are the first preventive medication for migraine and have a significant potential market and impact.

▶ Christensenellaceae is a bacterial species found in the human gut that seems to play a role in obesity. Around 97% of us have detectable levels of this bacterium but it has been found to be more present in lean people. Research linking obesity to microbiome could lead to groundbreaking therapies for treating obesity.

▶ New gout therapies have been explored over the last decade due to increased prevalence. Gout is caused by elevated serum urate levels, which can be treated using suppressors of the uric acid transporter, URAT1. This novel therapeutic approach has led to the development of new URAT1 inhibitors.

▶ Octapeptins is a family of cyclic lipopeptides, first reported in the 1970s but largely ignored at the time. Today, the advent of widespread drug resistance in Gram-negative bacteria has led to their 'rediscovery' as having antibiotic activity against polymyxin-resistant bacteria.

▶ Nlrp3 inhibitors are a promising class of new drugs for treating Parkinson. These inhibitors disrupt the NLRP3 inflammasome, a multiprotein complex that serves as a sensor of cell stress and abnormal proteins.

▶ Nusinersen is the first approved drug for the treatment of spinal muscular atrophy, a group of rare neuromuscular disorders caused by the depletion of the SMN protein in the central nervous system (CNS) that leads to the loss of motor neurons and progressive muscle atrophy. Nusinersen is an antisense oligonucleotide that functionally converts the SMN2 gene into an SMN1 gene, thereby increasing the level of SMN protein in the CNS.

▶ PCSK9 inhibitors are a new class of injectable drugs that have been shown to dramatically lower cholesterol levels, when combined with a statin. These new drugs are monoclonal antibodies targeting and inactivating the protein PCSK9, known for inactivating receptors on the liver cell surface that transport LDL into the liver for metabolism.

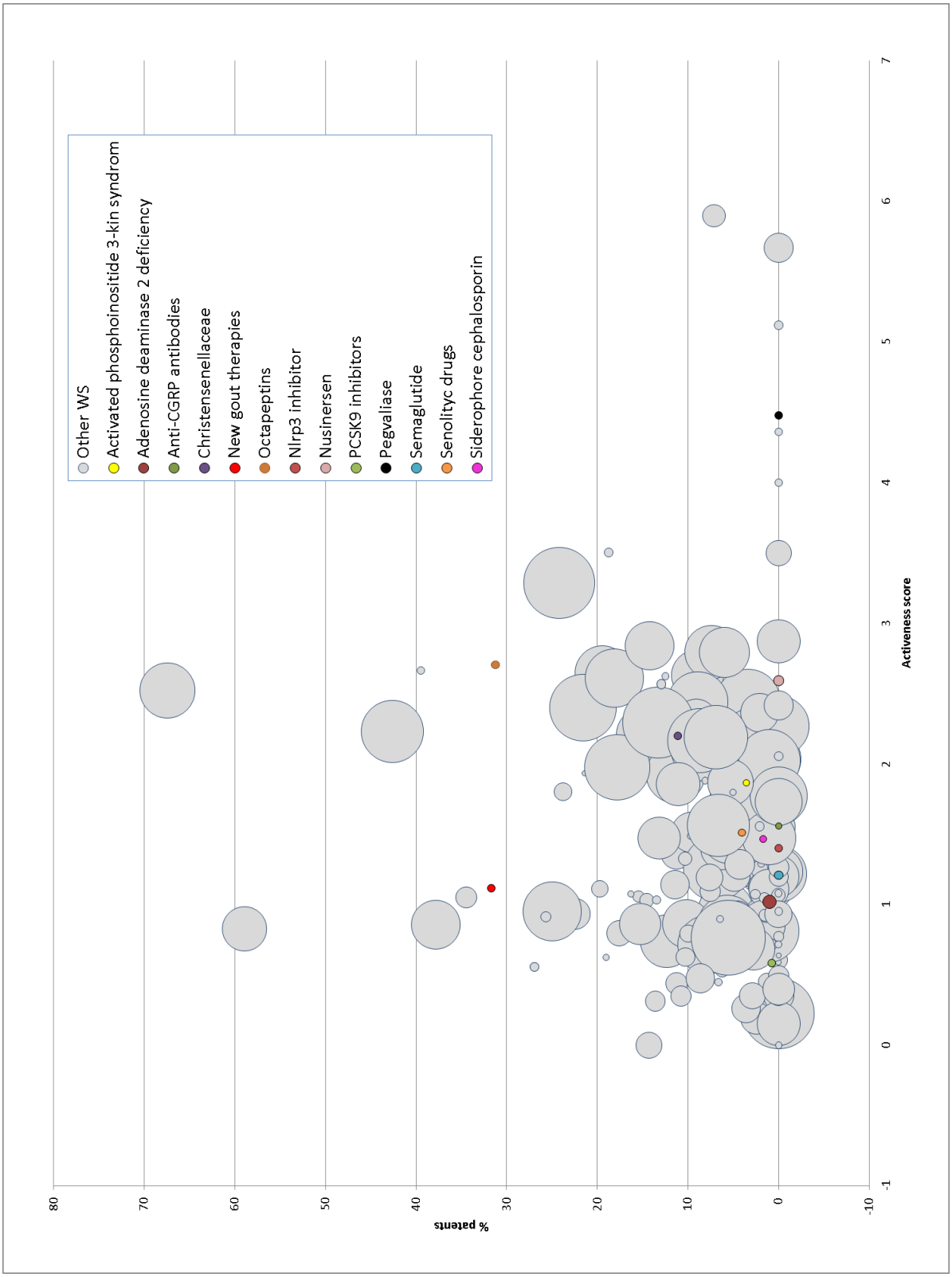
▶ Pegvaliase is a novel treatment for the treatment of phenylketonuria, a genetic disorder that leads to intellectual disability, mental disorders and seizures. Pegvaliase is an enzyme substitution therapy targeting the underlying cause of phenylketonuria (the deficiency of the enzyme breaking down the amino acid phenylalanine).

▶ Semaglutide was recently approved for the treatment of type 2 diabetes mellitus. An unexpected and significant weight loss was observed for patient under semaglutide, which makes it a promising drug for the treatment of obesity.

▶ Senolityc drugs are being studied for their potential to selectively induce cellular death of senescent cells, which-rather than dying-persist and become toxic to viable cells around them. Cellular senescence is connected to various age-related diseases. Any molecule that could delay, prevent, alleviate, or reverse age-related diseases would have a tremendous impact.

▶ Siderophore cephalosporin is an antibiotic that could counter multi-drug-resistant Gram-negative bacteria. It has been described as a "Trojan-horse antibiotic" for its mechanism of entering bacterial cells by binding to iron, which is transported into the bacterial cells. It provides proof-of-principle for a novel method of therapeutic treatment, and will be of wider interest to researchers and physicians interested in future antibiotics.

Figure 15: Weak Signals Health – New medicines/diseases.



Cancer

Cancer is the leading cause of mortality in developed countries. It presents significant scientific challenges, with anti-cancer drugs having one of the lowest success rates in clinical trials. This calls for a very intense research activity on cancer and its mechanisms, and on novel therapeutic strategies.

▶ Androgen receptor inhibition complements androgen deprivation therapy (ADT, the principal treatment in prostate cancers) when tumours become resistant to it. Androgen receptor is one of the most promising targets for cancer drug discovery because of its importance in male reproductive systems and homeostasis of bone and muscle.

▶ Anti-CD38 antibodies are new emerging immunotherapy treatments for myeloma. CD38 is a glycoprotein expressed at the surface of plasma cells and other lymphoid and myeloid cells and is the target of this treatment.

▶ Anti-PDGFR monoclonal antibodies bind to a receptor for a protein called platelet-derived growth factor (PDGF), which is found on some types of cancer cells. Blocking this protein receptor may help keep cancer cells from growing and prevent the growth of new blood vessels used by tumors to grow.

▶ CAR T cells immunotherapy modifies T cells to recognize cancer cells in order to effectively target and destroy them. CAR-T cells therapies are a major breakthrough in fighting cancer.

▶ Cyclin-dependent kinase (CDK) 4/6 inhibitors are a novel therapeutic strategy for advanced cancer patients previously classified as unfit for current treatment options. CDKs are enzymes that are important for cell division. CDK4/6 inhibitors interrupt signals that stimulate the proliferation of malignant cancerous cells.

▶ Ferroptosis is a novel therapeutic strategy to fight cancer and other diseases, based on the toxicity of iron. Some cancer cells, prone to metastasis and often resistant to treatment, have shown a high death rate by ferroptosis. Current studies have boosted the perspective for its usage in cancer therapeutics.

▶ Gasdermin proteins have been identified as an effector for pyroptosis, a programmed cell death that involves the formation of pores in the plasma membrane. The role of gasdermin-type proteins in pore formation during pyroptosis provides a new avenue for developing new drugs for treating cancer, auto-inflammatory conditions, sepsis and septic shock.

▶ Programmed death-ligand 1 (PD-L1) inhibitors are emerging as a front-line treatment for several types of cancer. PD-L1 is a surface protein that prevents the immune system from attacking tumor cells. This type of drugs pertains to the group of checkpoint inhibitors therapy, a form of cancer immunotherapy that targets immune checkpoints (key regulators of the immune system).

▶ Radiomics machine learning applies machine learning to the results of radiological imaging procedures. Machine learning algorithms are combined with the results of other analyses to allow for a more rapid and accurate interpretation of image streams.

▶ Radiotheranostics refers to the integration of therapeutics with diagnostics by imaging.. Radionuclides contain both an imaging component that allows the imaging and a therapeutic component for targeted treatment. New radiotheranostic molecules have been studied recently and are promising for targeted treatment of various cancers.

▶ Rovalpituzumab tesirin is a novel antibody-drug conjugate directed against delta-like protein 3 (DLL3), a recently discovered target in tumour-initiating cells which is expressed in more than 80% of patients with small-cell lung cancer. Rovalpituzumab binds to the DLL3 and delivers a cytotoxic payload (tesirine) to the cancer cells expressing the receptor.

▶ Tyrosine Kinases (TK) inhibitors block the action of TK enzymes, which play a role in many cell functions, including cell signalling, growth, and division. These enzymes may be too active in some types of cancer cells, and blocking them may prevent cancer cells from growing.

▶ Taurine-upregulated gene 1 (TUG1) is a long non-coding RNA (lncRNA) that can be used to stop cancer cell proliferation by apoptosis. Recent evidence shows the oncogenic role that TUG1 plays in various cancers e.g. breast cancer, gastric cancer, and colorectal cancer.

▶ Tumour mutational burden (TMB) seeks to improve cancer treatment by fitting it to the type of tumour. Using DNA sequencing, TMB measures the number of acquired DNA mutations by tumours, which have been reported to respond differently to different types of therapies depending on the number of mutations.

▶ X-inactive specific transcript (Xist) is a long non-coding RNA that is aberrantly expressed in various cancers. It has been proposed as a novel predictor of prognosis in human cancers.

Figure 16: Weak Signals Health – Cancer.

Miscellaneous

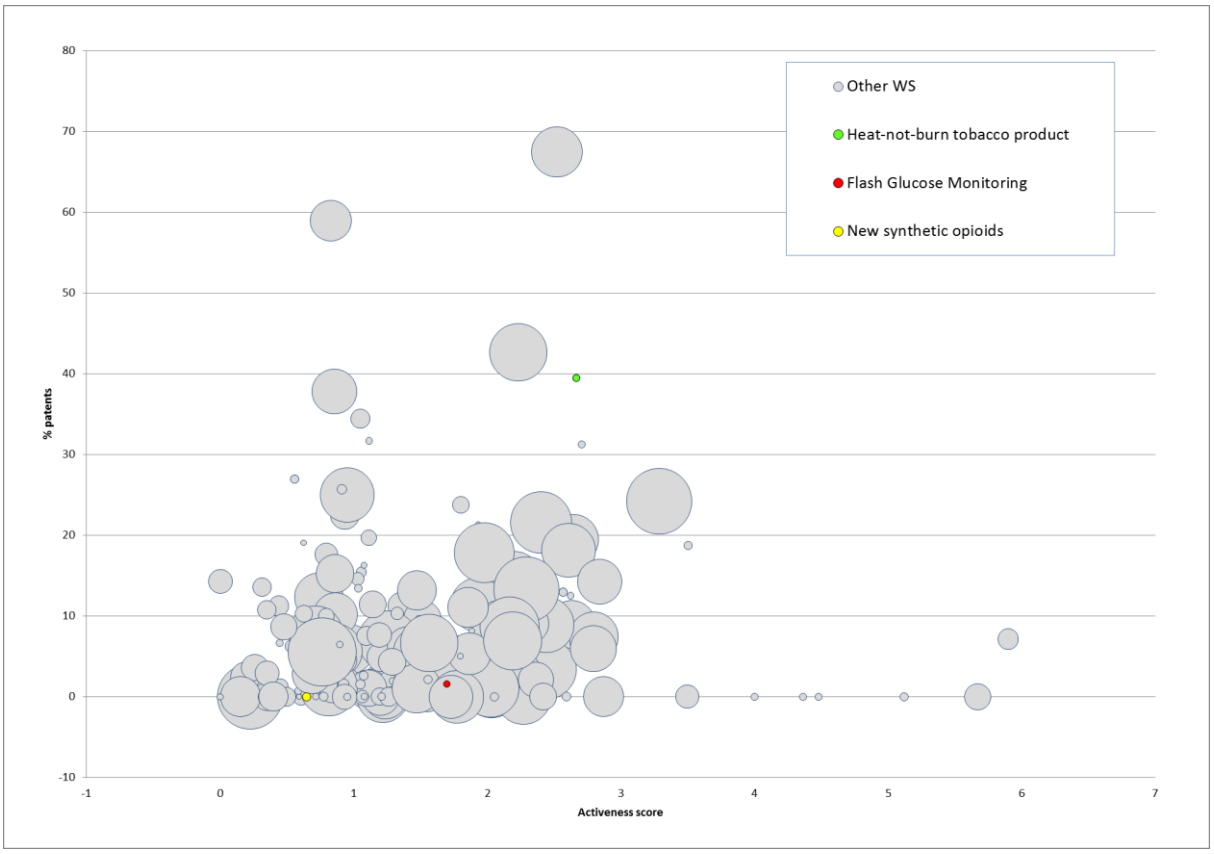
▶ Heat-not-burn Tobacco Product is a new substitute for tobacco products mimicking cigarettes. Tobacco is heated to a temperature below combustion to produce an aerosol containing nicotine and tobacco flavour. The absence of combustion by-products reduces the risk of smoking-related diseases.

▶ Flash Glucose Monitoring is a monitoring device that uses a sensor inserted under the skin to measure interstitial glucose level, which is the glucose found in the fluid between the cells. The sensor tests glucose every few minutes and enhance the management of diabetes.

▶ New synthetic opioids

The last decade has seen a continuous increase in the use of new unregulated psychoactive substances. In particular, novel synthetic opioids (diverted prescription opioid analgesics, failed opioid drug candidates, and various legal and illegal fentanyl analogues) have reappeared on the recreational drug market in the last few years and their use has increased rapidly posing a serious threat to public health.

Figure 17: Weak Signals Health – Misc.



4.4 Viruses

A striking number of new viruses have emerged or re-emerged over the past years. The causes for this are numerous (climate change, population increase, deforestation, urbanization, irrigation, etc.) and it is not surprising that many weak signals related to viruses were observed.

Viruses in agriculture

Climate change is the main cause for the increased prevalence of diseases of animals, cultivated plants and wild plants. It therefore threatens biodiversity and puts food security at risk.

▶ Atypical porcine pestivirus has been recently discovered and characterized in piglets with congenital tremor (CT). Piglet pre-weaning mortality is a major problem in pig farms around the world and atypical porcine pestivirus is a suspect.

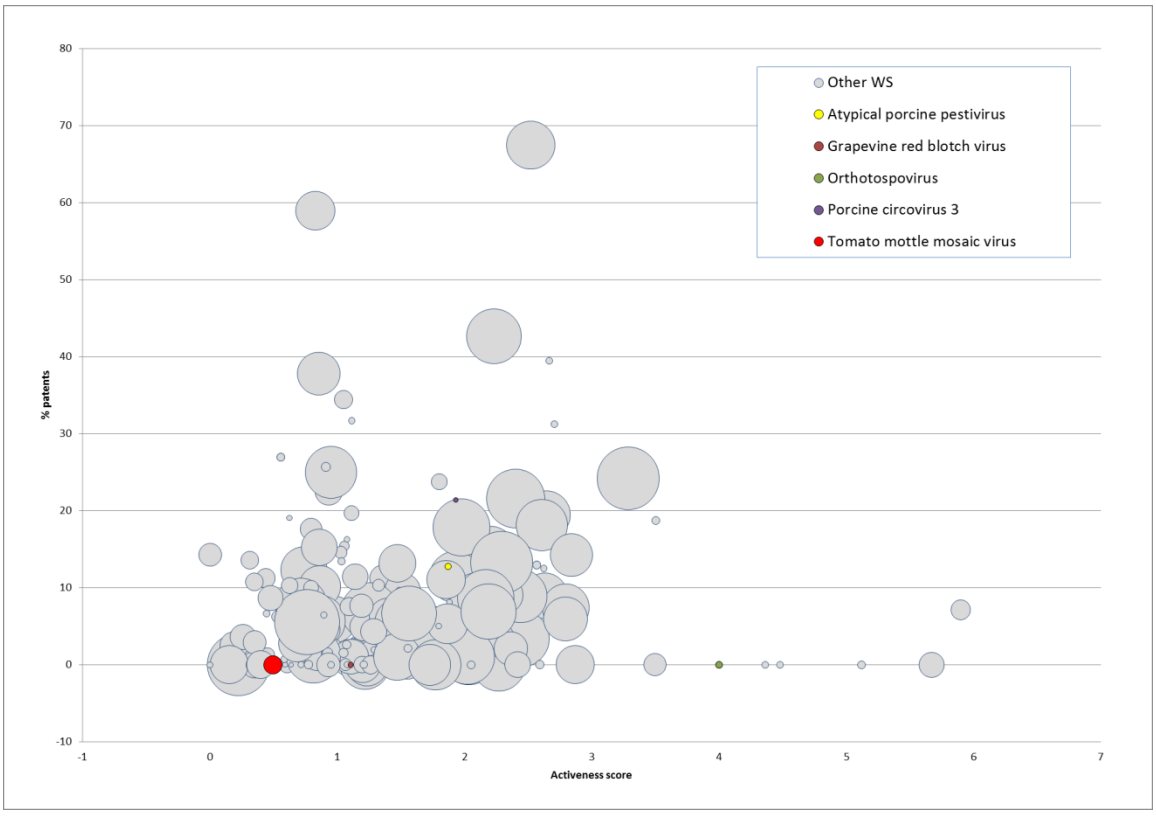
▶ Grapevine red blotch virus (GRBV) is a newly identified virus of grapevine, which is responsible for an emerging disease that affects vineyards by substantially reducing fruit quality and ripening.

▶ Orthotospovirus are a genus of negative RNA virus able to infect many plant species. Infection with this virus leads to spotting and wilting of the plant, reduced vegetative output, and eventually death. No antiviral cures have been developed so far, and infected plants have to be removed from the fields and destroyed to prevent disease spreading, which could disturb entire segments of the food industry (e.g. peanuts, watermelons, capsicums, tomatoes, zucchinis) and the ornamental plants sector.

▶ Porcine circovirus 3 (PCV3) is the third and latest virus belonging to the family Circoviridae, known for infecting pigs. The potential detrimental impact on the swine industry is not yet known, but PCV3 is of growing concern considering the impact PCV2 had. and the difficulty to fight it.

▶ Tomato mottle mosaic virus (ToMMV) has recently been detected in several countries around the world, including the US. For many years, the Tomato/Tobacco mosaic virus seriously affected tomato production worldwide. The use of disease-resistant tomato cultivars kept viruses at bay but there are concerns that the ToMMV could end this resistance and impact the tomato industry.

Figure 18: Weak Signals Viruses – Viruses in agriculture.



Vaccines and antiviral treatments

▶ Ebola vaccine candidates have been developed, but none of them is yet approved. A vaccine for Ebola is of utmost importance to prevent another outbreak like the one in Western Africa recently (2013–16), which was the most widespread in history, causing more than 10.000 deaths and socioeconomic disruption in the region.

▶ Glecaprevir/pibrentasvir is an antiviral approved for treating adults chronically infected with hepatitis C virus. This combination is the first pan-genotypic drug against hepatitis C.

▶ Herpes zoster vaccine has been recently approved and is the only way to be protected against shingles and postherpetic neuralgia, the most common complication from shingles.

▶ MK-8591 is a novel long-acting nucleoside reverse transcriptase translocation inhibitor and is a promising new drug for fighting human immunodeficiency virus (HIV). MK-8591 could be implanted directly in the body and released continuously, which would improve the success rate of treatment and prevention of HIV infection.

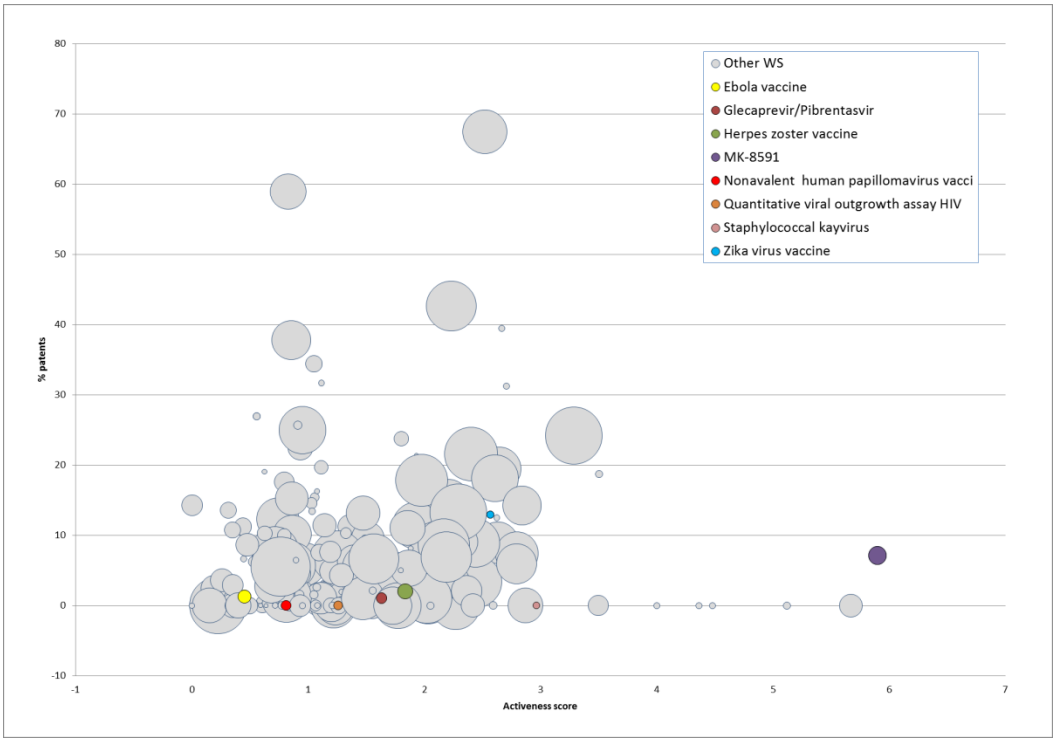
▶ Nonavalent human papillomavirus vaccine has recently been approved for treating various types of HPV. This vaccine will broaden significantly the impact of HPV vaccination against cervical cancer and pre-cancer. HPV is the most common sexually transmitted infection globally.

▶ Quantitative viral outgrowth assays for HIV is a robust measure of the size of the latent HIV reservoir in infected patients. Quantitative viral outgrowth assays are the gold standard for assessing the size of the viral reservoir, which is essential to quantify the effect of treatment.

▶ Staphylococcal kayviruses and their derived endolysins are excellent candidates for the treatment of infections caused by *Staphylococcus Aureus*, which is involved in many biofilm-associated diseases and is a major cause of nosocomial infections. New methods to eradicate *Staphylococcus Aureus* are urgently needed, due to the increasing prevalence of multidrug-resistant strains.

▶ Zika virus vaccines have been intensely researched over the last years. The devastating consequences of this virus led the World Health Organization to declare a Public Health Emergency of International Concern in 2016, and to call on the global R&D communities to prioritize the development of preventative and therapeutic solution. No vaccines have been yet approved for clinical use; however a number of them are currently undergoing clinical trials.

Figure 19: Weak Signals Viruses – Vaccines and antiviral treatments.



4.5 Materials

Many of the most pressing current technological challenges are related to inherent limitations of existing materials and to the way these materials are used. It is therefore not surprising that numerous research groups around the world are working on the discovery of new materials. Breakthroughs in materials science can greatly impact many technological fields.

2D Materials

Since the discovery of graphene, the field of 2D materials has witnessed intense research to find post-graphene alternative materials. 2D materials have unique optical and electronic properties with potential applications in many fields, including electronics and energy storage.

▶ Graphene like materials

Eight weak signals related to research on allotropes of various chemical elements with a structure similar to graphene or graphene were detected:

▶ Antimonene ▶ Arsenene ▶ Bismuthene

▶ Borophane ▶ Borophene ▶ Phagraphene

▶ Phosphorene ▶ Stanene

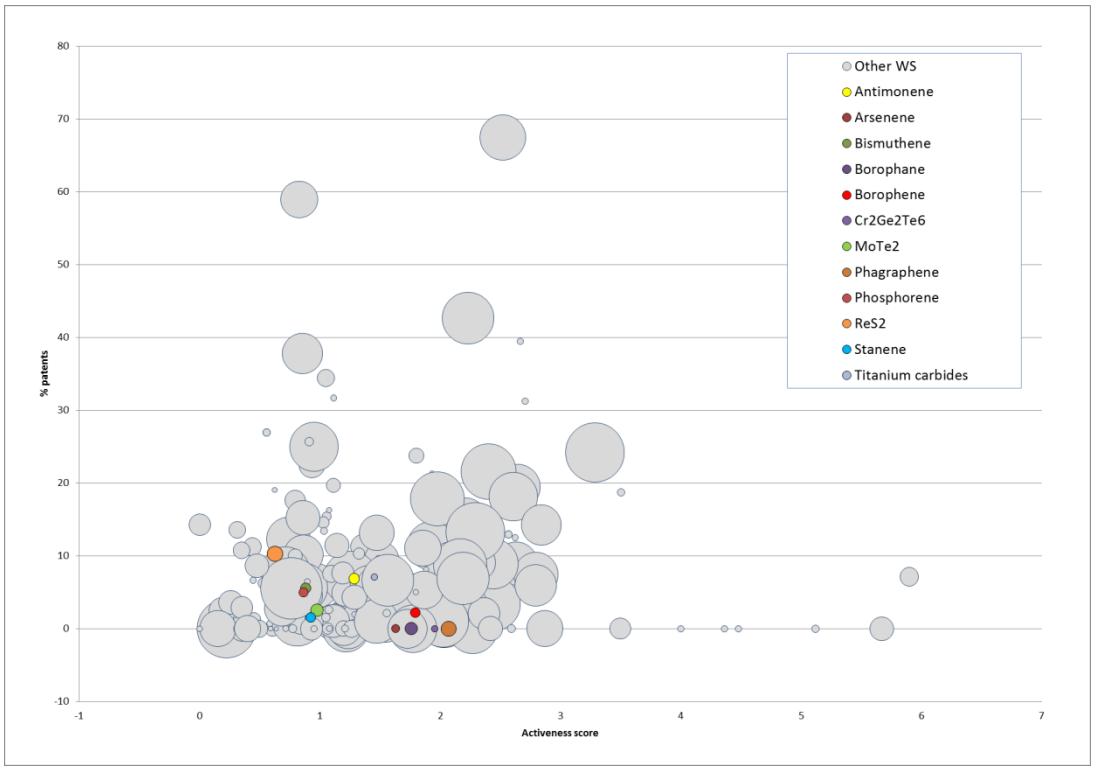
▶ Cr2ge2te6 is a known material that has been revisited recently due to its potential as a two-dimensional semiconducting ferromagnet and as a substrate to induce anomalous quantum Hall states in topological insulators.

▶ MoTe2 is a transition metal dichalcogenide composed of Molybdenum and Tellurium that can crystallise in two dimensional sheets, which can be thinned down to monolayers that are flexible and almost transparent and have new semiconductor and fluorescence properties.

▶ ReS2 is a transition metal dichalcogenide composed of Rhenium and Sulphur with a layered structure bonded together by Van der Waals forces. ReS2 has shown interesting layer-independent electrical, optical, and vibrational properties. It is of interest for electronic and optoelectronic devices and for energy storage, photocatalytic and electro-catalytic applications.

▶ Titanium Carbides (Ti2C, Ti3C2) are MXenes (a class of two-dimensional nanostructured inorganic compounds) composed of Titanium and Carbon atoms with unique properties (high surface area to volume ratio, ease of surface functionalization) and potential applications in the design of batteries, supercapacitors, new composites, antennas, optoelectronics, chemical sensing, catalysis etc.

Figure 20: Weak Signals Materials – 2D materials.



Wearables

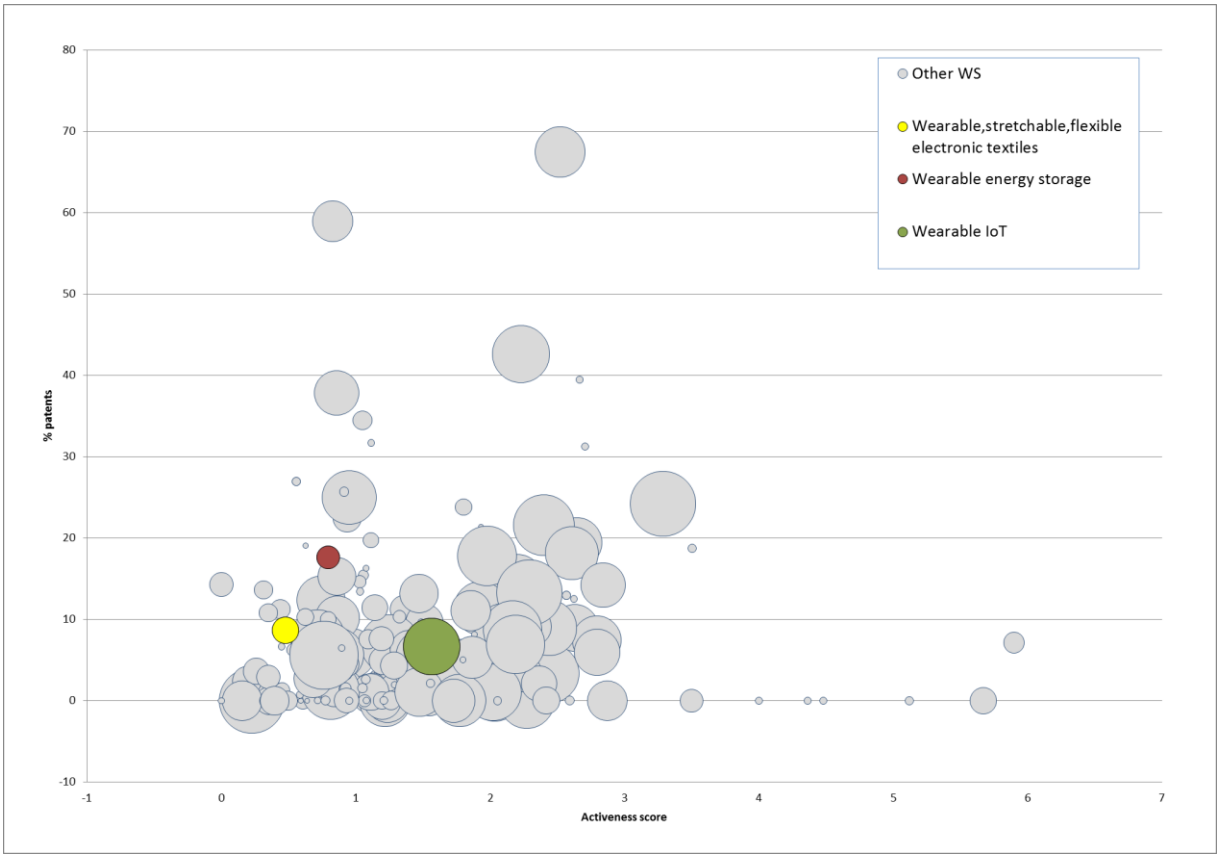
Wearables are either smart electronic devices that can be incorporated in textiles or clothing or the body (as an implant), or new materials that are both textiles and electronics devices.

▶ Wearable flexible electronic textiles are attracting attention due to their potential applications in personal heating systems or medical applications like e.g. perioperative warming, electronic skin, or controlled transdermal drug delivery. A race is on to develop a new generation of electronic textiles that are aesthetically pleasing, lightweight and washable.

▶ Wearable energy storage devices are batteries integrated to clothing. They represent a paradigm shift for consumer electronics, entertainment, textile and communication industries. These new materials will radically change some aspects of our daily lives.

▶ Wearable IoT is the merging between wearable devices and the Internet of Things (IoT). Through pervasive connectivity, large collections of wearable devices will be connected to each other. By sensing, computing and communicating autonomously, these devices will change the game in e.g. healthcare, entertainment, banking, industry.

Figure 21: Weak Signals Materials – Wearables.



Nanomaterials

Nanomaterials are an increasingly important product of nanotechnologies. They are slowly becoming commercialized and are beginning to emerge as commodities. Materials with structure at the nanoscale often have unique optical, electronic, or mechanical properties and applications are being developed in healthcare, electronics, cosmetics, energy and other areas.

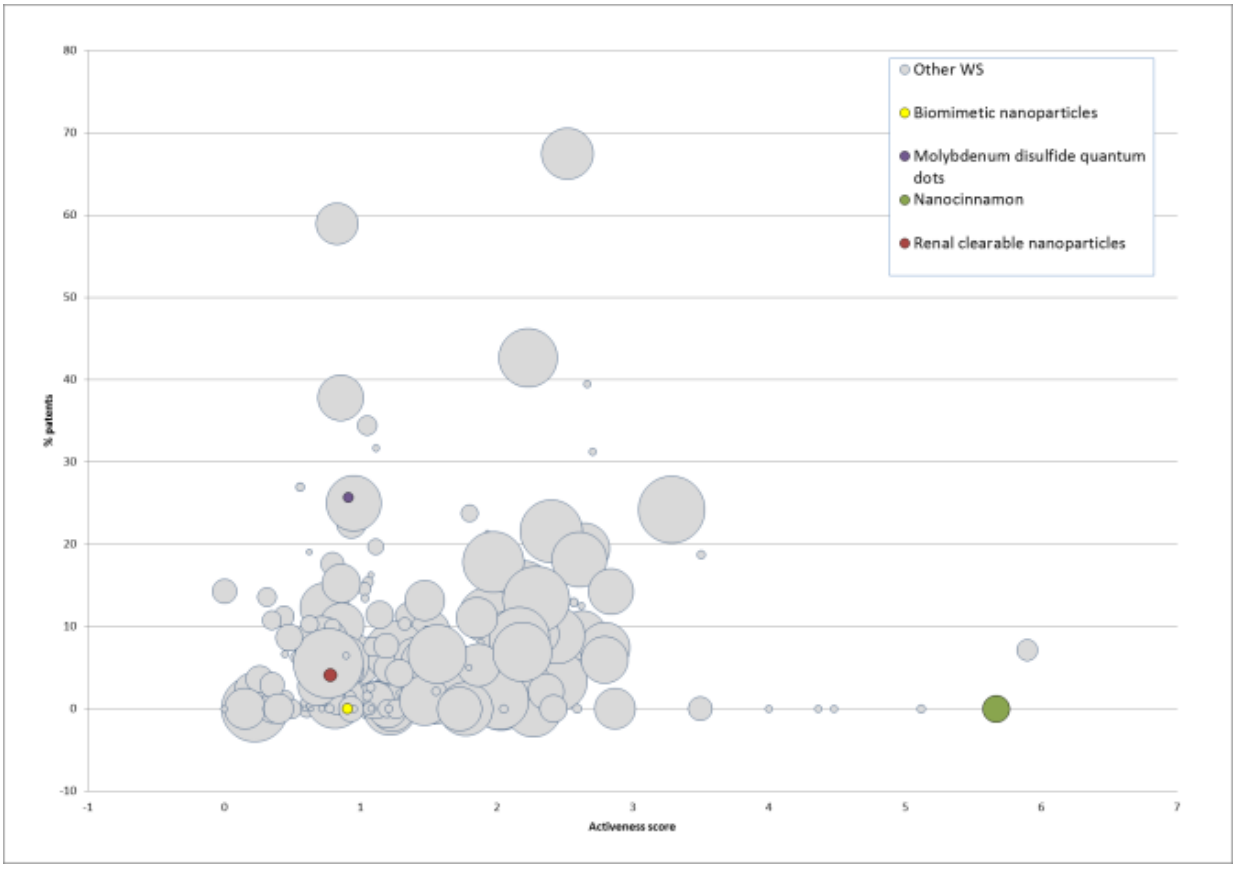
▶ Biomimetic nanoparticles are the product of biomimetic strategies in the synthesis of new nanoparticles that can interact efficiently with biological systems. As a drug delivery vehicle, biomimetic nanoparticles exhibit biological compatibility, low toxicity for the human body, and ease for surface modification.

▶ Molybdenum disulfide quantum dots are a novel type of tiny semiconductor particles of a few nanometres with unique properties (e.g. adsorption, fluorescence) which are promising for applications in storage of gas, delivery of molecules, catalysis, and others.

▶ Nanocinnamon are nanoparticles of cinnamon that exhibit antibacterial and antioxidant properties, together with a high biocompatibility. This makes it a promising new material for food or biomedicinal applications, as well as a drug delivery agent.

▶ Renal clearable nanoparticles are a new class of nanoparticles that can be easily excreted by kidneys. Over the last years, nanoparticles with tuneable and diverse material properties have shown unprecedented potential for new biomedical technologies. Yet, using these nanoparticles in clinical protocols has been hampered by their toxicity for healthy tissues and organs. To overcome this, renal clearable nanoparticles are being developed and studied.

Figure 22: Weak Signals Materials – Nanomaterials.



Catalysis

Catalysis plays a vital role in contemporary science and innovation and underpins around 30% of gross domestic product in European economies. 80% of all manufactured products are the results of processes that involve catalysis by one material or another. Catalysis enables the making of materials that are essential and innovation in this field is key to meeting many of the challenges faced by society today like achieving clean water, clean energy, clean environment, or a sustainable supply of food and feed.

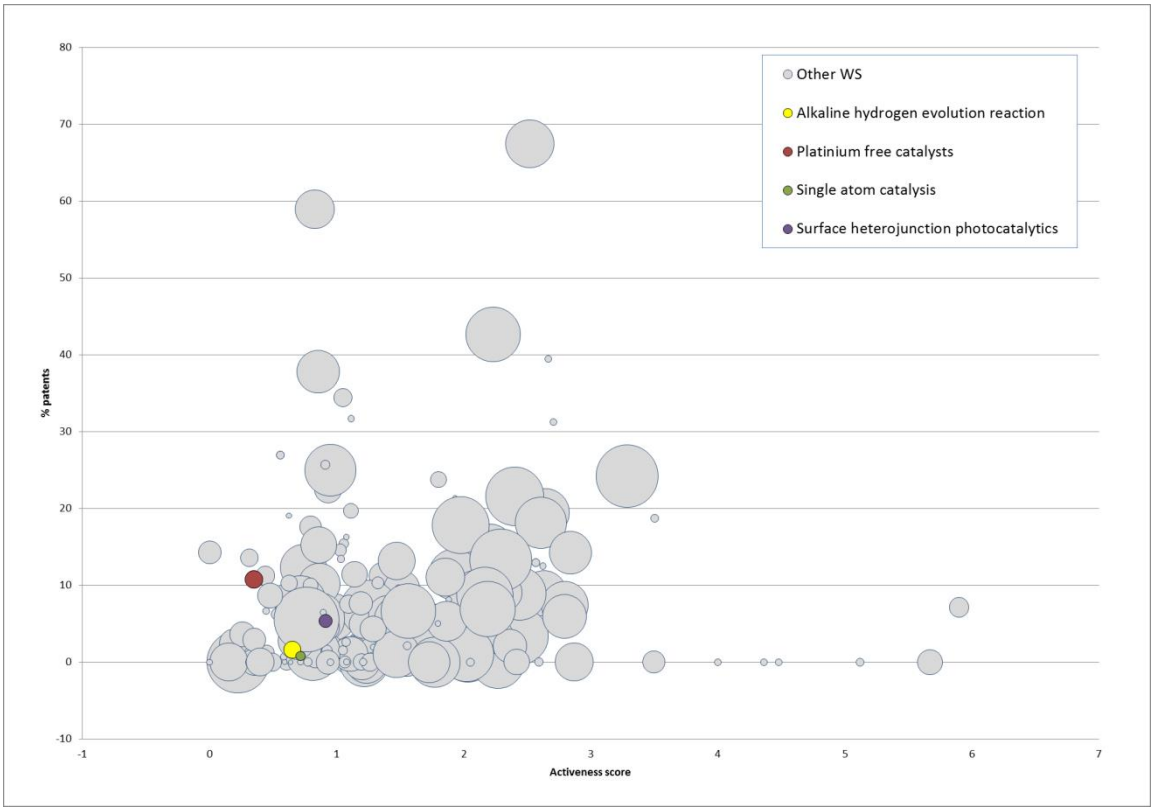
▶ Alkaline hydrogen evolution reaction is not a new technology, but research on the electrolysis of water in alkaline conditions has received accrued interest over the last few years, in relation to the use of Hydrogen fuel cells for producing electricity. Contrary to other water electrolysis technologies, alkaline electrolysers of water can be made by using abundant and inexpensive materials, which is essential for the adoption of fuel cell technology by the market, and therefore intensively investigated.

▶ Platinum free catalysts are under scientific investigations for their use in proton exchange membrane fuel cells (PEMFC), a promising technology for the production of electricity that has high energy conversion efficiency, high power density and zero emission of pollutants. Catalysts used for the cathodes of membrane fuel cells contain a lot of Platinum and the high cost of this material impedes large-scale application of PEMFC. Large efforts are therefore devoted to developing low-cost platinum-free catalysts.

▶ Single atom catalysis is a rapidly emerging field of research in catalysis that aims to reduce significantly the use of precious metal in traditional heterogeneous catalysis by replacing metal nanoparticles with "single-atom" active sites. This would dramatically reduce the costs of catalytic processes using noble metals and would offer great potential for achieving high activity and selectivity.

▶ Surface heterojunction photocatalytics Photocatalysis could contribute significantly to the quest of environmentally-friendly energy production. Photocatalytic systems also have applications in sterilisation, decontamination, anti-fouling paints, degradation of pollutants, etc. Yet, photocatalytic systems are far from having *practical* applications, mainly due to low efficiency and lifetime issues. Research is ongoing to combine various materials to form photocatalytic heterojunctions that can provide effective harvesting of solar energy to enhance the photocatalytic activity and stability.

Figure 23: Weak Signals Materials – Catalysis.



Polymers

Polymers are large molecules composed of many repeated small molecules and are an important class of materials that includes plastics. Polymers are essential to our economies but are currently at the centre of major environmental challenges.

▶ Gelatine methacrylate hydrogel is a promising material in tissue engineering applications because of its bio-functionality and mechanical tenability, cost-effectiveness, ease of synthesis and bio-compatibility.

▶ Microplastics ingestion by marine organisms has recently become an important subject of research. Microplastics have been detected in a wide variety of habitats in the ocean from shallow coasts to the deep sea. Increasing numbers of studies report the ingestion of microplastics by many marine animals, including those targeted by fisheries. The transfer of microplastics and associated contaminants to humans via their diet is under investigation and may present a significant health challenge.

▶ Microplastics sampling has become a hot area of research because of the various methods used in the numerous studies on the environmental effects of microplastics. A wide variety of operating techniques are employed for sampling, processing, identifying and quantifying microplastics from different environmental matrices and the inconsistencies of operation protocols is a major problem which impedes spatial and temporal comparisons of measurements.

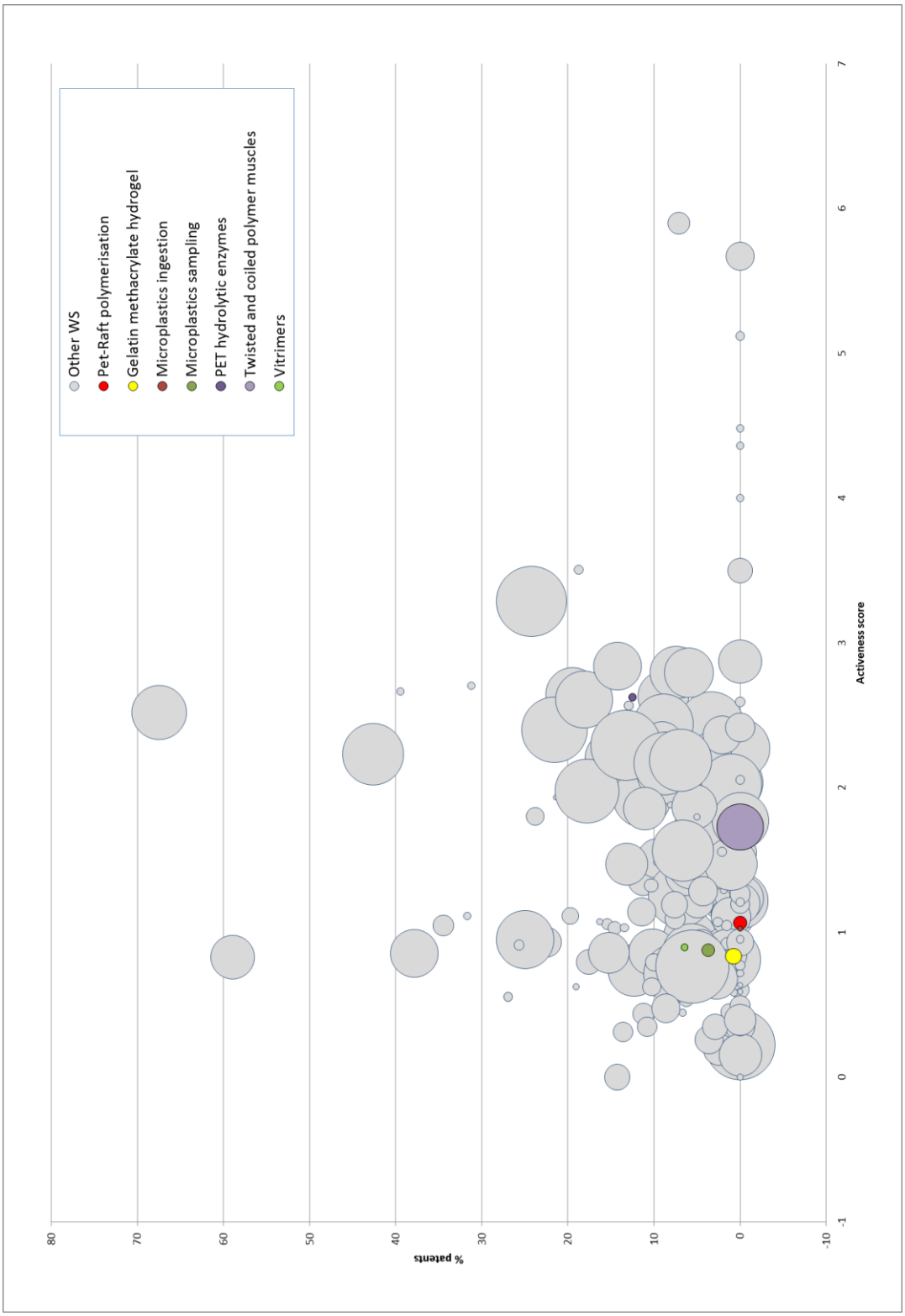
▶ PET hydrolytic enzymes have been identified for the degradation of poly-ethylene terephthalate (PET), used extensively in plastics worldwide, and for which accumulation in the environment has become a global concern. PET degradation by a microbial consortium and its bacterial resident, *Ideonella sakaiensis*, has been reported, making bioremediation an alternative for recycling plastic waste.

▶ Pet-Raft polymerisation is one of the most recent photocatalysed polymerisation processes using organic molecules as catalysts. These processes have attracted broad interest because of the ease of operation in ambient environments and low toxicity compared with metallic catalysts. In recent years, visible light-driven polymerization has been rapidly developed, as many efficient photocatalysts or photosensitizers have been discovered, including metallic and non-metallic materials. Photo-induced electron transfer-reversible addition-fragmentation chain transfer (PET-RAFT) polymerization has an important role to play in the synthesis of a broad range of complex polymers, in bio-systems and in microelectronics.

▶ Twisted and coiled polymer muscles are high-performance linear actuators, or movement enablers, that respond to change in temperature, acting essentially as artificial muscles, able to handle and manipulate non-uniform objects. Actuators are the most important elements that affect the performance of robotic systems and twisted and coiled polymer are being investigated to be used in the musculoskeletal system of robots.

▶ Vitrimers are a new class of polymers consisting of molecular, covalent networks, which change topology by thermally activated bond-exchange reactions. They flow like viscoelastic liquids at high temperature and behave like classical plastics at low temperature. This particular behaviour opens the possibility for e.g. self-healing or shape memory materials and a higher processibility in industrial processes.

Figure 24: Weak Signals Materials – Polymers.



Metasurfaces

The manipulation of sound waves and electromagnetic waves using artificial materials is a central topic in materials physics. Recently, a family of two-dimensional artificial materials of subwavelength thickness called "metasurfaces" have attracted much attention because of their exceptional ability to manipulate the amplitude, phase, polarization, propagation direction, etc. of both light waves and sound waves.

▶ Acoustic metasurfaces cause non-trivial local phase shifts and have extraordinary sound absorption. Acoustic metasurfaces are used to engineer the wave front and create self-bending beams, twisted wave fronts, non-diffraction beams, diffuse reflection, asymmetric transmission, beam focusing, or near-perfect absorption.

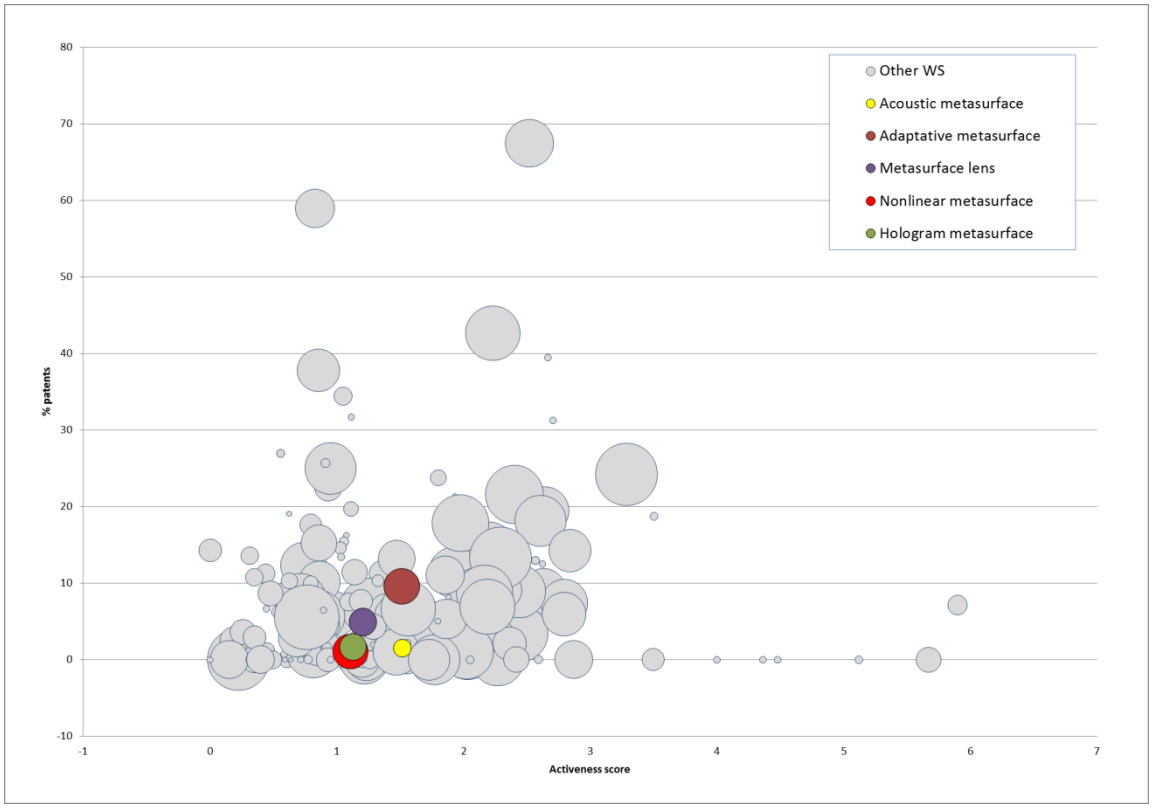
▶ Adaptative metasurfaces is a class of metasurfaces whose surface properties can be controlled in real-time to dynamically control electromagnetic waves. They have the potential to disrupt many technology fields including beam scanning and modulation, dynamic holographic displays, wireless communication, sensors, stealth devices, medicine, etc.

▶ Hologram metasurfaces are being considered as novel holographic devices called meta-holograms, showing an unprecedented ability to control electromagnetic waves, thus overcoming previous shortcomings of conventional optics (narrow time-space bandwidth product, low massive data processing speed, low image quality).

▶ Metasurface lenses, also known as metalenses, are optical metasurfaces capable of fully manipulating most of the properties of light, mimicking the action of a lens. They have the potential to substantially reduce the size and complexity of imaging systems and to achieve new imaging modalities. Metalenses are truly flat and compact, exhibit superior performance and will be a game changer in many applications that are difficult or impossible for traditional lenses.

▶ Nonlinear metasurfaces are a broad subclass of metasurfaces (also called gradient metasurfaces) and exhibit spatially varying optical responses resulting in spatially varying amplitudes, phases and polarizations of scattered fields. Nonlinear metasurfaces have potential applications in optical retarders, polarimeters, flat lenses, spiral phase plates, broadband absorbers, colour printing, holograms, surface wave couplers, etc.

Figure 25: Weak Signals Materials – Metasurfaces.



Perovskites

Perovskite microcrystals are a promising material with many applications, but are mostly considered for the fabrication of high-yielding photovoltaic (PV) solar cells. They are cheap to produce, flexible and they can be coated or produced to have various optical and electronic properties. Due to their high absorption efficiency, a few layers of a few hundred nanometers can also boost the performance of standard silicon PV technology. Perovskite solar cells are not yet commercially available. However, huge efforts are being made to bring them to mass production.

▶ Cesium lead halide perovskites attracts much attention due to their excellent photo-physical properties and promising applications in LEDs, solar cells, photodetectors, lasers, photocatalysis, etc.

▶ FAPbI3 perovskite or formamidinium lead iodide perovskite is one of the most promising hybrid organic-inorganic perovskites.

▶ Lead free perovskite are being developed as an alternative to traditional lead-halide perovskites (containing lead). The latter have been by far the most studied to date but their toxicity and difficult recycling pushes the search for lead-free perovskites.

▶ FASnI3 and MASnI3 perovskites, or Formamidinium tin iodide and Methylammonium tin iodide perovskites, are both concrete examples of lead-free perovskites.

▶ Triple cation perovskites are being investigated for their increased stability, efficiency, and ease of manufacturing compared to traditional perovskite-based solar cells.

▶ Perovskite LEDs are one of the promising technologies for the next generation of LED displays. Perovskites LEDs would benefit from the unique properties of perovskites, such as high charge-carrier mobility, tuneable emission wavelength, narrow emission linewidth, and intrinsically high photoluminescence yield.

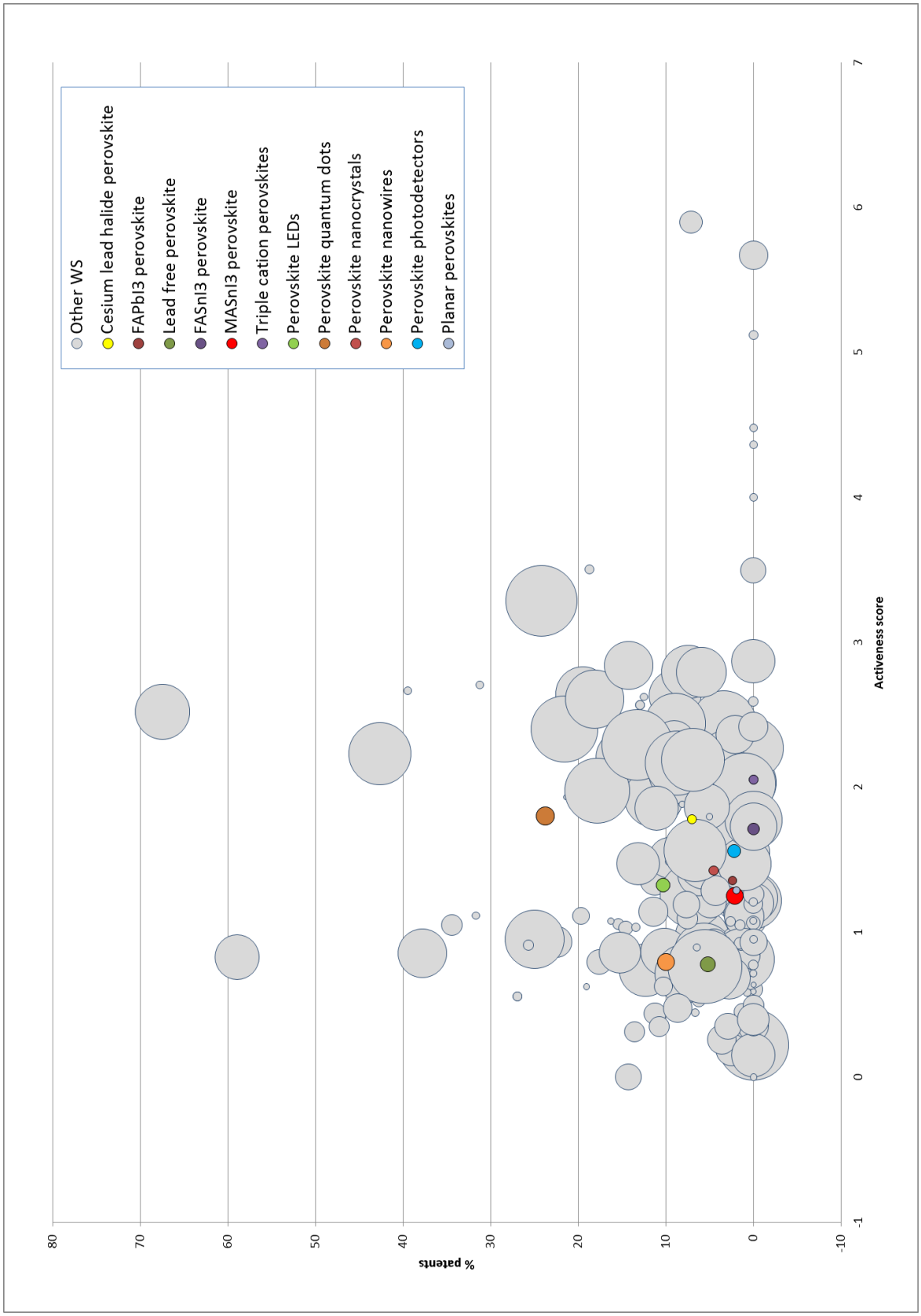
▶ Perovskite quantum dots and Perovskite nanocrystals have received considerable attention lately due to their high photoluminescence quantum yields, variable morphologies, and tuneable optical bandgaps obtained by changing their composition, size or dimensions. Their promising applications in solar cells, LEDs and photodetectors are facing issues like toxicity, chemical instability.

▶ Perovskite nanowires are new nano-structures for perovskite materials which can find applications in laser, biosensing, electronic devices, batteries, etc.

▶ Perovskite photodetectors could be one of the applications of perovskites. Their high light absorption coefficient, long charge carrier diffusion length and intense photoluminescence make them promising materials for improving the responsivity, detectivity, noise to power ratio, and response speed of photodetectors significantly.

▶ Planar perovskites are a form of two-dimensional halide perovskites that recently emerged as a more stable and more versatile family of materials than three-dimensional perovskites. Intense research is being performed to bring solar cells made with 2D perovskites to the same level of light conversion efficiencies with 3D perovskite solar cells.

Figure 26: Weak Signals Materials – Perovskites.



Miscellaneous

▶ 0d 2d heterostructures are materials made of heterostructures that combine two-dimensional layers with zero-, one-, or three-dimensional materials. The development of these materials paves the way towards novel device architectures at the crossroads of two-dimensional material physics and spin electronics. They are very promising for improving performance in electronics and optoelectronics e.g. in photovoltaic, light-emitting, and logic devices, as well as in photodetectors and semiconductor technologies.

▶ Bimetallic organic frameworks are a novel class of metallic organic frameworks (MOFs) that contain 2 different metal ions as nodes of the framework. MOFs are currently being massively investigated for their applications in many fields including storage of hydrogen or methane, catalysis, biological imaging, drug delivery, semiconductors, carbon capture and desalination of water.

▶ CaKFe4As4 superconductor is studied for its inherent defect structure that makes it superconducting, and may open new ways to manufacture high temperature superconductors.

▶ CrMnFeCoNi high entropy alloys are a class of high entropy alloys, which are composed by five or more principal elements. These alloys are promising new materials with unique properties compared to normal alloys: high strength/hardness, outstanding wear resistance, exceptional high-temperature strength, good structural stability, good resistance to corrosion and oxidation.

▶ Cs2HfCl6 is one of the most recent scintillator crystals discovered. It has high light output, is non-hygroscopic, has no self-activity, and has an energy resolution significantly better than current materials used in radioactivity detectors. This type of material is essential for human safety in case of a nuclear incident, where isotopes produced by nuclear alpha decay need to be detected.

▶ Dihydrolevoglucosenone is a bio-based and fully biodegradable molecule, derived in two simple steps from cellulose, which demonstrates significant promise as an aprotic dipolar solvent. It is a safer and greener alternative to toxic organic solvents.

▶ Eutectic high entropy alloys are a class of high-entropy alloys that exhibit eutectic properties i.e. all the components melt at the same temperature. Eutectic high-entropy alloys simultaneously possess high strength and high ductility, which have potential industrial applications.

▶ Natural deep eutectic solvents are composed of primary metabolites (amino acids, organic acids, sugars, or choline derivatives) and are being developed to replace organic solvents which are often toxic and/or harmful for the environment. Natural deep eutectic solvents are greener and applications in e.g. catalysis, electrochemistry, bioremediation, extraction, carbon capture, and biomedicine are emerging.

▶ PbTaSe2 superconductor is a promising candidate as a topological superconductor. The search for this type of superconducting materials is one of the most active research areas in condensed matter physics nowadays.

▶ Tin selenide crystals are promising eco-friendly and highly performant thermoelectric materials and are currently a hot topic in thermoelectric research. These crystals have exceptionally high thermoelectric efficiency, are lead-free, abundant on Earth, low-cost and environment-friendly materials.

Figure 27: Weak Signals Materials – Miscellaneous.

4.6 Environment

Some weak signals are related to the preservation of Earth's environment as the increasing impact of anthropogenic pressure on Earth's various ecosystems is triggering new research in various fields.

Climate change

Climate change is one of the biggest challenges we are facing. It is transnational and requires solutions that need to be coordinated at the international level. Technology alone will not solve the problem: deep transformations in all aspects of society would be necessary to tackle the climate crises.

▶ Climate clubs is an economic model for international climate policy that creates a strong incentive for countries to collectively address climate change. The climate club concept has received a lot of attention, as it aims to address the free-rider problem in the context of climate change.

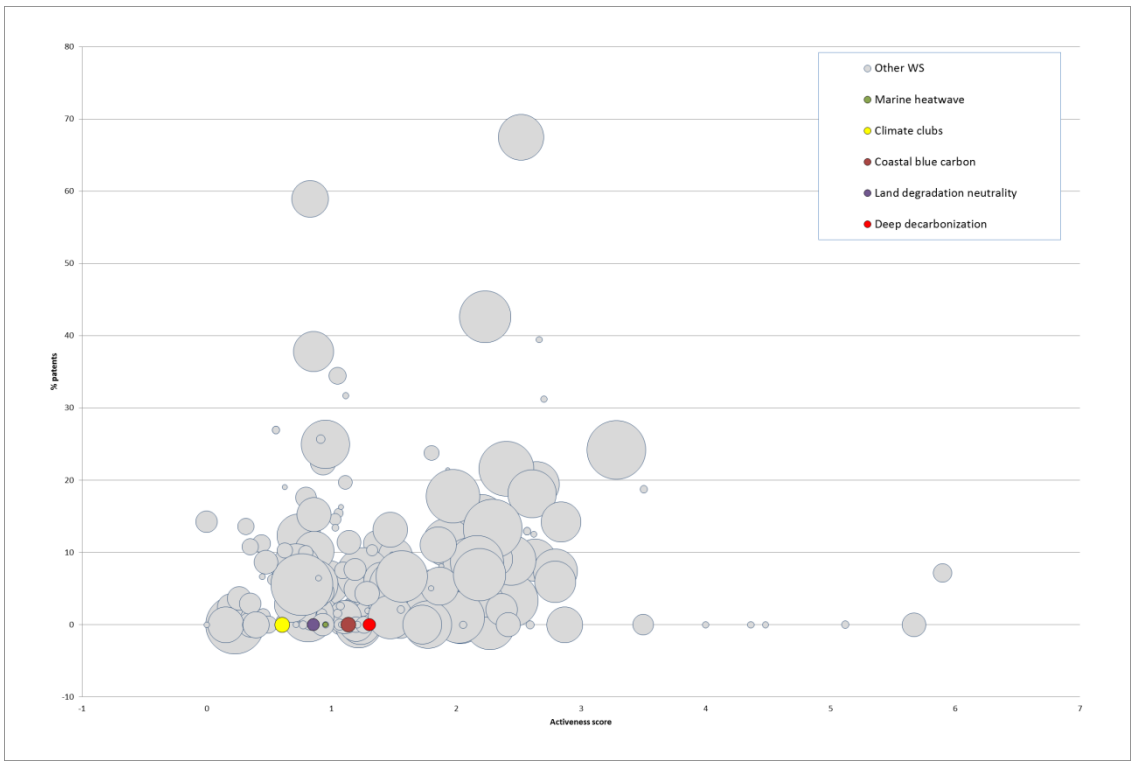
▶ Deep decarbonisation refers to the transformation of economies that must decouple economic growth from carbon emissions, in order to reduce greenhouse gas emissions to a level consistent with limiting global warming.

▶ Coastal blue carbon describes the carbon sequestered and stored in, or released from, salt marshes, mangroves, and seagrass ecosystems. In the context of carbon emission trading systems, this concept highlights the significance of carbon sequestration and storage in these highly productive coastal ecosystems.

▶ Marine heatwave are prolonged periods of anomalously high sea-surface temperatures. These events are becoming more frequent and are accompanied by large-scale shifts in marine species location and life cycles, changes in ecosystem structure and in some cases high levels of mortality, often with widespread and devastating ecological and socioeconomic consequences.

▶ Land degradation neutrality describes an equilibrium where the amount and quality of lands necessary to sustain ecosystems and food supply security remain stable or increase with time. It represents a paradigm shift in land management policies and practices as it is a unique approach that counterbalances the loss of productive land with the recovery of degraded areas. It places measures to conserve, manage in a sustainable way and restore land in the strategic context of land use planning.

Figure 28: Weak Signals Environment – Climate change.



Pollutants mitigation and degradation

Pollutants are everywhere. Significant efforts are being made by the research community to bring solutions to decrease their impact on our environment.

▶ Comammox (COMplete AMMonia OXidiser) is an organism that can convert ammonia into nitrate by a process called nitrification. Usually, nitrification is a two-step process that requires two separate groups of microorganisms. A bacterium that can transform ammonia directly into nitrate has recently been discovered (*Nitrospira inopinata*). This new ammonia-oxidiser is of keen interest, as it can play an essential role in the nitrogen cycle, wastewater treatment, and the release of greenhouse gases to the atmosphere.

▶ Electro-fermentation is a novel electrochemical process that controls microbial fermentation metabolism with electrodes. This could optimise existing fermentation technologies and increase the use of residues from the agrofood industry in biorefineries to produce biopolymers, biosolvents, electrofuels, or other active molecules.

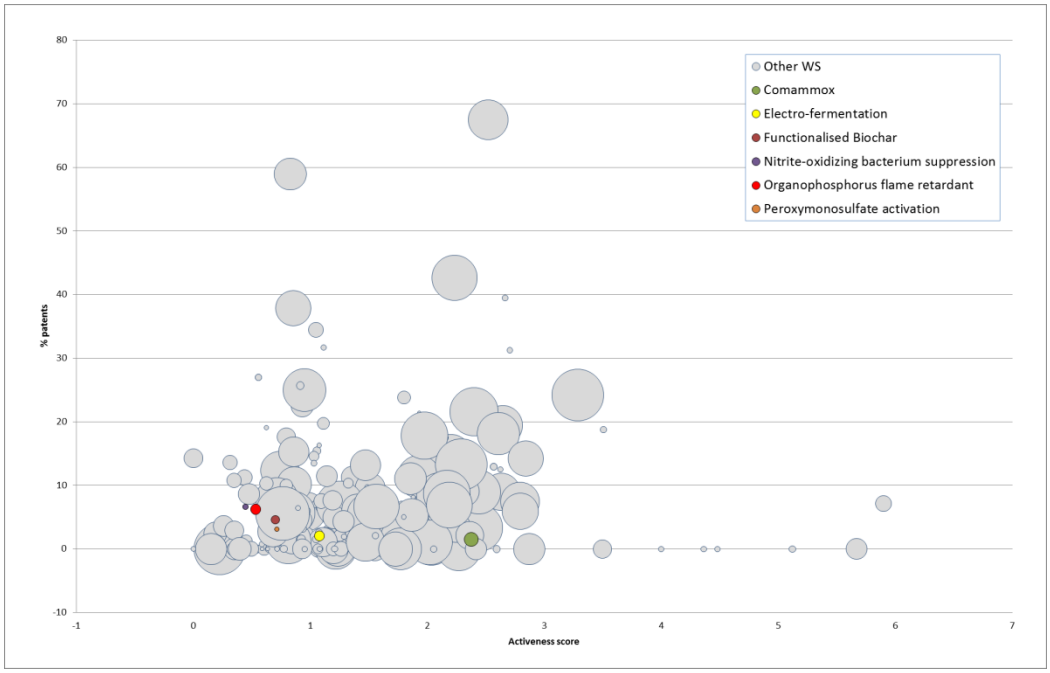
▶ Functionalised Biochar is a new material resulting from the modification of the structure and functional groups of Biochar, the product of thermochemical decomposition of biomass. Biochar's unique structure gives it interesting physicochemical properties. Its sorption capacity in particular is very high. Functionalised biochar has applications in carbon sequestration, reduction of greenhouse gas emissions, waste management, production of renewable energy, soil amendment, water purification and environmental remediation.

▶ Nitrite-oxidizing bacterium suppression relates to the process of water treatment in municipal wastewater plant. A key step towards more efficient sewage treatment is to maintain the population of ammonia-oxidizing bacteria, which can only be done by suppressing the population of nitrite-oxidizing bacteria. Reliable suppression techniques would improve sewage treatment and reduce water treatment costs.

▶ Organophosphorus flame retardants (OPFRs) are used as flame retardants, plasticizers, stabilizers, lubricants and antifoaming agents. Their production and use have recently increased due to the phasing out of brominated flame retardants. OPFRs are not chemically bonded to the material they cover, which facilitates their release to the environment (aquatic, terrestrial, and atmospheric). The risks posed by OPFRs to the environment and human health are not well-known and have attracted a lot of attention.

▶ Peroxymonosulfate activation is an inexpensive oxidizing agent that, once activated, produces highly reacting radicals that can degrade a wide range of organic pollutants like pharmaceuticals, odour-causing compounds, or pesticides. Various oxidation processes based on peroxymonosulfate are being investigated, opening new perspectives to degrade organic pollutants and contribute to the remediation of contaminated environments.

Figure 29: Weak Signals Environment – Pollutants mitigation and degradation.



Miscellaneous

▶ Black soldier fly larvae biodiesel is the biodiesel produced using the larvae of the black soldier fly. These larvae degrade various organic wastes to accumulate high fat content and can then be considered as a potential source for the production of biodiesel.

▶ Cargo bikes are one of the solutions explored to reduce traffic in cities by ensuring the last mile delivery by bikes equipped with loading platforms.

▶ Ecoacoustics is an interdisciplinary field that investigates natural and anthropogenic sounds and their relationship with the environment over a wide range of study scales, both spatial and temporal, including populations, communities, and landscapes. Ecoacoustics operates in all types of terrestrial and aquatic (freshwater and marine) ecosystems.

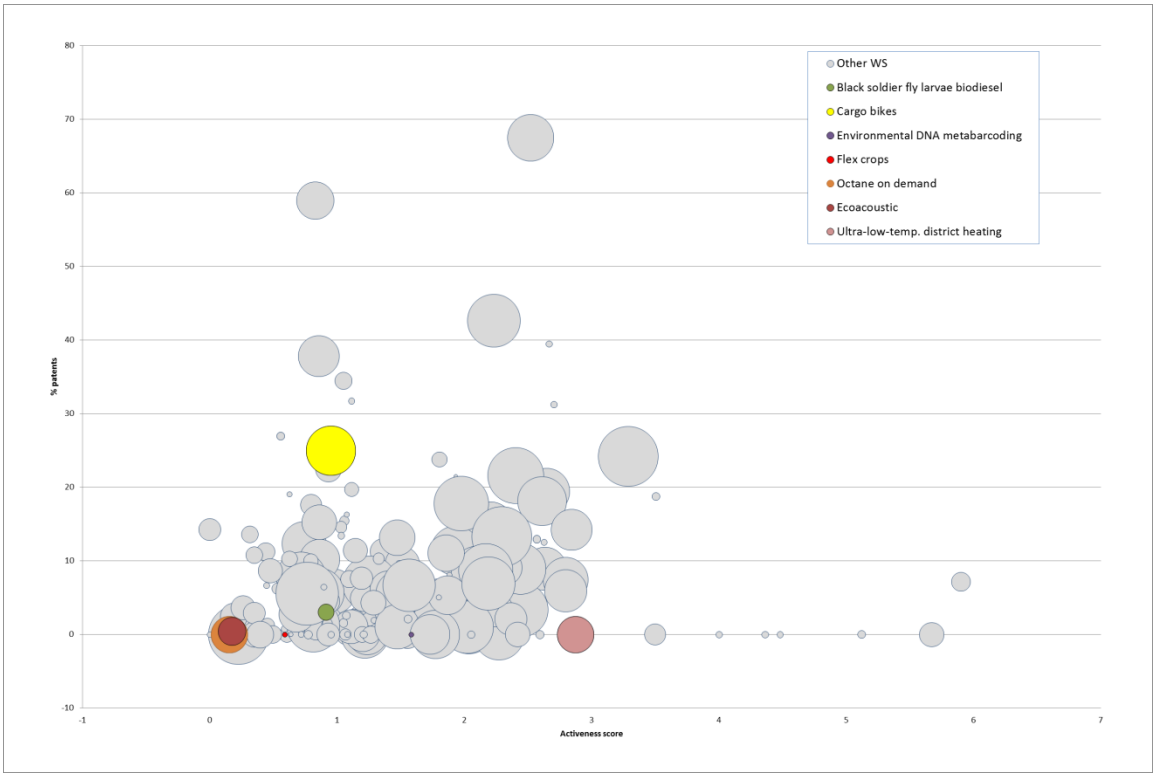
▶ Environmental DNA metabarcoding is a novel method that assesses biodiversity and detects the presence of species in the environment. It is an interdisciplinary method bringing ecology, molecular biology and advanced computational tools together. eDNA metabarcoding has the potential to revolutionise modern biodiversity surveys.

▶ Flex crops are crops with multiple uses: as food, fuel, material for housing or industry, etc. For millennia, many plants have had multiple uses and the concept of flexible crops is not new. However, the new emerging debate on "flex crops" looks at how a small number of crops (maize, soy, sugarcane, and oil palm) have been under pressure for meeting the demands of various markets and how the new concept of "crop-use change" is emerging.

▶ Octane on demand is a new dual-fuel injection system being developed to increase fuel economy through the efficient use of high-octane fuel components. The system customizes octane based on real-time engine requirements. This approach could improve fuel efficiency by 25 to 30 percent and reduce greenhouse gas emissions by 30 percent overall. Therefore, this technology could have a major impact on fuel usage and pollution.

▶ Ultra-low-temperature district heating aims at improving the overall efficiency of traditional heat distribution networks and reduce operational costs by decreasing the supply temperature below 50°C. Lowering the supply temperature is expected e.g. to minimize heat losses, improve the performance of heat generation plants, facilitate the integration of low temperature heat sources (solar, geothermal). The potential environmental and economic benefits of using ultra-low-temperature district heating makes it a promising application for future energy systems..

Figure 30: Weak Signals Environment – Miscellaneous.



4.7 Social Sciences

Social sciences study human societies and are increasingly important in a time when we face numerous societal challenges and when the pace of technological innovation keeps accelerating, continuously bringing cohorts of small and large disruptions.

Digital-related

One of the main societal perturbations is related to the advent of the digital age, which impacts every aspect of our modern societies.

▶ Algorithmic fairness is a response to the bias of artificial intelligence (AI) and the so-called "black box" algorithms. Many machine learning experts, technology companies and governments have called for more fairness, accountability, and transparency in AI. Algorithms can be sexist, racist, and perpetuate other inequalities found in society. But unlike humans, algorithms aren't (so far) under any obligation to explain themselves.

▶ Algorithmic journalism, also called "robot journalism", is the automated production of news in journalism by algorithms that edit, aggregate, publish, and distribute content. Most of the journal articles will be written by these algorithms within 5 to 10 years. Ethical, moral, and operational considerations are being debated and concerns expressed for the future of journalists.

▶ Civic technologies focus on informing, engaging and connecting citizens with their government and to one another in order to improve public governance. They enhance e.g. citizen communication, public decisions, or government services. The importance of civic technologies has increased over the last year, following the rise of the Internet of Things and Artificial Intelligence.

▶ Digital constitutionalism aims at rethinking and redefining the limits of the exercise of power in a networked society. The key challenge of digital constitutionalism is to identify how values of good governance and public good can be protected in the digital age.

▶ Digital humanitarianism refers to the new trend of using digital and mobile technologies as well as social media for humanitarian crisis management. Digital humanitarians are volunteers from all over the world who support research and relief efforts through online work, regardless of their geographic location. Digital humanitarianism can quickly provide complementary information on a crisis outside of the official channels.

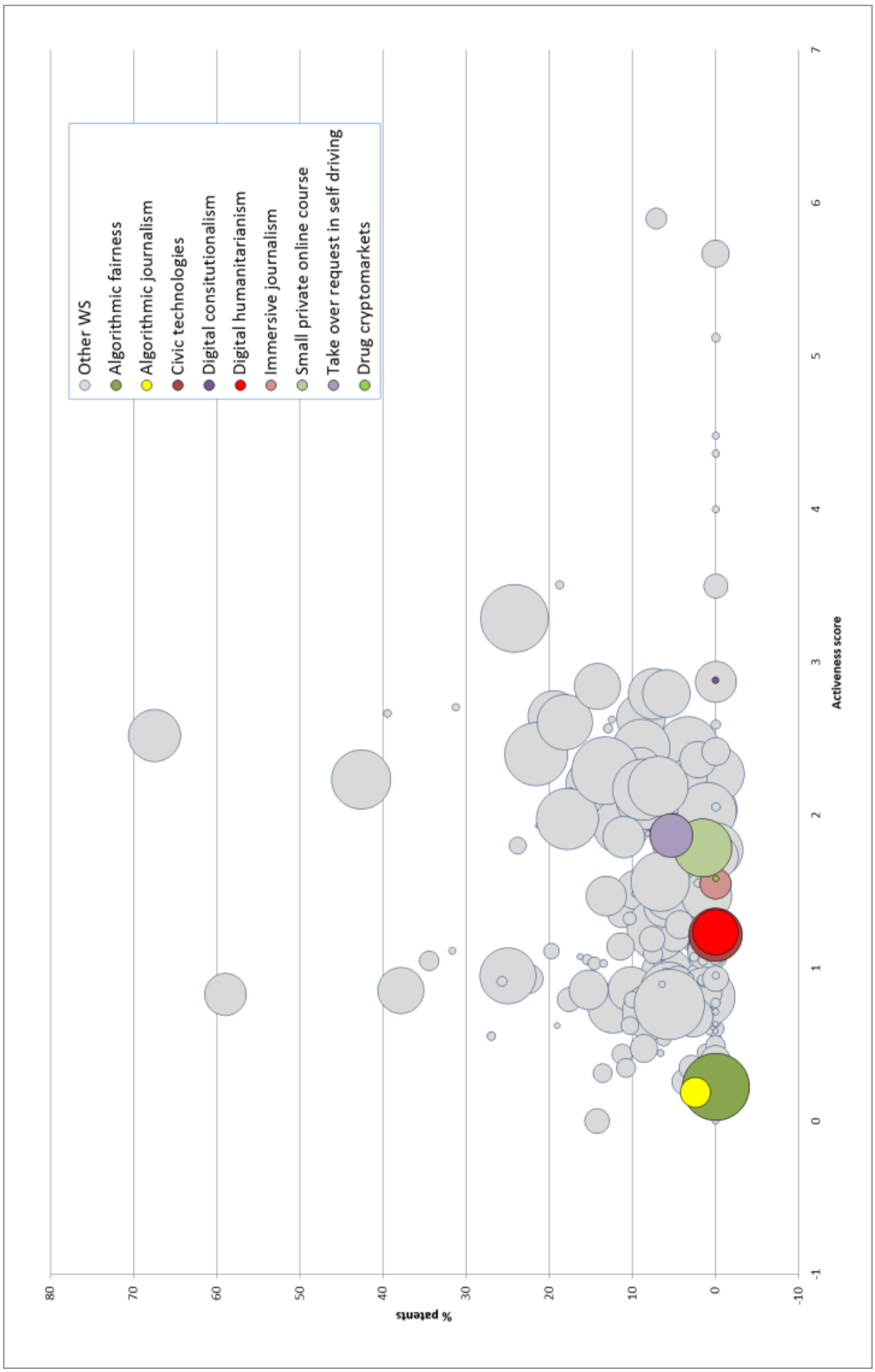
▶ Drug cryptomarkets are on-line, anonymous market-places for illicit drugs which account for a small but rapidly growing share of the illicit drug market in many countries. Drug cryptomarkets are a growing channel for drug diffusion, both in terms of volume and of variety. They host multiple drug vendors, provide participants with anonymity and use cryptocurrencies as payment means. Buyers and sellers of illegal drugs completely escape control by the authorities.

▶ Immersive journalism, also called virtual reality (VR) journalism, is a new form of journalism that uses VR and similar technologies to bring news to people through a virtually reconstructed scenario of a story. Immersive journalism could be a paradigm shift to conventional journalistic practices, but entails ethical challenges like image integrity and manipulation, rewriting of news, sources, the role and responsibility of the journalist and the audience, etc.

▶ Small private online courses (SPOC) is a recent trend in digital learning that focuses on certain groups of students and favours their interaction with the teacher and with each other. SPOCs complement traditional teaching and massive open online courses (MOOCs) but could also bring a methodological change that makes better use of face-to-face time between students and teachers.

▶ Take-over request in self-driving is an important research question at the cross-road of social science, automation and IT. In automated driving, the question is "how to support drivers in switching from automated to manual control?" When automation reaches its operational limit in a given traffic situation, a take-over request is initiated and asks the driver to take back control of the vehicle. As the level of urgency of the situation cannot be assessed by the on-board algorithms, the take-over process is therefore an important weakness in the road towards highly automated vehicles.

Figure 31: Weak Signals Social Sciences – Digital-related.



Miscellaneous

▶ **Biophilic cities** are a growing trend among architects and designers. This type of city aims at providing close and daily contact with nature and seeks to foster awareness of and a sense of caring for nature in general. They are designed to be sustainable and foster social and landscape resilience in the face of climate change, natural disasters, economic uncertainty and various other perturbations.

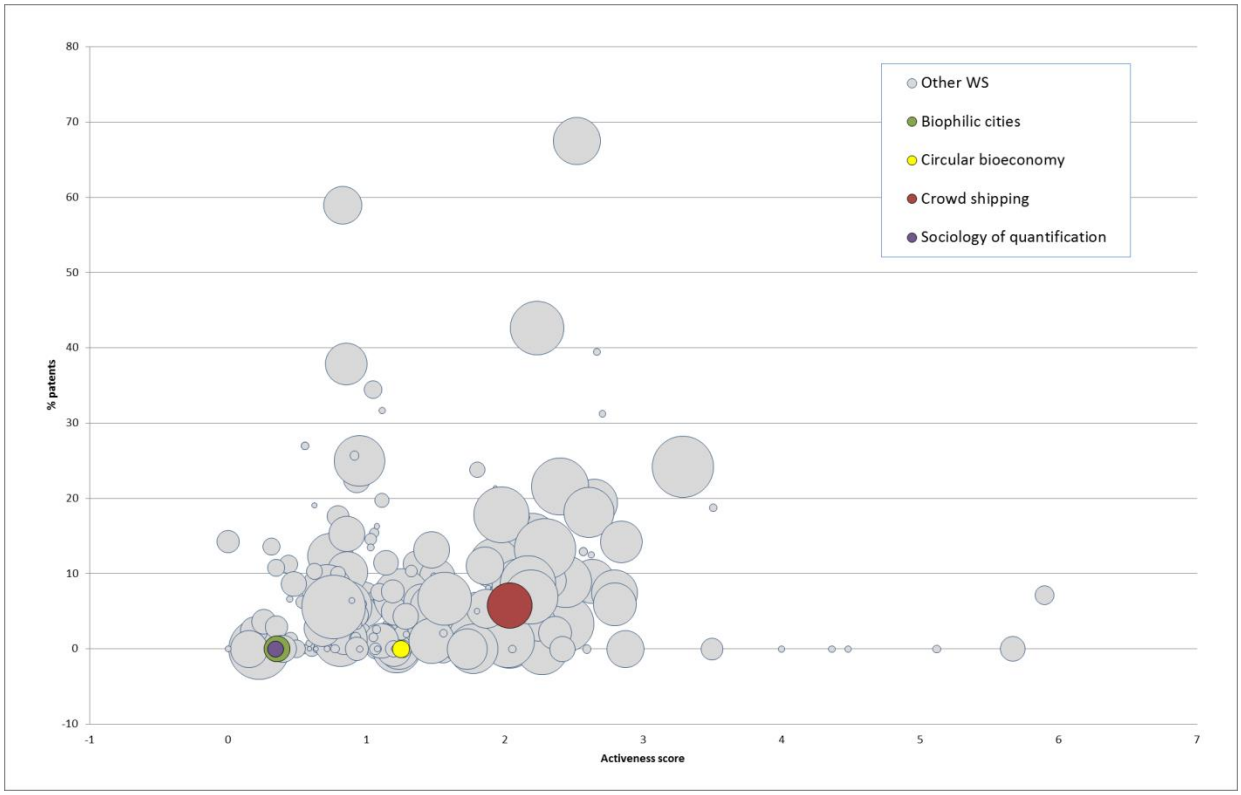
▶ **Circular bioeconomy**

Circular economy and bioeconomy are two very popular concepts have been influencing policy making for about a decade now. Circular bioeconomy is a growing policy model that lies at the cross-road of these two concepts and applies the circularity model to bioeconomy.

▶ **Crowd shipping** also called crowdsourced delivery, crowd logistics, cargo hitching or collaborative logistics, is a concept that seeks to develop the delivery of goods via the crowd. It uses the excess capacity of available transport modes to perform such deliveries. Urbanisation of our societies and the development of e-commerce push supply chains to adapt and ensure that deliveries, and in particular "last mile" deliveries, are fast, cheap, reliable and more environment-friendly.

▶ **Sociology of quantification** is an emerging field in social sciences. This transdisciplinary approach analyses the processes of production and communication of numerical data and graphs. It aims at understanding better the impact of the ever increasing quantification of social phenomenon and of the significance of new regimes of measurement.

Figure 32: Weak Signals Social Sciences – Miscellaneous.



4.8 Physics and Engineering

Light-related

▶ Photoelectrochemical aptasensors use synthetic nucleic acid molecules (aptamers) as a sensor for detecting biological molecules. They bring into biomolecular detection advantages such as faster responses, robustness, low cost, the potential for miniaturization, higher sensitivity, and more significantly, cheaper and simpler instrumentation than other optical techniques.

▶ Photoelectrochemical immunosensors are compact devices that detect antibody-antigen reactions and produce an electrical signal that can be processed. Photoelectrochemical immunosensors are more sensitive and performant than regular immunosensors, and are drawing interest due to their desirable advantages and attractive potential in biological analysis.

▶ Photoinduced force microscopy is a new nanoscale imaging technology that combines optical absorption spectroscopy and atomic force microscopy to provide imaging topography, as well as chemical imaging at a very high resolution (less than 10 nm).

▶ Remote photoplethysmography is a method for detecting blood volume changes, or measuring cardiac pulse rates, without the need to illuminate the skin with LED light, as is the case with traditional photoplethysmography. The measurement can be taken from live or recorded videos. This can be advantageous in cases where contact-based monitoring is limiting and cumbersome.

▶ Structure-from-motion photogrammetry is an imaging technique for reconstructing three-dimensional structures from two-dimensional image sequences that may be coupled with local motion signals. This emerging, low-cost method for high-resolution topographic reconstruction is ideally suited for low-budget research and application in remote areas. Many applications can be envisaged, but to date it has been mostly used as a non-invasive technique in geosciences (e.g. settings as rivers, sandy coastlines, landslides, rock masses, coral reef) and in 3D mapping of cultural heritage.

▶ Topological photonics is an emerging field of research in which geometrical and topological ideas are exploited to design and control the behaviour of light inside photonic crystals, coupled resonators, metamaterials and quasicrystals. Potential practical applications include new photonic circuitry and future optical transmission lines that can survive to any material disorder.

▶ Visible light positioning is a technology that uses signals transmitted by white LEDs in order to determine the position of a person or object within a room, without compromising the primary function of the LEDs. This presents a unique opportunity to create an indoor positioning system that is accurate and ubiquitous, paving the way for numerous applications including indoor navigation, personnel and asset tracking, as well as rescue operations.

Figure 33: Weak Signals Physics & Engineering – light-related.

Detection

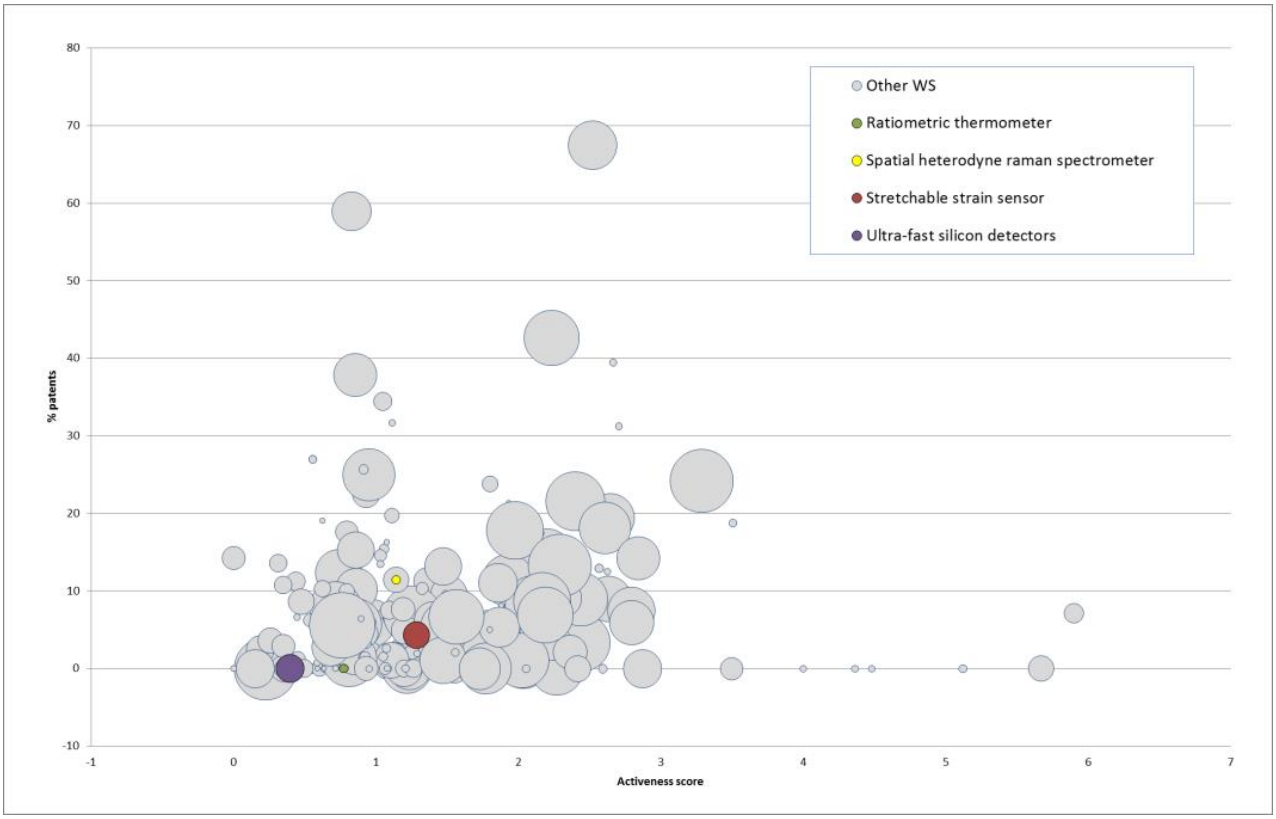
▶ Ratiometric nano-thermometers are non-invasive precise thermometers working at the nanoscale with high spatial resolution, encompassing organic dyes-among others-as thermal probes. One striking application is the measurement of the temperature of individual living cells, which is now possible for the first time.

▶ Spatial heterodyne Raman spectrometer is a small, rugged, high-resolution ultraviolet version of the Raman spectrometer, compatible with pulsed laser sources and suitable for planetary space missions. A Raman spectrometer is an instrument used in chemistry that provides structural fingerprints of molecules allowing for their identification.

▶ Stretchable strain sensors are developed to measure strain on an object, while being highly-stretchable and flexible. This pliability is a requirement for modern wearable electronics that can be used for soft robotics, artificial e-skins and healthcare monitoring devices.

▶ Ultra-Fast Silicon Detectors are the latest advancement in subatomic particle tracking devices, which are ubiquitous not only in research laboratories such as CERN, but in almost every high-tech apparatus, from customized portable phones to hospitals. Their advantage is that they can measure both the space and time coordinates of a charged particle with great precision.

Figure 34: Weak Signals Physics & Engineering – detection.



3D Printing

3D printing technology has existed since the mid-1980s, but only became available as a mainstream product 20 years later. It has started revolutionising the production of physical objects, and new applications and methods keep appearing in many different fields.

▶ 3D Bioprinting aims at manufacturing living tissues using 3D printers and has the potential to disrupt many fields of medicine. Intensive research is ongoing on the 3D printing of tissues (bone, organ, skin, cartilage, lungs, muscles, neural, etc.) with the aim to use them in therapeutic applications.

▶ 3D Concrete printing is a novel approach to construction, offering a higher degree of optimization and flexibility for producing structures or structural elements with complex geometries that are impossible to achieve today using concrete. It has the potential to significantly disrupt the construction sector.

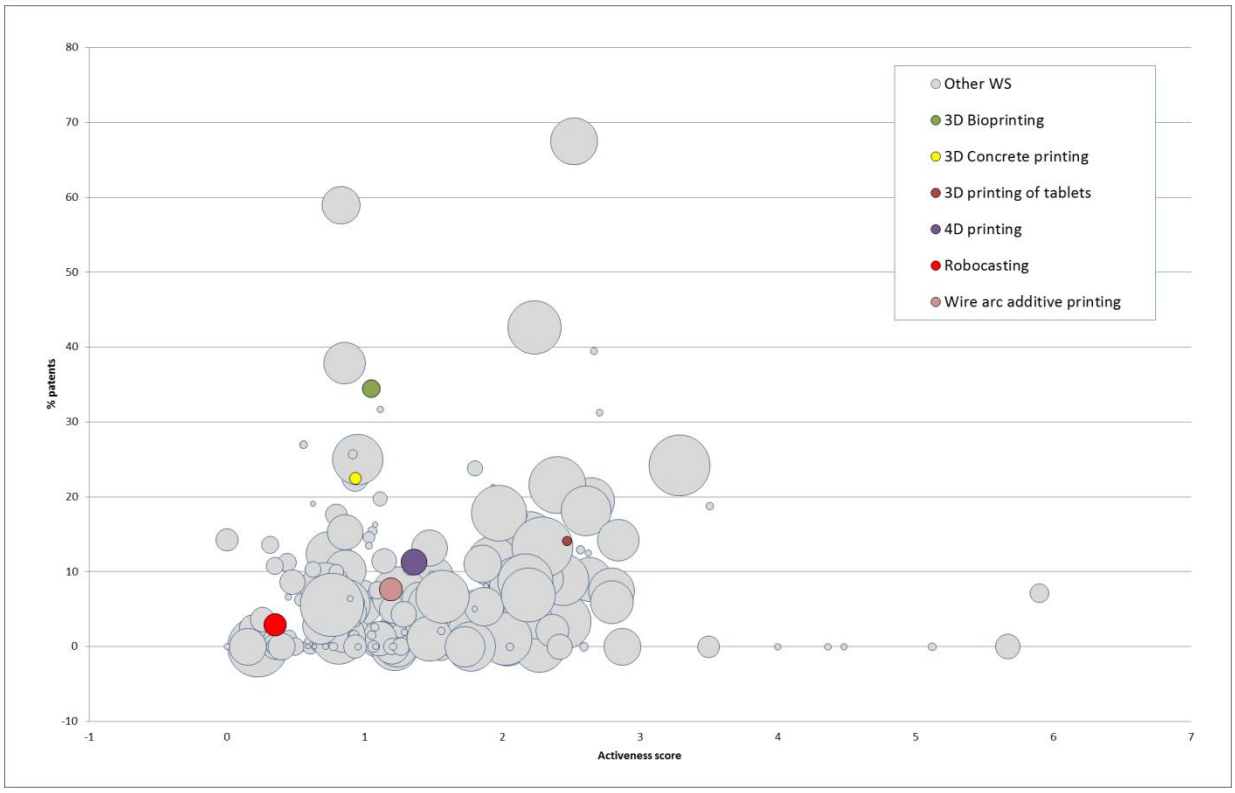
▶ 3D printing of tablets is a very promising technology that could revolutionize the delivery of drugs to patient by allowing the design and 3D printing of drug formulations customised to patients and the decentralisation of the delivery to them.

▶ 4D printing aims at giving 3D printed materials the capacity to transform over time, when submitted to particular conditions such as change in temperature, pH, light, or humidity. Reliable 4D printed materials could have a high impact on society by introducing shape-shifting products in our daily lives.

▶ Robocasting is not a new technology, but new applications of robocasting are presently being explored. Robocasting is a 3D printing technique in which a filament of a paste is extruded from a small nozzle while the nozzle moved across the printing area. The recent increase in research related to robocasting is related to its use for manufacturing e.g. electronic wearables devices, bio compatible materials, or materials for soft robotics.

▶ Wire arc additive printing is a 3D printing technique that melts metal wires to produce (layer by layer) 3D metallic parts. It is attracting a lot of interest as it allows fabricating large and/or complex metal components at a rather low cost and within a short production time.

Figure 35: Weak Signals Physics & Engineering – 3D Printing.



Wireless power transfer

Power transmission without wires is not a new concept. In fact, inductive coupling, the common technology already used for low power transfer, has been invented by Nikola Tesla at the end of the 19th century and is all around us. The exponential growth of battery-powered devices has triggered new research in this field.

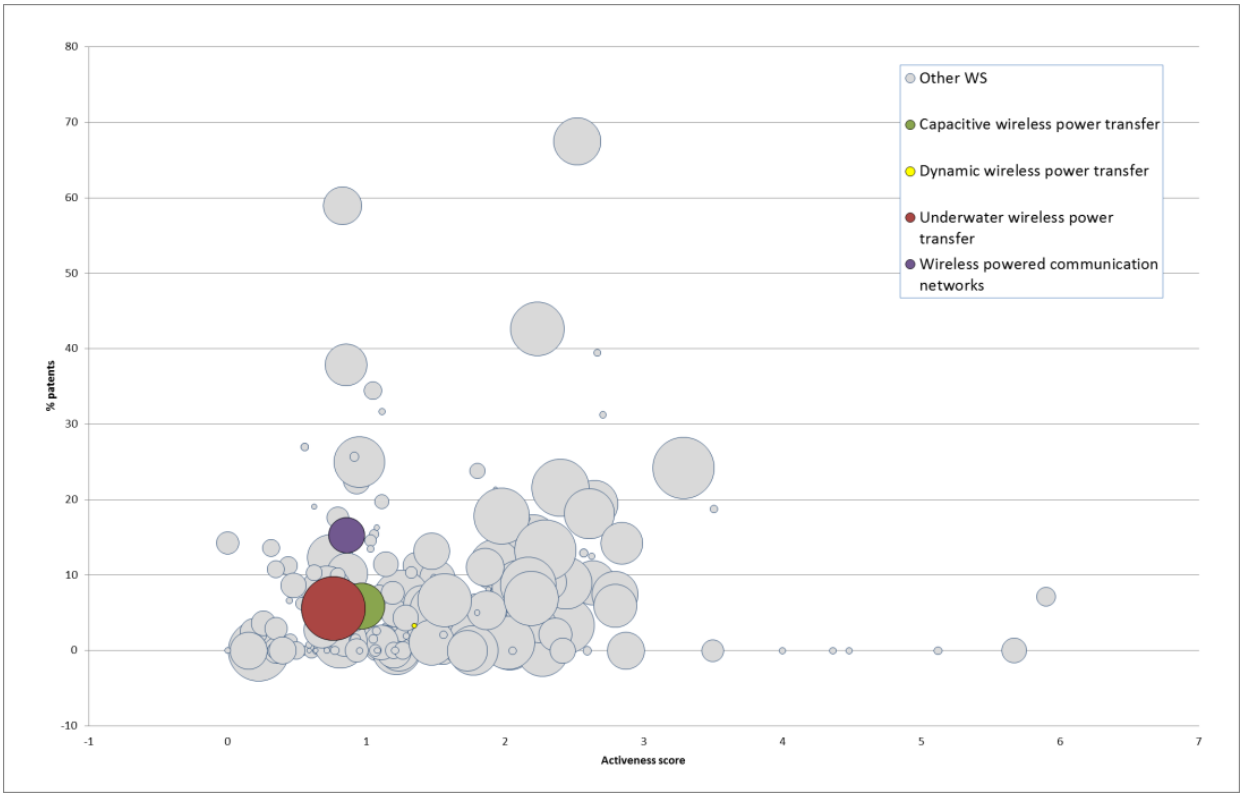
▶ Capacitive wireless power transfer technology is an effective and important alternative to the conventional inductive power transfer that utilizes high-frequency electric fields to transfer power. This results in lower costs and weight, as well as better performance and energy loss, making the technology suitable for faster stationary electric vehicle charging applications.

▶ Dynamic wireless power transfer is a technology that charges electric vehicles while they are moving, thus extending or even providing an infinite driving range, while allowing for significantly reduced battery capacities for the vehicle. This could create a paradigm shift in the automotive industry.

▶ Underwater wireless power transfer has been challenging to achieve because of the random nature of big water bodies such as the ocean and the salty water environment. However, recent developments have led to increased transmission efficiency, making wireless power transfer possible and thus paving the way for emerging maritime applications, such as the charging of underwater autonomous vehicles.

▶ Wireless powered communication networks is a new technology, where the battery of wireless communication devices can be remotely replenished by means of microwave wireless power transfer technology. This eliminates the need for frequent manual battery replacement/recharging, and thus significantly improves the performance over conventional battery-powered communication networks in many aspects, such as higher throughput, longer device lifetime, and lower network operating costs.

Figure 36: Weak Signals Physics & Engineering – Wireless power transfer.



Miscellaneous

▶ Air-Filled Substrate Integrated Waveguide is an essential technology for the future low-cost and extremely high-rate data communication systems, as well as for the highly sensitive sensors that will be used in millimetre-wave applications (30 to 300 GHz), which includes the new 5G wireless broadband technology.

▶ Cold sintering process is not a new process; however, it has received accrued interest lately mainly for the production of composite ceramics at low-temperature and for the production of Solid-State batteries using inflammable solid-state electrolytes.

▶ Hybrid modular multilevel converters are promising new topologies for high-power voltage source converters that are being explored. They have many industrial applications such as renewable energy resource interfaces, Flexible AC Transmission System devices or High Voltage Direct Current lines.

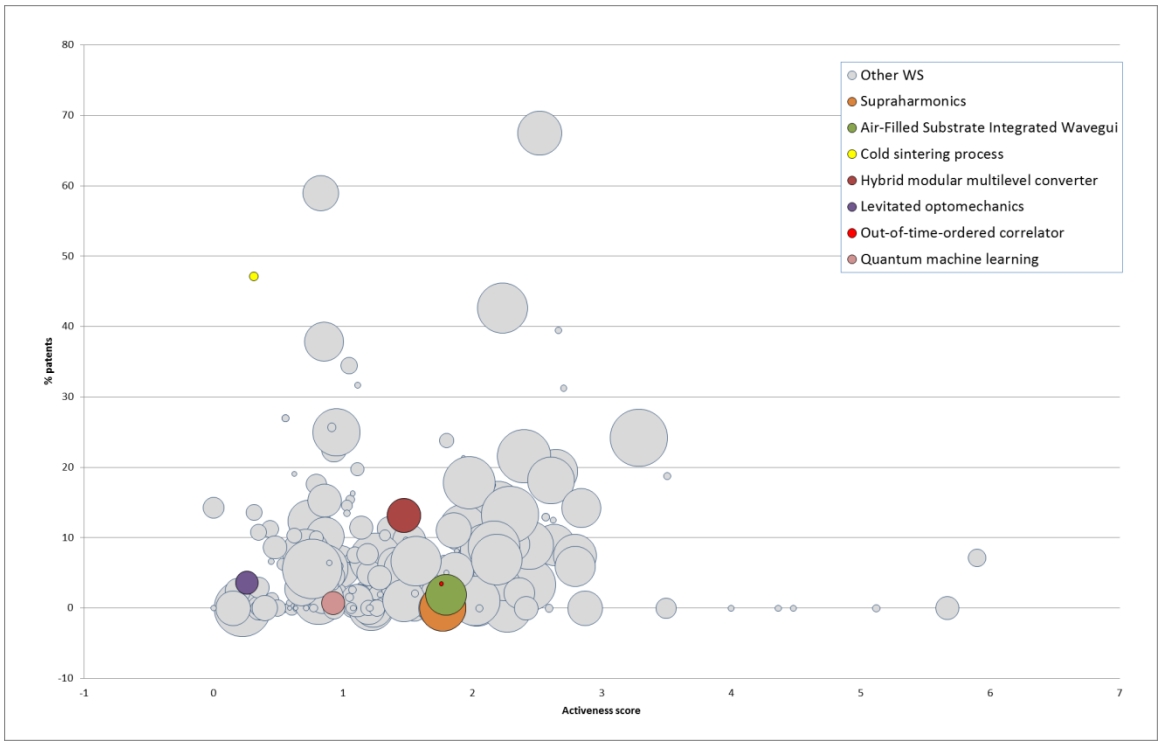
▶ Levitated optomechanics is an emerging field of optomechanics, a field of physics concerned with the use of light to control mechanical objects. Applications of levitated optomechanics are numerous and range from creating micro-actuators without friction or contributing to the search for evidence of dark matter, to trapping of particles and the development of new and hyper-sensitive sensors.

▶ Out-of-time-ordered correlators are quantitative tools that were once considered to be promising for measuring or characterizing chaos in quantum systems. They are now found to be very useful in measuring the propagation of information through quantum many-body systems, or in bringing new insights into the black hole information problem or thermalization.

▶ Quantum machine learning is an emerging research area that focuses on improving the performance and computation speed of classical machine learning, by using quantum computation and by exploring how to combine machine learning with quantum mechanics. This new method has potential applications in finance, image classification, and others areas where the flow and volume of data is significant.

▶ Supraharmonics are harmonic distortions in the frequency range from 2 to 150 kHz, resulting from the interaction between electronic devices. Supraharmonics are responsible for the rapid aging of electronic devices and are of growing concern in the context of ever-increasing connectedness between electronic devices and power grids.

Figure 37: Weak Signals Physics & Engineering – Miscellaneous.



4.9 Information and Communication

It is safe to say that ICT has an impact on every aspect of our daily lives. The ongoing digitalisation of our economies brings along new technological developments, some of which have been spotted as weak signals.

5G Communication

5G communication technologies hold the promise for massive changes in the way we communicate, while it is also expected to enable a paradigm shift in device-to-device communication.

▶ 5G Security is of growing concern for the 5G community. The growth in both number of connected devices and sensitive data available and transmittable over 5G in the coming years will expand the attack surface and scale for cyber criminals significantly, making network security more relevant than ever.

▶ Drone base stations are mobile aerial radio transceivers that can assist existing wireless communications or provide on-demand cellular networks to areas that have no 5G coverage or that have lost coverage due to e.g. disasters.

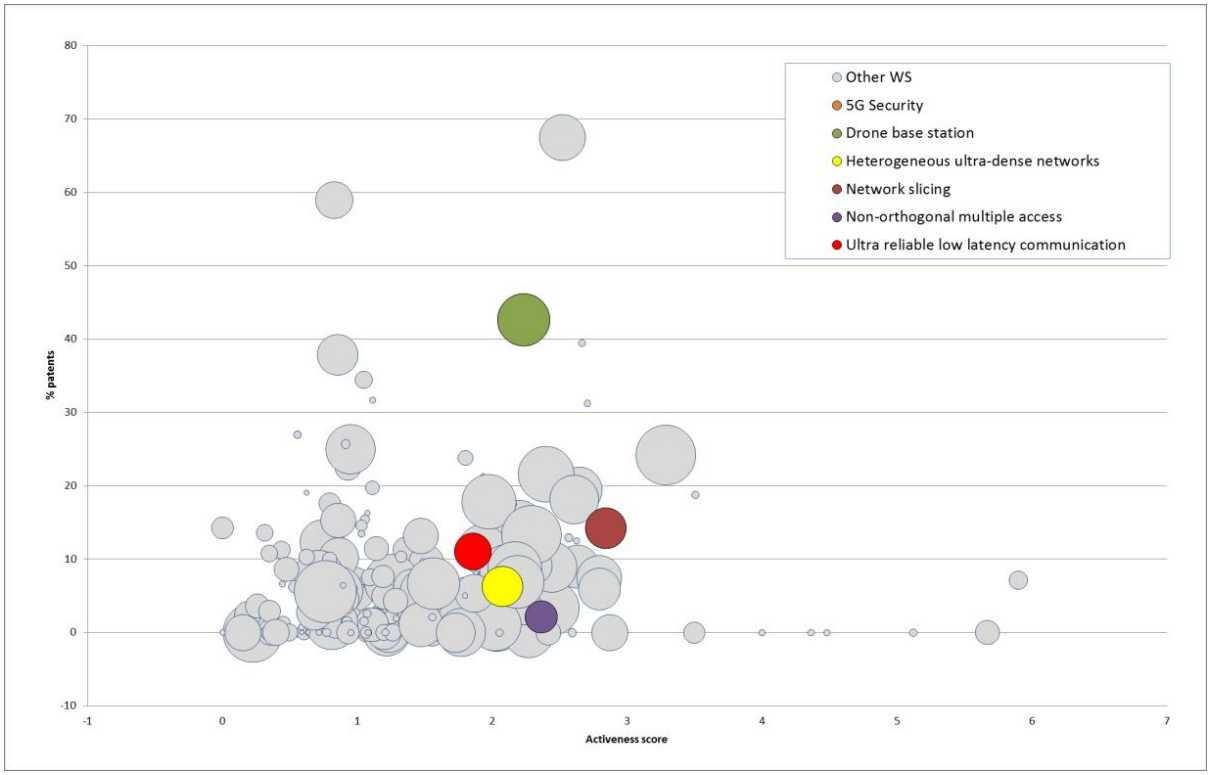
▶ Heterogeneous ultra-dense networks refer to the idea of densifying the cellular networks to a very high level, including both mobile devices and base stations, with a view to effectively serving the exponentially growing data flows in wireless networks.

▶ Network slicing is a technology that allows multiple virtual networks to be created on top of a common shared physical infrastructure, allowing a mobile network operator to partition its network resources in order to allow for very different use cases simultaneously, such as running Internet of Things, mobile broadband and very low-latency applications or communications with high-speed vehicles.

▶ Non-Orthogonal Multiple Access (NOMA) is a radio access and encoding technique that promotes massive connectivity, lower latency, spectral efficiency and improved reliability. Its basic idea is that it allows several users to use the same frequency bandwidth.

▶ Ultra-reliable low latency communication (URLLC) is a new service category in 5G to accommodate emerging services and applications having stringent latency and reliability requirements, as are remote surgery, autonomous driving, and factory automation.

Figure 38: Weak Signals Information and Communication – 5G Communication.



Blockchain

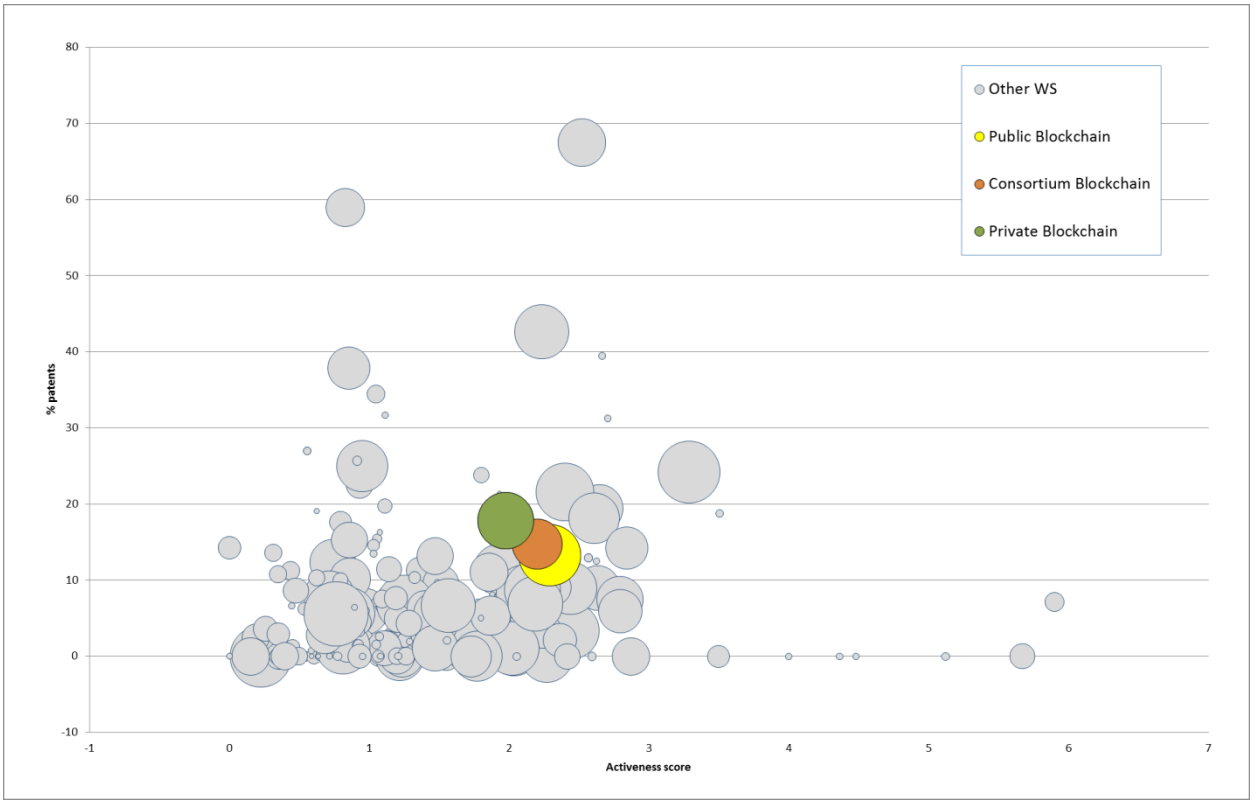
A blockchain is a growing list of blocks containing transaction data, resistant to any modification after their creation, and linked using cryptography. This makes the blockchain work as an open and distributed ledger that can record transactions between two parties efficiently and ensure that verification is possible at all times. Blockchain brings security and transparency to online transactions. It has potential applications in many sectors.

▶ Consortium blockchains are semi-private systems that have a controlled user group, but work across different organizations. A blockchain consortium of like-minded companies can leverage information to improve workflows, accountability, and transparency. Consortium blockchain have applications in smart grid regulation, food trading, electronic voting, vehicle fraud, etc.

▶ Private blockchains are used in enterprise solutions, for B2B scenarios, supply/value chain relationships or for creating any kind of shared infrastructure between enterprises. They require permission for participating and thus anonymity is undesirable. Potential applications are expected in academic publishing, forensics of self-driving vehicle accidents, real time supply chain monitoring, etc.

▶ Public blockchains are available to anyone who has an internet connection. They are decentralised and noone has control over the network; they are secure as data cannot be changed once validated on the blockchain, and they also protect the user's anonymity. Main applications are in cryptocurrencies (e.g. bitcoin).

Figure 39: Weak Signals Information and Communication – Blockchain.



Internet of Things

The Internet of Things (IoT) describes the empowerment of daily objects (cars, sensors, consumer products, etc.) to connect to the internet and exchange data. This emerging topic will have vast repercussions on the way we live, work, and interact with our environment.

▶ Internet of battlefield things introduces the use of robots in battle and connects soldiers with smart technology embedded in their armour, radios, weapons etc. in order to give troops "extra sensory" perception, offer situational understanding, prediction powers and better risk assessment.

▶ Internet of drones is the combination of the Internet of Things with Unmanned Aerial Vehicles. It involves multiple drones cooperating and communicating in an aerial mesh network for collecting information through sensors. Important issues like security and safety have to be resolved before real applications in e.g. delivery, aerial surveys, traffic and environment monitoring, or search and rescue operations, can be launched.

▶ Internet of vehicles integrates three networks: an inter-vehicle network, an intra-vehicle network, and vehicular mobile Internet. It is essentially a moving network made up of IoT-enabled cars that can communicate with each other, as well as with humans, external road sensors and the internet, that makes use of modern electronics and integrates information to help maintain traffic flow, and to perform more effective fleet management and accident avoidance. The development of Internet of vehicles is an important step in reaching highly automated vehicles.

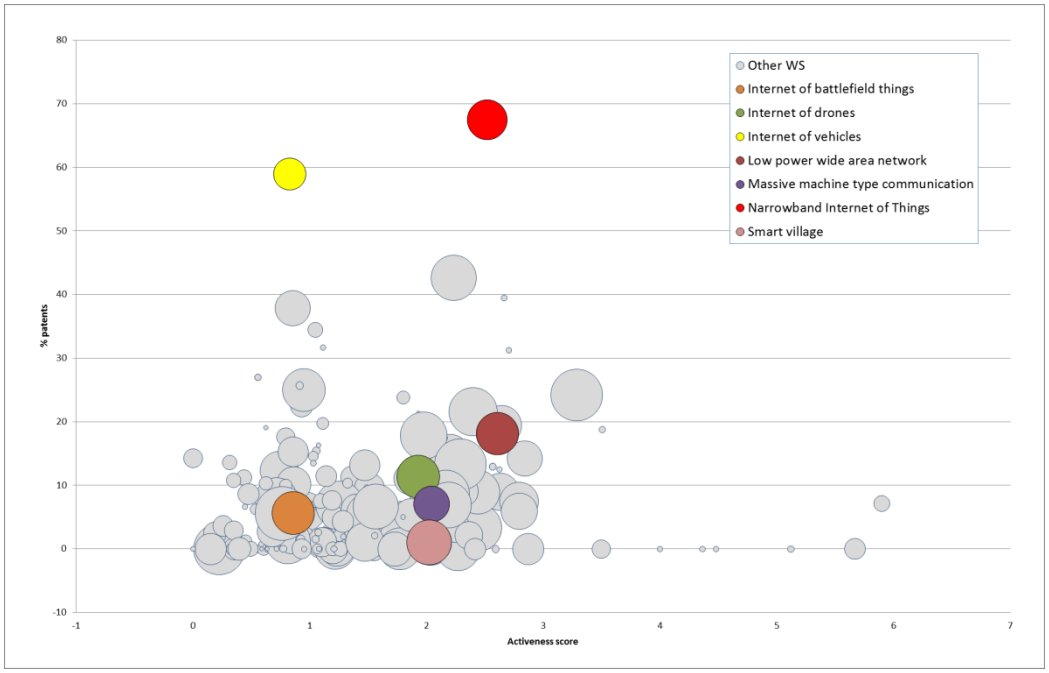
▶ Low-power wide area network (LPWAN) is a new wireless communication technology that is essential for the deployment of the IoT. Current solutions like Bluetooth (short-range) or 4G/5G (excessive energy demand) are not adapted. LPWAN is gaining interest as a low-power, long-range, and low-cost solution to IoT communication requirements.

▶ Massive machine type communication is a new communication paradigm expected to play a key role in 5G. It is characterized by fully automatic data generation, processing and exchange among intelligent machines ("machine-type devices"), which will eventually account for a much larger proportion than the existing mobile phone devices, shifting communications from human- to machine-centric.

▶ Narrowband internet of things is a standard-based LPWAN radio technology developed by 3GPP that enables a wide range of cellular devices and services and focuses specifically on indoor coverage, low cost, long battery life and high connection density.

▶ Smart village is the concept that encompasses all the digital transformations brought by the Internet of Things to rural areas, which are facing numerous challenges both on the economic and social level.

Figure 40: Weak Signals Information and Communication – Internet of Things.



Neural networks

Neural networks mimic the functioning of neurons in the brain to detect hidden patterns and correlations in large volumes of data. They also have the capacity to learn continuously and to become better at the tasks they are performing. In the age of big data, neural networks help in solving complex problems in many areas.

▶ 3D convolutional neural networks are a new type of convolutional neural network, usually applied to analysing visual imagery. A 3D convolutional neural network is helpful in event detection in videos, 3D medical images, etc. but can also be applied to 2D space inputs, such as high definition images.

▶ Convolutional autoencoders are a family of neural networks used widely for reconstruction, noise reduction, and enhancement in images.

▶ Deep Q learning is a deep reinforcement learning algorithm that allows scaling to problems that were previously unsolvable, such as learning to play video games directly from pixels, or allowing control policies for robots to be learned directly from camera inputs in the real world.

▶ Dilated convolutional neural networks are performant neural networks that specialise in dense prediction. They can capture data dependencies in a large spatial or temporal range, while only requiring that the number of parameters grow logarithmically. As a result, they are more efficient to train and provide more accurate forecast than other NNs.

▶ Generative adversarial networks are deep neural network architectures that can be taught to create worlds extremely similar to our own, in any domain: images, music, speech, prose. Their applications have exploded recently, spanning areas from fashion to astronomy to computer games, but have also raised some concerns about malicious use, such as the production of fake photographs and videos

▶ Hierarchical recurrent neural networks are neural networks designed with the objective of modelling hierarchical structures in sequential data (unsegmented, connected handwritten text, video streams, speech, genomes, programs etc.). The algorithm behind this takes both time and sequence into account.

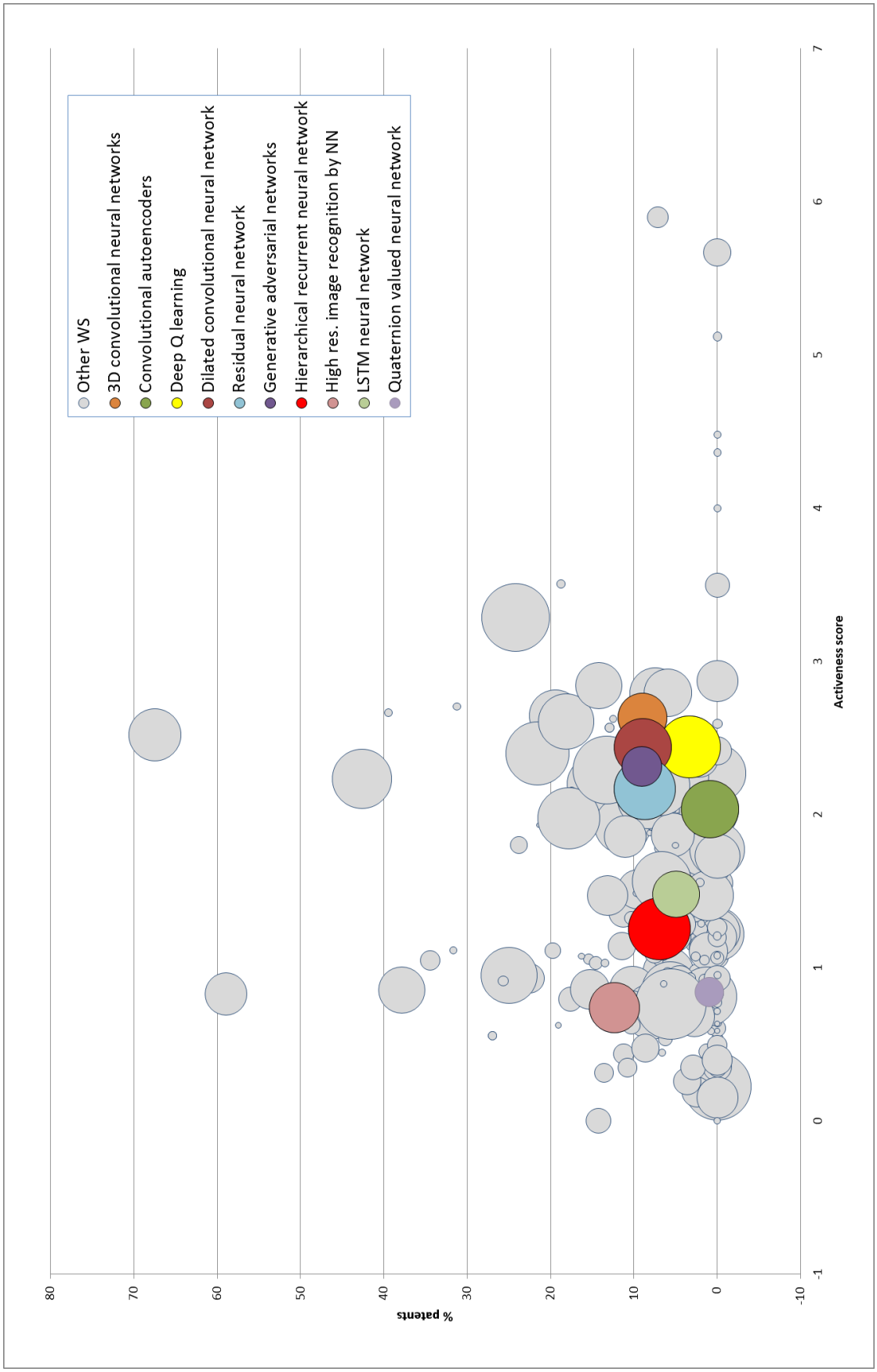
▶ High-resolution image recognition by neural networks allows generating high-resolution images from low-resolution ones, and/or improving the details within an image. This makes this type of neural network very interesting for improving automatic image recognition systems, which require relatively high-quality images in order to perform acceptably.

▶ Long Short-Term Memory neural networks are recurrent neural networks that are well-suited to classifying, processing and making predictions based on time series data, making them ideal for unsegmented handwriting recognition or speech recognition.

▶ Quaternion valued neural network are neural networks that make use of a four-dimensional hyper-complex number system called quaternion numbers, and they are specialised in automatic speech recognition. Their main benefit is that the number of inputs and outputs is reduced by four times with respect to other neural networks.

▶ Residual neural networks mimic a specific structure of the neocortex (layer VI), in which pyramidal cells receive signals from various cortex layers. Similarly, information in a residual NN can skip layers and be used to amplify a signal, avoiding the problem of vanishing gradients, where a signal fades away.

Figure 41: Weak Signals Information and Communication – Neural Networks.



Computing

The increase in connected devices and sensors is calling for new computing mechanisms. The centralised model will not be able to cope with the amount of data that will have to be handled and new decentralised computing models are under development.

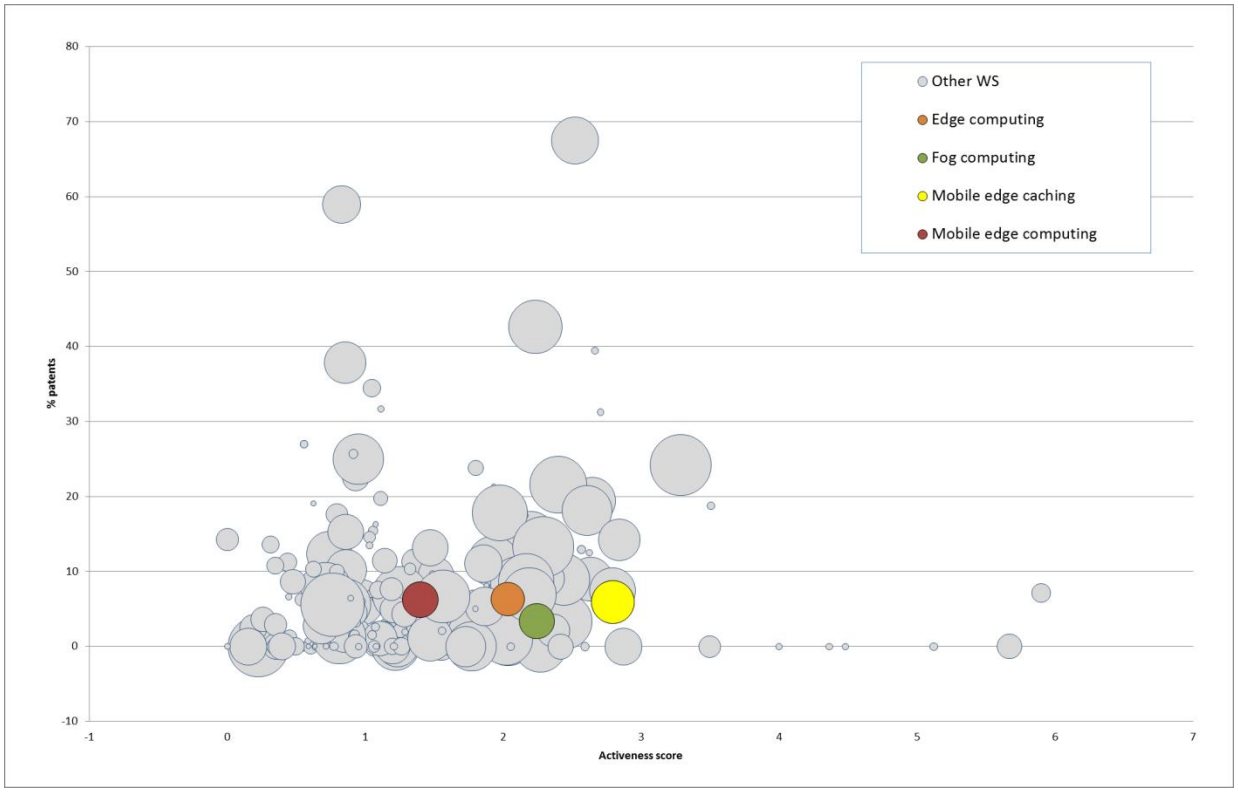
▶ Edge computing is one of the solutions to the explosion of connected devices that are producing massive amounts of data to be computed at various datacentres, pushing network bandwidth requirements to the limits. Edge computing is a new paradigm that brings computation and data storage closer to the location where it is needed, in order to improve response times and save bandwidth.

▶ Fog computing is an architecture that uses edge devices (such as routers, switches and metropolitan area network access devices) to carry out a substantial amount of computation, storage and communication locally and routed over the internet backbone. Differentiating itself from cloud computing, fog computing brings data and computational proximity to the end-users, lower latency, dense geographical distribution and backbone bandwidth savings in order to provide a better user experience and quality of service.

▶ Mobile edge caching, which enables mobile edge devices with cache storage, is a promising solution to address the challenge related to the widespread adoption of various mobile applications, namely the exponential traffic growth in wireless networks, which exerts a great burden on mobile core networks and intermediate links.

▶ Mobile edge computing, or multi-access edge computing, is a network architecture concept that enables cloud computing capabilities and an IT service environment at the edge of a network, i.e. closer to the cellular customer, in order to reduce network congestion and augment application performance.

Figure 42: Weak Signals Information and Communication – Computing.



Miscellaneous

▶ Ambient backscatter uses existing radio frequency signals (such as radio, television and mobile telephony) to transmit data without using power. This technology would allow devices to communicate without the need for a battery or connection to the power grid.

▶ Crypto supersingular isogeny is a special kind of mathematical graph that is known for its use in a post-quantum cryptographic algorithm called "Supersingular isogeny Diffie-Hellman key exchange" (SIDH). This algorithm is used to establish a secret key between two parties over an otherwise insecure communications channel, and is designed to resist attacks from quantum computers. One of its main features, forward secrecy, improves the long-term secrecy of encrypted communications, helps defend against mass surveillance and reduces the impact of serious computer vulnerabilities.

▶ Digital twin in industry is a concept with multiple equivalent definitions, one of which is that it's a real-time digital replica of a living or non-living physical entity, where that could be a process, a device, a system, a physical asset, a place or an individual. In the Industry, the main use is optimising operations and predictive maintenance, but the applications are potentially endless, integrating the internet of things, artificial intelligence, machine learning and spatial network graphs.

▶ Drone detection has become necessary following the advent and proliferation of drones for commercial or recreational use. These bring a new set of problems, such as disruption of flights and privacy invasion. Thus comes the necessity to be able to detect the drones by means of specialised object-detection algorithms, RF communication and vibration patterns.

▶ Micro-service architecture is a variant of the service-oriented architectural style, where an application consists of mostly independent services communicating through lightweight protocols. This allows for faster development, better maintainability, continuous delivery and deployment.

▶ Online multiple object tracking aims to estimate trajectories of multiple objects, by finding target locations and maintaining target identities across video frames. The online aspect refers to real-time tracking, thus using the information available up to the current frame, in contrast to the offline variant, which uses all past and future frames.

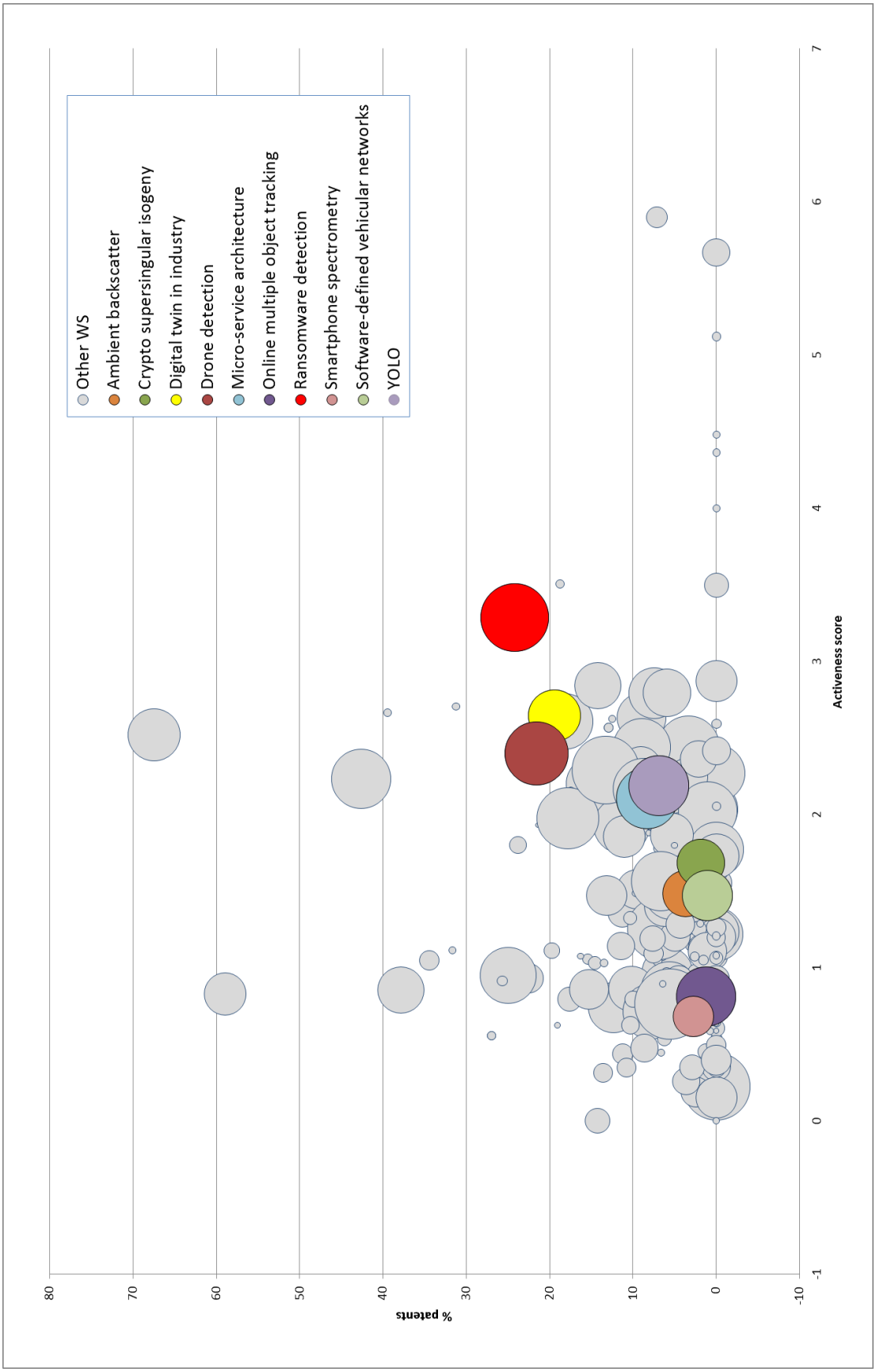
▶ Ransomware detection aims at detecting a special form of malicious software that encrypts users' files, making them inaccessible, until a ransom fee is paid. Detection of Ransomware is what its name suggests: the attempt to detect a ransomware attack and eliminate it before it occurs.

▶ Smartphone spectrometry refers to the use of smartphones to capture spectrum data, mostly by coupling fore-optics with data capture via the smartphone camera. It has promising applications in healthcare and in biomedical, chemical and agricultural areas.

▶ Software-defined vehicular network is a novel networking paradigm that brings flexibility, programmability and other advancements to vehicular ad-hoc networks (VANET). SDN-based VANET have applications in collision avoidance, sharing of information with other vehicles, public safety and passenger comfort.

▶ YOLO, or "You Only Look Once", is an extremely fast real-time multiple-object detection algorithm that uses a single neural network and logistic regression. Its applications are numerous e.g. pedestrian detection, livestock surveillance, firearm detection, vehicle identification, object tracking and detection, etc.

Figure 43: Weak Signals Information and Communication – Miscellaneous



5 Conclusions

JRC has designed and developed a semi-automated system to extract weak signals of emerging technologies from scientific publications. The methodology is using a combination of text mining algorithms and indicators to extract meaningful early signals of technology development.

The detection of weak signals in technology development is the first step in establishing a new quantitative method to complement and reinforce technology foresight methods and tools to strengthen the anticipatory capacity of JRC. In a next phase, JRC will:

- Adapt the developed tool and methodology to a corpus of patent data to evaluate the feasibility and usefulness of detecting weak signals of technology development in patents.

- Apply the newly developed tool and methodology to a specific policy field to assess further how the new method can support policy makers.

- Continue to develop the tool and methodology and ensure scientific validation through peer-reviewed processes (publications, conferences).

- Use the results of the present report in a Delphi process to collect recommendations from experts on the significance of the weak signals detected and on the future direction the development of the new quantitative method should take.

- Organise workshops with stakeholders to analyse the most adequate way to integrate the new method with anticipation and foresight mechanisms and look into how the use of technology foresight can be further used at JRC and other Commission services.

List of figures and tables

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