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Evidence-based technology trends grown into "play-grounds" for sparking creativity

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Abstract: A methodology for the analysis of technology trends with great impact potential is described. PREFET H2020 project implemented a process iterating from manually identified trend seeds to Intelligence-Augmented desktop research supported with text-mining, data-mining and machine-learning. "Weak signals" were detected and trends were "informed" (insight generation), resulting into a list of 45 "pre-validated Trends" that were mapped with UN's Sustainable Development Goals to leverage responsible research. In parallel, they were opened to a consultation involving thousands of researchers in ICT, Health Sciences, Biotechnology and Enrironmental Sciences; enriched with interviews with artists, architects and designers. A workshop around priorisation of technology trends was organised, resulting into a list of "top 20 future and emerging trends", graphically presented in this paper. Insights about some trends in the list are given. The paper finally presents how trends are transformed into "play-grounds" where building disruptive project ideas, and summarizes conclusions from this integral process.

Keywords: Future, technology foresight, data mining, trend identification, evidence-based trends, data intelligence, data collection, text mining, trend consultation, trendington.

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1 Introduction

PREFET is a EU funded project within the European Framework Programme for Research, Technology Development and Innovation, Horizon 2020, focused in the detection of early-stage technology trends and their analysis, combining the most advanced data mining AI engines with human intelligence and crowd/expert perception, tools for the implementation of responsible research and innovation, and innovation capacity building. PREFET started in November 2018 and will keep running until October 2020, carried out by a consortium of four organisations in UK and Spain specialized in responsible management of research and innovation, technology foresight and integral management of R&I projects (from idea – cradle – to markets and society – growth) – www.prefet.eu

This paper describes the methodology followed for the detection, documentation and analysis of top emerging trends in technology with great potential for social impact and R&I development, and how different profiles of stakeholders were engaged in the process in order to help prioritisation, enrichment, identification of strongest synergies and paving the way for these areas to become "play-grounds" were researchers can dream of new disruptive project ideas for a better future. Main results obtained are then described, and certain co-creation experiments towards the ideation of high-impact R&I projects are announced.

2 Quantitative scouting of future technologies

For many years, qualitative and semi-quantitative methods were devised for early identification of emerging technologies. However, only recently attempts to include and develop quantitative methods have been undertaken. These quantitative methods (e.g. data and text mining) usually apply AI techniques (e.g. neural networks, machine learning) to large corpora of data, aiming to extract early signals of new scientific developments or technologies. These so-called weak signals have specific characteristics that allow them to be:

1. Detected;
2. Analysed (to assess their disrupting potential);
3. Monitored (to follow their evolution in time).

PREFET deals with the first two challenges, namely detection and analysis. Monitoring of technological trends is not part of the PREFET's methodology. Nevertheless, the project takes into account the evolution of trends over time, one of the critical aspects and challenges of tech foresight, to avoid static pictures with quantitative methods. One of PREFET partners, LINKNOVATE, launched recently a machine-learning based alert system precisely to address this challenge, taking into account lessons learnt during PREFET[1].

Foresight methods have three crucial shortcomings, as summarised by Gutsche et al (2018)[2]:

1. Firstly, these are usually built on qualitative approaches and expert opinions. Methods fully based on expert opinions or qualitative work, can by nature not be conducted automatically.
2. Secondly, existing approaches rely on manual input and expert opinions in various steps of the process.
3. Thirdly, whenever companies decide to practice foresight, only the currently available information can be taken into consideration. Therefore, the methods are built on static information and are not adaptive to the changing environment with changing information.

Consequently, the identification of promising long-term opportunities remains the primary challenge of strategic planning, as mentioned by Gutsche et. Al (2018).

PREFET acknowledges these shortcomings and tries to tackle each of them, with a focus on the first two points by delivering automatic and semi-automatic methods, and tools suggestions.

Quantitative methods are a big part of PREFET original response, as they have provided added value and can strengthen foresight methods through:

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.

According to a recent report by the Joint Research Centre (JRC, the European Commission's science and knowledge service), weak signals can be evaluated by following an iterative and structured process showing their significance and future impacts on the European economy and society[3]. Such evaluation process could include, for instance, the use of Delphi Method to collect both qualitative and quantitative insights, and workshops to validate and further deepen the implications of these insights. The JRC has designed and developed a technology monitoring system (TIM Trends[4]) to detect weak signals of emerging technologies or scientific topics. The JRC's approach combines text mining techniques with computation and data visualisation means. Precisely this example of quantitative forward-looking ran by the JRC between May and August 2019 constitutes a proof of the alignment of PREFET with ground-breaking work done at EU level, in two independent efforts to achieve similar outcomes, albeit more complex in the case of PREFET, as the (technology) horizon is further afar (JRC focuses on scientific literature covering 1996 to 2018, to "envision" a near-in-time horizon, PREFET concentrates on sources dated from 2017 to present, targets heterogeneous data sources, not limited to scientific publications and conference proceedings and tries to anticipate trends in the far-end future horizon, i.e. 2025 and later).

3 PREFET Methodology

PREFET takes a unique approach to identification and analysis of early signals for promising future and emerging technologies. The project uses four layers of analysis (Figure 1):

1. Massive data analysis through a semi-automated scanning: It could be understood as human cognition augmentation (what is now deemed as **Intelligence Augmentation, IA** – albeit, a more realistic term than AI).
2. Manual scanning through desktop research (**Human Intelligence**): To provide an essential creative dimension.
3. Crowd (expert) feedback (**Social Intelligence**): To broad the expertise available for trend validation, prioritization and augmentation through engaging larger numbers of experts via an internet-based approach.
4. Unconventional expert feedback during an event (**Expert Intelligence**): To provide further insights, better understanding of embedded opportunities and challenges (technological as well as legal, ethical and societal), and mapping the synergies and multidisciplinarity of trends. Complemented with in-depth interviews with other non-usual stakeholders (designers, artists and architects).

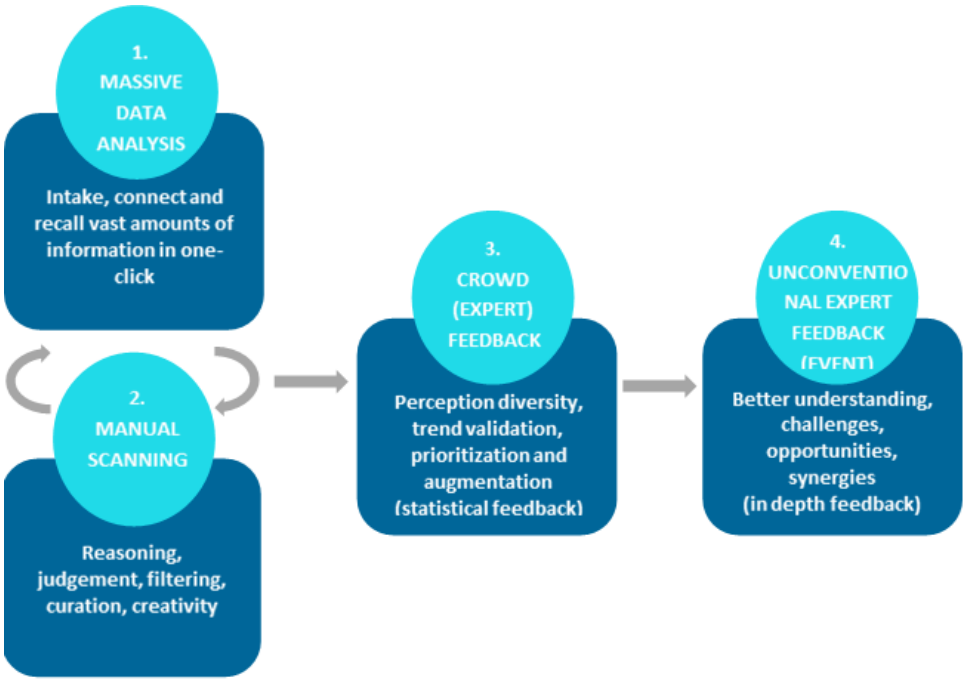

Figure 1 Stages and intelligence layers along PREFET Methodology.

This way, PREFET addresses relevant shortcomings of technology foresight in recent history, and provides a manner to improve by integrating quantitative and qualitative methods enriched at community level. Furthermore, it tackles the significant challenge related to the fact that newly developed data & text mining tools cannot account for all types of open data (primarily because in many cases open data is not machine reusable or machine-friendly[5]). Hence, there is a significant need for manual input and curation.

The importance of manual human curation and pre-scouting at defining data sources has been established, among others, in H2020 project OBSERVE[6]. PREFET takes this

approach one step further to be permeable to human curation during quantitative analysis with the software tools proposed (AI layer), and developing it in a cyclic manner.

PREFET took an iterative cycle approach between desktop research and massive data analysis via data mining of multiple heterogeneous data sources (Figure 2). The following list of parameters was considered for listing "signals of seeds" for future and emerging technologies:

- Appearance of signals on the same topic in different geographic locations;
- Appearance of signals in different industries;
- Appearance of signals in different research groups (academic or industrial);
- Appearance of signals in basic research tasks forces, as opposed to applied research (academic or industrial);
- Detection of similarities (more than one) from public or private funding to future and emerging technologies;
- Nature of the technology requiring multidisciplinarity, and/or teams from multiple research fields effectively engaged in the generation of the signals.

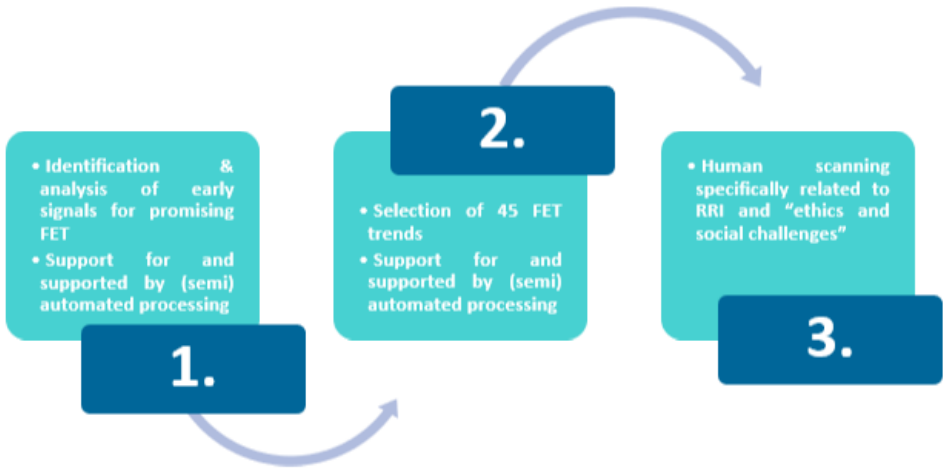

Figure 2 PREFET manual scanning activities.

These parameters are qualitative, and hence have not been quantified. In fact, it is important to note that a few exceptional trends were included without fulfilling all of these factors to favour the variety in their nature (e.g. weak signals may have not have time to appear in other countries, groups, industries, etc., but the topic shows a promise, and this promise may or may not be validated by the other knowledge layers along PREFET Methodology). For example, 'Photoacoustics in Communication' has few weak signals, as it is ground-breaking research done in specific groups in just one institution. However, it was picked up by press and specialised journals crossing borders in terms of visibility, echo and citations. This example of "outlier" does not translate into an issue, as the methodology validates these trends in subsequent layers of knowledge.

These "signals of seeds" were then informed and labelled by using massive data analysis through an AI-augmented process (Figure 3). As a result, they grew into what were called "pre-validated trends", in total 45 belonging to three main areas[7]:

1. ICT for an interconnected society;
2. Biotechnology and Health Sciences;
3. Environment, Energy and Climate Change.

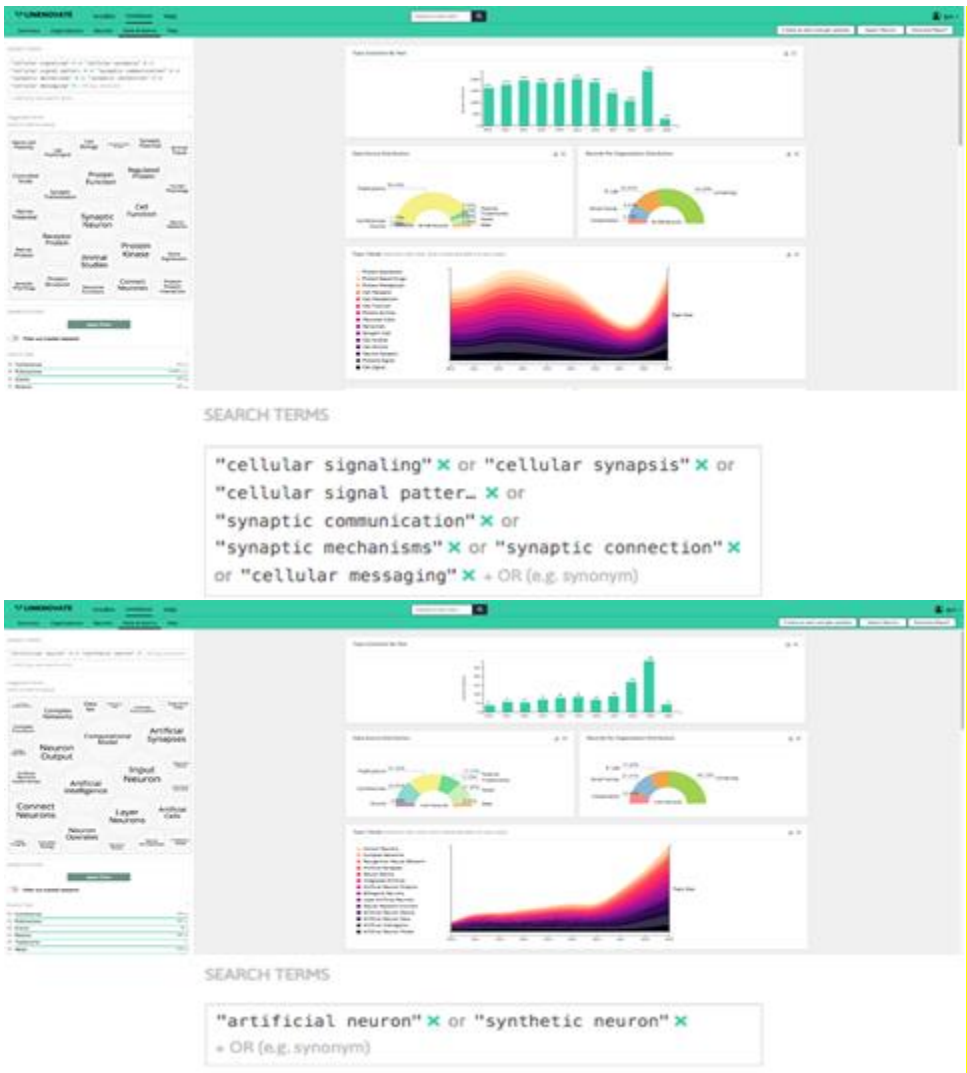

Figure 3 Informing queries with Linknovate.com (e.g. Cellular Signaling and Artificial neuron).

The 45 pre-validated trends were refined by mapping them with UN's 2030 Sustainable Development Goals (SDGs), in order to leverage a responsible research and innovation perspective/assessment on them (RRI). After this work, the list of trends was opened to an online (trend) consultation in which thousands of researchers in ICT, Health Sciences, Biotechnology and Environmental Sciences participated by voting and giving feedback on missing and complementary perspectives. This process was enriched with a series of surveys around the trends to artists, architects and designers. They all came together in

November 2019 in Madrid to celebrate the Trendington Event, a workshop convening researchers and other stakeholders around prioritised long-term technology trends with potential impact over SDGs and the need for the RRI oversight. As a result, a final list of "Top 20 Future and Emerging Trends" was released.

For the Trendington event, a special participatory methodology was implemented in order to integrate feedback from participants on the go, make it specific, relevant and processable, and to allow identifying opportunities for vertical and horizontal merges amongst trends into "multidisciplinary ideation play-grounds" where creativity for the definition of long-term / high-impact / disruptive projects could be leveraged through a series of experiments.

4 Top 20 trends in Future and Emerging Technologies

The final result from PREFET Methodology was a list of top 20 trends with major potential for growth and impact from 2020 towards 2025 (Figure 4).

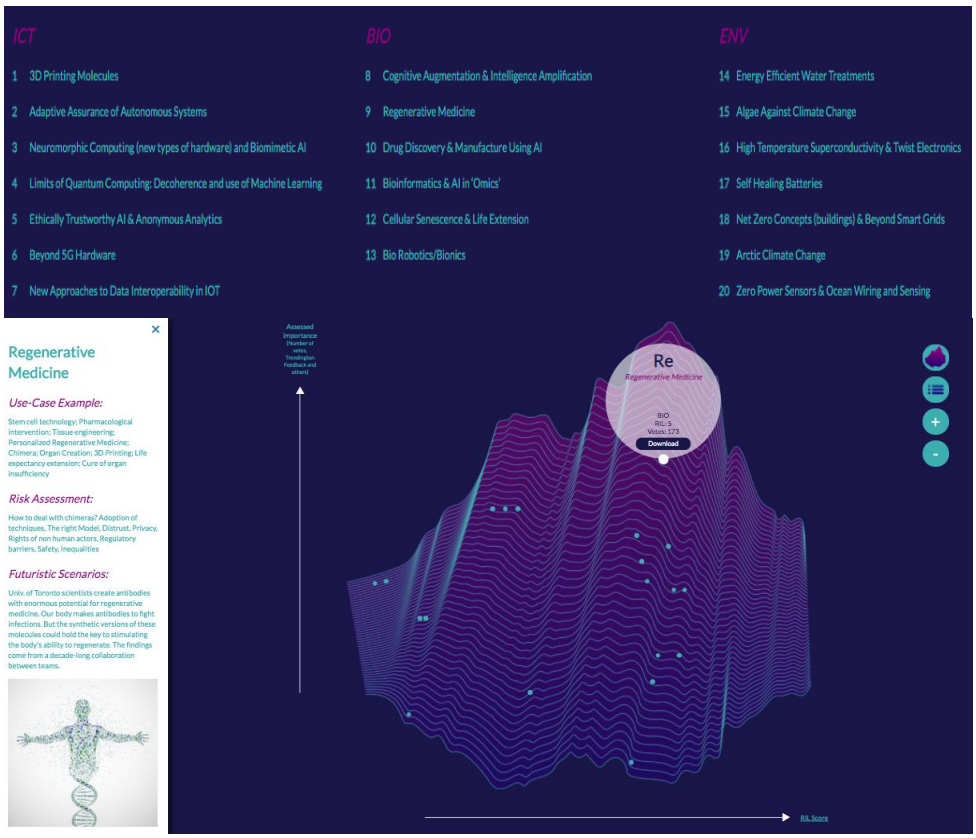

Figure 4 PREFET's list of Teo 20 Future and Emerging Technologies[8].

Some main topics in this list are described as added value examples. Additionally, in the context of COVID-19 crisis, a recent and preliminary exploration has been carried out to start assessing if and how these trends could play a role in relation to increasing the

understanding and improving management of this disease, from the multiple perspective of its transmission, epidemiology, immunology, diagnosis, prognosis, treatment and prevention.

Neuromorphic Computing & Biomimetic AI

Artificial Intelligence (AI) is strongly influencing how societies work, changing the way manufacturing, economics, governance and human relationships occur, and how cities and fundamental services are implemented (e.g. health). Although we are still at the tip of this iceberg, it is already envisioned how a new generation of AI is meant to go much further, and change humanity itself and the world we live at, opening the door for a new era. The challenge is to convert **ultra-high performance, ultra-low-power systems** into a reality, so that we can:

- Improve computational efficiency while lowering power consumption and computing complexity: towards achieving processing power similar to human brain at the neural level with equivalent requirements for functional power.
- Reduce training times: the vision of real-time machine learning and self-adaptive autonomous systems.

Nature offers us unique inspiration to achieve this goal, and great opportunities could be created from researching **blends** between Neuromorphic Computing and Biomimetic AI. The animal kingdom runs hyper-efficiently under low power, reduced learning paradigms that could leverage the potential for synaptic computing. Animal communication could also create new horizons towards ubiquitous intensive communication. Some existing lines of research believe that insect brains might hold the secret to next-generation AI, but we need the next generation of neuromorphic computing hardware to make it possible.

The scope of application grounds could be enormous, such as in unmanned aircraft or robotic ground systems with a more refined perception of the environment, at a much smaller scale and lighter; new smart devices and sensors for humans and the Environment (e.g. oceans preservation); new paradigms of Virtual Reality (VR) and ubiquitous Communication; the idea of "digital back up" for brain memories in Health; etc.

There is already emerging top-level activity in this area in Europe, mainly within research institutions, although strongly lagging behind in terms of entrepreneurial momentum and the engagement of the main industries to be impacted (health, EdTech, telco communication, transport, smart cities, etc.), as well as in adoption areas where Europe leads the world (Environment).

Hardware seems to be the category inside Neuromorphic Computing poised for disruption and with higher impact (e.g. synaptic supercomputer or microscale biomimetic robust AI networks), together with cybernetic fuse with AIs (new control and communication systems between the animal and machine kingdoms).

In relation to aspects in which this trend could be applied to contribute to **COVID-19** management, or where it is already showing potential lines of development towards this aim, new Neuromorphic Computing and ultra-efficient Biomimetic computing power, and specifically AI computing power, will enable new Edge capabilities for vision, audio and smart transducer applications that can increase applications for massive population testing. For example: artificial vision in super accurate temperature measurements, audio

super early symptom detection or increase diagnosis of existing respiratory symptoms, and even smell. Triage of patients could also benefit from this trend.

Regenerative Medicine

Regenerative medicine focuses in the process of replacing, engineering or regenerating human or animal cells, tissues or organs to restore or establish normal function. There are substantially three approaches to this purpose: gene therapy, cell-based therapy, and tissue/organ engineering. A lot of research happening in the area focuses into specific diseases (e.g. diabetes and chronic pain). It is time to explore new, more horizontal horizons such as growth factors, degradable prosthesis replaced by human tissues, synthetic antibodies and how to stimulate the body's ability to regenerate.

Ground-breaking areas are human **life extension** (and the less explored cryonics and transhumanism), and **cellular senescence** (senolytic compounds that can curb aging by regulating senescent cells).

The concept of **Personalized Regenerative Medicine** needs to be reinforced. It would also be worth exploring blends among new advanced therapies as well as with pharmacological intervention.

A specific open challenge is the possibility of surveillance of multiple BIO trends (e.g. not only data of a patient, but also of his/her family, life-long clinical trials, new types of ethically approved animal-model tests, etc).

In relation to aspects in which this trend could be applied to contribute to **COVID-19** management, or where it is already showing potential lines of development towards this aim, several academic research centres and therapeutic developers have announced that they are investigating the application of regenerative medicine technologies to treat this disease in the short term and address related complications in the future. Approaches may include therapies intended to promote immune response and manage inflammatory responses in patients with the disease, as well as approaches to repair tissues damaged by the disease in the long-term.

Bioinformatics and AI in 'Omics'

In the last years, preventive medicine has gained strength in European society and was even deemed the single most important breakthrough area of the 20th century in healthcare. Focusing on the health of individuals and communities, the goal of preventive medicine is to promote health and well-being and prevent disease, disability and death. However, for this to really work, it is needed that the so-called "Predictive medicine" develops further and faster. This is a branch of medicine that aims to identify patients at risk of developing a disease at some point of life, thereby enabling either prevention or early treatment of that disease in order to significantly decrease its impact, with measures really personalized to the risks borne by each individual, increasing their efficiency with lower impact over other aspects of well-being.

Bioinformatics and AI in 'Omics' (e.g. genomics, proteomics or metabolomics) will allow making decisions about care, what an organism might be susceptible to in the future, or what mutations might cause different diseases and how to prepare for it.

Bioinformatics help advance gene sequencing as well as gene editing, a most relevant area of R&D. Furthermore, Bioinformatics could create disruptive additional opportunities such as the potential to develop data-driven models of "bio-assets" (e.g.

proteins). New horizons could be created at all levels if research efforts were to be leveraged in applying new paradigms in machine learning technology, computing and AI ("making sense of data").

It is also crucial to search for the integration of various data layers, and to pave the way towards universal and open interoperable standards.

Finally, the idea of 'Exposome' could be addressed; that is, measuring the complex exposures we face as humans and their impact on our health (chemicals in our environment, diet, our lifestyles and our behaviours as well as behaviours around us).

Projects in this area could also assess the risk of 'Infobesity'; that is, information overload of systems, professionals and citizens (e.g. how much do we really want to know and when in life; designer babies, and others).

In relation to aspects in which this trend could be applied to contribute to **COVID-19** management, or where it is already showing potential lines of development towards this aim, the genome sequencing of the coronavirus can provide clues regarding how it has evolved, combining genomic and epidemiologic data can help to address questions about the transmission and evolutionary dynamics of COVID-19, to identify genomic and other biological factors of patient susceptibility, and to better understand immune responses.

Algae against Climate Change

Growing algae farms with CO_2 captured from factories' emissions and the atmosphere are raising the interest in developing new paradigms around this opportunity. Resulting algae can produce electricity and act as an energy vector (equivalent to energy storage), capture environmental carbon oxides, and simultaneously serve as an alternative source of protein for humans and animals. All with a "by-product", which is reducing crops lands (1ha of algae ponds can generate 27 times as much protein as 1 ha of soybeans), deforestation, and CO_2 emissions, and therefore, increasing sustainability of societies and regions. Algae also thrive in dry, warm areas not-suitable for other organisms. Apart from a potential gigantic impact in farming and agriculture, it can also benefit industries (oil, chemistry and food) and, if new horizons are open, have an impact into urbanism and cities (e.g. district heating).

However, although R&I using algae for combating Climate Change has dramatically increased in the last two years, the same trend is not yet mirrored in public funding open calls and projects. Most active organizations and research focus on growing algae ponds to produce biofuels. Most recent trends also explore turning algae into an alternative source of protein (spirulina) or materials (carbon fibre).

Additional opportunities can be created from extending the scope of R&I efforts to also tackle (micro)biome around us, and its impact over our health. This strategy can be enriched by designing indoor (micro)biomes and involving architects to shape and modify biological communities within homes and office buildings. This is related to aspects in which this trend could be applied to contribute to COVID-19 management, or where it is already showing potential lines of development.

High-temperature superconductivity & Twist electronics

If it could be achieved, so-called room-temperature superconductivity, above 0 degrees Celsius, would revolutionise electrical efficiency, vastly improving power grids, high-speed data transfer, and electrical motors, to name a few potential applications. Just as an

example, superconduction from graphene plates can be a gamechanger in the energy industry or energy-powered infrastructure.

High-Temperature Superconductors could be used to levitate trains and produce astonishing accelerations, also in power plants, replacing conventional methods which spin turbines in magnetic fields to generate electricity; and in quantum computers as the two-level system required for a "qubit," in which the zeros and ones are replaced by current flowing clockwise or counter clockwise in a superconductor.

4 Creativity experiments

PREFET has entered into a second stage, aiming at inspiring and supporting the generation of project ideas in order to explore and develop specific technologies within these trends.

For this purpose, the project is organising a series of 'creativity online workshops' during which participants will be guided and animated to work jointly on a 'project idea canvas' related to a 'context canvas' which is prepared using PREFET information about most relevant trends on future and emerging technologies (Figure 5). Afterwards, results will be shared with participants and "idea owners" will be invited to online training offered from PREFET's website, and the IdeAcademy Week.

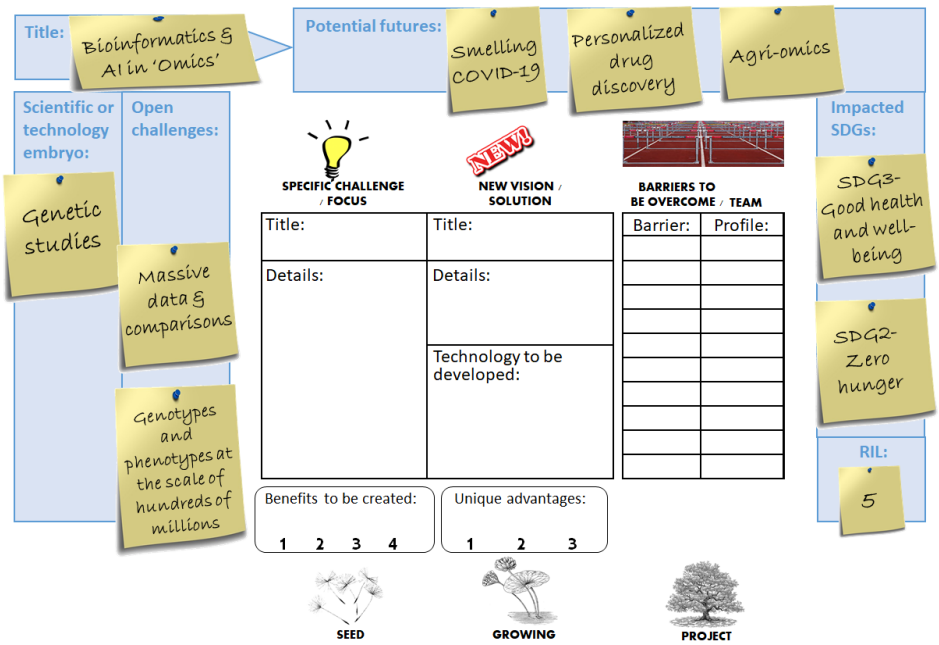

Figure 5 PREFET project idea canvas (with an example 'context canvas' for the trend 'Bioinformatics & AI in 'Omics'', in blue background).

The IdeAcademy Week will happen from the 26th to the 29th of October 2020, as an event mixing visibility and networking activities, added value training, dissemination of PREFET Trends and communication about strategic opportunities for funding R&D (mainly in relation to the next European framework programme, Horizon Europe).

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5 Conclusions

- PREFET addresses relevant shortcomings of technology foresight by integrating quantitative and qualitative methods enriched at community level, and iterating between (manual, human-based) desktop research and the use of AI software for data mining and text mining over large volumes of data and sources.
- Furthermore, it tackles the significant challenge related to the fact that newly developed data & text mining tools cannot account for all types of open data, and considers human curation during quantitative analysis with the software tools proposed in a cyclic manner.
- PREFET also acknowledges foresight methods need to count in some phase of their methodology with expert input. It semi-automatizes this step by opening pre-validated trends to massive targeted (expert) consultations, in what became known as Open Trend Consultations (OTC), again enabled by software tools.
- Multiple video channels, specialised news, or even open-horizon R&D grants seemed relevant, but had to be discarded after analyst consideration (human intelligence layer played an important role at filtering sources). For example, video channels from museums speaking about the future were initially classified as relevant for exploring signals for future disruptive technologies, but turned out they were serving the purpose of the creator/exhibitor and therefore too limited to certain topics (e.g. for an event, an anniversary, newsworthy temporary events in society, science or technology, etc.). Multiple specialised news outlets with titles referencing future forecasting also turned out to serve media purpose for immediacy. Even some grants with programmes whose titles referenced disruption, were limited in topic selection and focus on a short-term technology evolution (e.g. Internet of Things, cybersecurity, and similar). This constitutes another reason why PREFET envisioned manual scanning as necessary. Nonetheless, the consortium feels that this is the part of the methodology for trend identification and validation with more room for improvement. As a result, it would translate into a bigger automation for technology foresight, time saving and considerable human resources reduction. As a consortium we believe open data, FAIR policy and open science movements will play a critical role in this regard.
- On the one hand, engaging scientific and technology experts was valuable:
    - Horizontal engagement (in terms of volume and statistical representativeness), through an open trend consultation managed online and announced via email individually to relevant experts previously identified. It allowed validating and raking trends, and in some cases, obtaining specific details to enrich information and trend description. During PREFET, more than 2,000 researchers participated in this exercise.
    - Vertically, through in-depth joint discussion with groups of interdisciplinary experts of a limited number, over 1 full day (Trendington event). It allowed detecting synergies among trends and opportunities for merging, obtaining information to enrich the descriptions of trends, complementing the assessment of Responsible Research and Innovation issues, and completing the ranking and prioritization exercise.

- On the other hand, involving also designers, artists and architects into the consultation and discussion created some interesting opportunities for increasing creativity and detecting relevant societal issues around the trends. However, it is important to prepare ad-hoc consultation mechanisms, and play an intermediation role between them and the trends, and also with researchers.
- Final trends show great potential as "play-grounds" where researchers can dream of new disruptive project ideas for a better future. However, again ad-hoc channels and instruments need to be designed and implemented to actively promote this creativity and potential for impact.
- They have also raised a relevant interest from policymakers in charge of defining future funding programmes focused into early-stage research and technology development with great potential for impact at technical and social levels.

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