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ANTICIPATECH

Scenario Game
using technological trends and megatrends

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Purpose and goals

Inspire, Inform, Instruct for Impact: Launched in 2013, the technology foresight research program of armasuisse Science and Technology has since explored numerous themes and methodologies, staying true to this motto.

In a world of rapid and chaotic change where technology plays an important role, we felt the need to create a foresight ecosystem from which we could structure and organise debates and exchanges between our different stakeholders.

The ecosystem consists of content referred to unsurprisingly as "trends" and of different methodologies and how to use them. If definitions and descriptions are important, the emphasis here is placed on the dissemination of the information and how private persons and organisations can adopt it, and use it as preparation for their individual purposes.

The 11 technology trends you find in this document are therefore the same as those used internally within armasuisse to structure our research. Out of the original 12, we have omitted the "New Weapons" trend, as it was considered to be too specific. Their descriptions are by default incomplete, but provide the necessary understanding to work with them creatively.

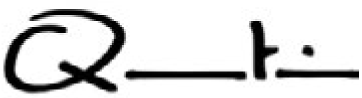
As technology does not develop in a vacuum, we have captured the main tensions within society in the 14 megatrends. These allow us to consider different use cases and to challenge them in the given circumstances – in short, to give context to how various potential future innovations could represent an opportunity or a threat for an industry or a country.

Of the infinite ways of organising workshops and games, this document contains some of the choices that we made according to the time that you would like or, more often, are able to dedicate to foresight activities. There is never enough time with enough material that you can hack, adapt and tailor to your needs. We intend to get the ball rolling and provide you (and us!) with enough material that we can hack, adapt and tailor to our needs.

Given the context, you may still be asking yourself: "Why opt for such a project with the Bavarian Foresight Institute?". I could answer this question, but I will not with the hope that the quality of what you will find here reflects the competencies, the energy and the enthusiasm we demonstrated while working with the team headed by Prof. Dr Jan Oliver Schwarz.

Enjoy the ride!

Foresightedly yours,



Dr Quentin Ladetto
Head of Technology Foresight
armasuisse Science and Technology

Foreword

While it has existed as a field of practice and research for many decades, foresight is gaining more and more relevance today. The numerous crises, the increasing levels of volatility and the rising uncertainty concerning the future have all emphasized one thing: the future will be very different from today, and in various ways that are hard to imagine today.

While organisations need to be agile in their reactions to constant changes, they need to simultaneously embrace the long term, be it because of long product- or planning cycles or because organisations also need a long-term perspective, i.e. a vision that guides their actions and delivers a sense of purpose.

Accepting that the future is not predictable is a first step towards developing foresight, but more needs to follow. Carrying out research to identify trends is fundamental for foresight, but foremost thinking in scenarios is paramount. Based on the trends that we can observe, we need to explore the possible futures. And this is best done by developing scenarios and alternative pictures of the future.

At the Bavarian Foresight Institute, we know from our work with many different types of organisations that providing well-researched trends is just one side of the coin. The other side of the coin is about involving decision-makers in thinking about the future. Following the paradigm of "understanding vs. consuming", we believe that active engagement with trends and scenarios will help decision-makers to develop foresight-thinking.

In this joint project with armasuisse Science and Technology, we want to embrace these thoughts. We not only provide a collection of relevant technology and megatrends, we also provide an engagement format, the "Scenario Game", that allows us to work with these trends and explore the future, eventually developing foresight.

We hope that you find this journey not only insightful but also enjoyable!

Foresightedly yours,

Prof. Dr Jan Oliver Schwarz
Head of Institute
Bavarian Foresight Institute, Technische Hochschule Ingolstadt

Executive summary

This project explores the following key emerging technologies and their future implications:

1. Data science and AI
2. Immersive technologies
3. Quantum technologies
4. Sensor technologies
5. New space technologies
6. New materials and digital production
7. Renewable energy and resilience
8. Human enhancement technologies
9. Cyber technologies
10. Digital communication
11. Robotic and autonomous systems

The aims of the project are as follows:

1. Expand research on emerging technologies.
2. Assess how these emerging technologies will be interconnected with the wider megatrends in the future.
3. Create an engaging workshop format for leaders of the Swiss Federal Department of Defence, Civil Protection and Sport.

This report discusses the outcome of this project. It is split into three parts.

In the first part, each of the above technological trends is defined and described.
The assumed impacts each trend will have are also presented, while any uncertainties and challenges surrounding a given technological trend are discussed. Some weak signals for the trend are given.

In the second part, a range of key megatrends are defined and discussed in a similar fashion. These are:

1. Aggravating resource scarcity
2. Changing nature of work
3. Changing security paradigm
4. Climate change and environmental degradation
5. Continuing urbanisation
6. Diversification of education and learning
7. Widening inequalities
8. Expanding influence of East and South
9. Growing consumption
10. Increasing demographic imbalances
11. Increasing influence of new governing systems
12. Increasing significance of migration
13. Shifting health challenges
14. Diversity-aware society

In the third part, the "Scenario Game" was developed to explore the dynamics of the above technological trends in a collaborative environment.
The concept of the "Scenario Game" is introduced and described, and instructions for its execution are provided. The game can be used as an interactive and fast method for collaboratively working on assessing the implications of these technology trends for a given industry, focus or organisation.

The detailed information on the key technology trends and megatrends, as well as the "Scenario Game", can serve as valuable resources for any expert or organisation to assess the future impact of these key trends quickly and interactively.

1 Introduction

Today, organisations face a more complex and dynamic environment than ever before, one that is characterised by discontinuation and an uncertain future – a situation that is most likely to persist. The major task for managers today is to make decisions, and then formulate and execute strategic management systems in the respective environment.

Organisations are faced with a VUCA (Volatile, Uncertain, Complex and Ambiguous) environment. One way of observing VUCA is to pay attention to the trends and issues in the environment of an organisation. Trends in the socio-political, socio-cultural, environmental, economic and technological environments may represent drivers of change in the future that are critical to strategy formulation. In addition, a firm's resources and competences may need to be re-evaluated due to emerging trends and issues. In this context, organisations need to develop foresight to compete and be a viable part of the future.

Strategic foresight can be defined as identifying, observing and interpreting factors that induce change, determining possible organisation-specific implications and triggering the appropriate organisational responses. It involves multiple stakeholders and creates value through providing access to critical resources ahead of competition, preparing the organisation for change and permitting the organisation to steer proactively towards a desired future [Rohrbeck et al, 2015]. Tools typically used in strategic foresight include scenario planning, trends and weak signals, the Delphi method, and business wargaming.

The overall goal of this study is to explore a range of key emerging technologies and their future implications. These technological trends are:

1. Data science and AI
2. Immersive technologies
3. Quantum technologies
4. Sensor technologies
5. New space technologies
6. New materials and digital production
7. Renewable energy and resilience
8. Human enhancement technologies
9. Cyber technologies
10. Digital communication
11. Robotic and autonomous systems

The aims of the project can be then broken down as follows:

1. Expand research on emerging technologies.
2. Assess how these emerging technologies will be interconnected with the wider megatrends in the future.
3. Create an engaging workshop format for leaders of the Swiss Federal Department of Defence, Civil Protection and Sport.

The above technological trends do not exist in isolation but evolve within a wider context. To explore the interactions between these technological trends and this context, a set of key megatrends was derived from the European Commission knowledge base. Megatrends are long-term driving forces that are observable now and will most likely have a significant influence on the future. The megatrends considered most relevant in the context of this project are :

1. Aggravating resource scarcity
2. Changing nature of work
3. Changing security paradigm
4. Climate change and environmental degradation
5. Continuing urbanisation
6. Diversification of education and learning
7. Widening inequalities
8. Expanding influence of East and South
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The structure of the project and the process of the work are shown in Figure 3. In this project, we first performed research on the twelve technological trends and the fourteen megatrends. The results of this research are provided in Chapters 2 and 3. The interactions and interdependencies between these technological trends and megatrends were assessed by means of a cross-impact analysis. The results of this analysis are provided in Chapter 4. We subsequently designed a Scenario Game workshop. All of the relevant concepts and materials for the Scenario Game as well as instructions for how to execute it are provided in Chapter 5. The main results, observations and conclusion of this work are discussed in Chapter 6.

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2 Technological trends

As a first step, research was carried out on the technological trends. The purpose of this was to provide the necessary understanding for each trend so that it can be used in the Scenario Game in an inspirational manner.
Each chapter follows a defined format. The different sections are defined here.

General description:
This section includes a definition of the trend to ensure transparency in further discussions. One or more frameworks are used to further define the scope of the trend. Finally, an explanation is provided on how the trend is changing and what is driving the change.

Impact and the main uncertainties and challenges:
First, the discussion is structured along three levels: which high-level functions the trend fulfils, how could these functions improve in the future and what applications and use cases could these improvements enable or improve. This discussion is set out in the form of a table.
A second discussion regarding impact follows the STEEP framework, a tool for assessing how Social, Technological, Economic, Environmental and Political external factors affect a given topic. This discussion focuses on the main uncertainties associated with this trend concerning its further development, consideration of the possible directions the trend could develop in, as well as the challenges that might hinder the further development of the trend.

Weak signals:
A weak signal is the first indicator of a change or an emerging issue that may become significant in the future. Weak signals for each trend were collected from the Trend Manager-curated database created and maintained by Trendone. The date of access to this database is set out in the "References and further reading" entry of the report for each technological trend.

Interactions between trends and megatrends:
First of all, initial and non-exhaustive indications of interactions with other technological trends and megatrends are discussed in this section. This section serves as a basis for a more detailed cross-impact analysis based on the method presented in Chapter 4 in a workshop setting.
The subsequent sections present the reports for each technology trend.

2.1 DATA SCIENCE AND AI

HARNESSING THE POWER OF DATA TO EMULATE AND SUPPLEMENT HUMAN INTELLIGENCE

DESCRIPTION:

Big data describes data that presents significant volume, velocity, variety, veracity and visualisation challenges. Increased digitisation, a proliferation of new sensors, new communication methods, the internet of things (IoT) and the virtualisation of socio-cognitive spaces (e.g. social media) have contributed significantly to the development of big data. **Advanced (data) analytics** describes advanced analytical methods for making sense of and visualising large volumes of information. These techniques draw from research such as artificial intelligence, optimisation, modelling and simulation, etc. **Artificial Intelligence (AI)** refers to the ability of machines to perform tasks that normally require human intelligence – for example, recognising patterns, learning from experience, drawing conclusions, making predictions and taking action.

Data science is a process that, simply put, generates insights and predictions from data. **Data analytics** methods can then be used to extract output such as insights, classifications and predictions. The need for data science stems from our increasingly digital and virtual world, and the subsequent need to make sense of the resulting avalanche of information.

The essential challenge faced by analytics is how to make sense of large amounts of non-homogeneous data that are generated too quickly, and that are of potentially dubious authenticity and accuracy. These challenges are also known as the 5V's (volume, velocity, variety, veracity and visualisation).

Artificial intelligence has moved through three development cycles. The initial period focused on rules-based approaches (expert-based decision trees, Boolean and fuzzy logic), e.g. expert systems. The second cycle focused on the development and application of statistical methods (i.e. supervised, unsupervised and reinforcement learning). Such machine learning methods have been highly successful and underlie everything from e-mail spam filtering to internet web searches. The third cycle of development focuses on the use of bio-inspired learning methods (neural networks[1], deep learning), with considerable success in the areas of sensing and perception.

Most concrete definitions of artificial intelligence fall into one of four categories; these categories represent approaches that take distinct positions on two conceptual dimensions:

- Whether it emphasises the attainment of specific "intelligent" or "sentient" thought processes (T) and reasoning, or whether it emphasises "goal-oriented"; "effective" behaviour (B);
- Whether it measures success against human performance (H) or against an ideal concept of intelligence – usually defined as "rationality" (R);

The four categories of artificial intelligence definitions can then be categorised as:

- (T-H) Systems that think like humans (e.g. cognitive science),
- (T-R) Systems that think rationally,
- (B-H) Systems that act like humans, and
- (B-R) Systems that act rationally.

From a practical perspective, the focus tends to be on the way artificially intelligent systems manage to act in the world. These are known as behaviour-focused (B) approaches.

Artificial intelligence functions can be broken down into two high-level categories:

- **Parsing inputs**, which deals with issues of perception, computer vision, natural language processing, and taking appropriate cues from social intelligence; and
- **Planning and executing outputs** ("behaviour"), which involves appropriate processes for knowledge representation, prioritisation and planning. For systems with physical forms, like robots, this involves moving, avoiding collisions and controlling arms or other parts.

Machine learning (ML) has been the subfield that is most responsible for the recent advances in artificial intelligence. Machine learning aims to create systems (i.e. algorithms) able to automatically learn the relationship between input data and the classifications or actions you want to happen without being explicitly programmed. There are three main approaches in this field:

- **Unsupervised learning** is defined as learning solutions (known as models) that are not overseen (or supervised) by data labelled or tagged by someone. An example application would be detecting unusual patterns (e.g. markers of fraud) in financial transactions.
- **Supervised learning** refers to the family of approaches in which the learning is overseen by the label examples or the output of the data. The machine is given examples or training data (labelled data) and is able to learn a function that maps the input of the training data to some output[2]. An example application would be image recognition, for example distinguishing between cats and dogs. Intermediate semi-supervised approaches exist between this and the above approach.
- **Reinforcement learning** is about learning the optimal behaviour in a specific environment to obtain the maximum reward. This optimal behaviour is learned through interactions with the environment and observations of how it responds. An example would be self-driving cars, which learn by trial and error.

Over the coming years and decades, data volumes will continue to grow, as the number of handheld and online devices grows exponentially and the internet of things becomes a reality. The sheer volume of data that this will create is difficult to comprehend. Future avenues for analytics and advanced computational techniques for data processing and fusion include increasingly capable methods from artificial intelligence, specifically machine learning, as discussed above.

A logical sequence along which progress on AI will unfold can be separated into three tiers:

- **Artificial Narrow Intelligence** (ANI or "narrow AI"): machine intelligence that equals or exceeds human intelligence for specific tasks such as chess, high-frequency trading or indeed any specialised automatic systems delivering performances beyond human reach;
- **Artificial General Intelligence** (AGI or "strong AI"): machine intelligence meeting the full range of human performance across any task; and:
- **Artificial Superintelligence** (ASI): machine intelligence that exceeds human intelligence across any task.

Data science is driven by the increasing digitisation of almost all aspects of how we work and live, aided by massive commercial investments, as well as the availability of publicly available training data sets and tools for algorithm development and testing. The move to cloud platforms has facilitated a massively accelerated improvement in data availability and data access.

Developments in artificial intelligence are driven by very strong commercial investments, given the recent rapid advances in the field.

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[1] An interesting type of neural network that is being used widely at the time of writing is the transformer model. The transformer model learns context and thus meaning by tracking relationships in sequential data like the words in this sentence.

[2] An interesting sub-class is zero-shot learning, few-shot learning and one-shot learning. These are all techniques that allow a machine learning model to make predictions or classifications with limited labelled data. The choice of technique depends on the specific problem and the amount of labelled data available for new categories or labels (classes).

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IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

In the table below, we summarise which functions are generally provided by the use of data science and artificial intelligence, which impact metrics for these functions are expected to improve and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF DATA SCIENCE & AI	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
DATA SCIENCE	IMPROVEMENTS E.G. IN: • DESCRIPTIVE CAPABILITIES. • PREDICTIVE CAPABILITIES.	• PREDICTION OF EXTREME WEATHER EVENTS. • PREDICTION OF CONFLICTS
AI - PARSING INPUTS	IMPROVEMENTS E.G. IN: • PERCEPTION. • NATURAL LANGUAGE PROCESSING. • TAKING CUES FROM SOCIAL INTELLIGENCE.	• PROCESSING AND UNDERSTANDING OF TEXT. • GESTURE MEANING RECOGNITION.
AI - PLANNING & EXECUTING OUTPUTS	IMPROVEMENTS E.G. IN: • KNOWLEDGE REPRESENTATION. • PRIORITISATION. • PLANNING.	• PLANNING AND SCHEDULING FOR LOGISTICS. • ASSISTED DECISION-MAKING, E.G. IN BATTLE.

Below, we will discuss the impact and the main uncertainties and challenges of data science and artificial intelligence for each category:

— SOCIO-CULTURAL:

- **Impact:** Data science and artificial intelligence have the potential to reshape labour markets and employment patterns. Although they create new job opportunities in technology sectors, they also cause displacement and changes in job requirements in other sectors. Data-driven algorithms can perpetuate biases present in historical data, leading to discriminatory outcomes. The integration of artificial intelligence into daily life (e.g. chatbots, virtual assistants) affects human-computer interactions and social dynamics.
- **Main uncertainties and challenges:** How will the benefits of artificial intelligence adoption be distributed across society? How will trust and acceptance of artificial intelligence technologies influence their adoption? How can artificial intelligence be applied ethically? How can users of AI be trained to be critical of AI output?

— TECHNOLOGICAL:

- **Impact:** Data science and artificial intelligence will have a significant impact on almost all sectors, providing improvements along the value chain. Embedding data science and artificial intelligence into engineering, operations and business workflows can reinvent product development and use.
- **Main uncertainties and challenges:** How can the data used for training artificial intelligence be improved? How will explainable artificial intelligence be further developed? How will the scalability and performance of artificial intelligence develop with increasing data volumes and model complexities? How will the energy efficiency of AI algorithms develop?

— ECONOMIC:

- **Impact:** Data science and artificial intelligence can have a groundbreaking economic impact. This can be due to productivity gains resulting from the automation of routine tasks, augmenting employees' capabilities and freeing them up to focus on more stimulating and higher value-adding work. Capital-intensive sectors such as manufacturing and transport are likely to see the largest productivity gains. Shifts in consumer demand, behaviour and consumption emanating from artificial intelligence are also important. Consumers will be attracted to higher levels of quality and more personalised products and services, but will also have the chance to make better use of their time.
- **Main uncertainties and challenges:** What will be the net effect of artificial intelligence on employment? Which sectors will be affected most? Will there be market concentration and reduced competition due to the dominance of large tech companies in artificial intelligence research and development?

— ENVIRONMENTAL:

- **Impact:** Data science and artificial intelligence can have both positive and negative environmental impacts. The data centres needed for AI and data science applications consume significant amounts of energy and the production of hardware components such as servers, GPUs and specialised chips requires natural resources and generates waste. Data science and artificial intelligence can also be used to address environmental challenges, facilitate climate modelling and even enable predictive models, for example for predicting natural catastrophes.
- **Main uncertainties and challenges:** How will the energy efficiency of the data centres and computing infrastructure used for training artificial intelligence evolve?

— (GEO)POLITICAL, REGULATORY:

- **Impact:** The proliferation of data collection and analysis raises concerns about privacy and surveillance. Artificial intelligence- and data-driven technologies often rely on personal data, leading to debates about the balance between individual privacy rights and societal benefits. Advanced artificial intelligence is often seen as high risk or even an existential threat to humanity. Efforts to effectively regulate it will be necessary.
- **Main uncertainties and challenges:** What is the best way of addressing concerns about data ownership, usage rights and compensation mechanisms? How can disputes over intellectual property rights related to artificial intelligence technologies be resolved? How can fake information generated by artificial intelligence be dealt with?

WEAK SIGNALS:

› **MIT** researchers have introduced technology that enables deep learning model training on edge devices like mobile phones, achieving up to 15-times faster training times on some hardware platforms without compromising accuracy.
› Researchers at the **Chinese Academy of Sciences** are utilising AI to accurately recognise and classify social behaviour in animals. This technology can identify an individual from several almost identical-looking animals and works across species.
› **South Dakota** State University researchers have pioneered AI-based model predicting share price movements and volatility.
› **Portcast**, a logistics start-up, has devised a predictive analytics solution that utilises data from various sources to cut freight costs by optimising transport routes and taking into consideration factors such as weather, tides and wind speed.
› **Google Deep Mind** is developing an artificial intelligence model to design millions of new materials for various applications.

INTERACTIONS WITH OTHER TRENDS:

› **Robotic** and autonomous systems: The increased use of intelligent, widely distributed, ubiquitous, cheap, interconnected sensors and autonomous entities (physical or virtual) will lead to large volumes of data. Data science and artificial intelligence methods can both take advantage of this wealth of data and also enable its analysis.

› **Immersive technologies:** Data science and artificial intelligence will play a significant role in the development of immersive technologies. Furthermore, the latter will be another source of rich data to assist in the further development of the former.

› **Quantum technologies:** Quantum computing can be used in the longer term to train new, more capable, quantum artificial intelligence algorithms.

› **Sensor technologies:** The miniaturisation and distribution of sensors in all aspects of human activity will provide a trove of data for further exploitation and enable digital twins of real objects.

› **New space technologies:** Space-generated data, e.g. from Earth observation, will be a key source of data. Artificial intelligence methods can be used in space applications, e.g. in spacecraft design and operational autonomy.

› **Materials and digital production:** Data science and artificial intelligence are two of the main enablers of novel digital production methods.

› Renewable energy and resilience: Data and artificial intelligence can assist in the deeper study of the climate and in mitigating the effects of climate change.

› **Human enhancement technologies:** Human enhancement technologies will be both provide a large volume of data and also make use of many advanced artificial intelligence methods.

› **Cyber technologies:** Storage and computational capabilities for the rapidly increasing amounts of data in the future will arguably be the main factor in the expansion of cyberspace. Artificial intelligence methods can also be used in advanced cybersecurity applications.

› **Digital communication:** Digital communication will be key in gathering and effectively communicating the growing amounts of data.

INTERACTIONS WITH MEGATRENDS:

› **Changing nature of work:** Data science and artificial intelligence will have a groundbreaking impact on the nature of work, eliminating some jobs while creating others.

› **Changing security paradigm:** Data science and artificial intelligence will become another tool in geopolitical competition.

› **Diversification of education and learning:** Data science and artificial intelligence will provide both significant challenges and also opportunities for future educational systems.

› **Widening inequalities:** Data science and artificial intelligence could drive inequality by replacing increasing amounts of labour with smart machines.

› **Growing consumption:** Data science and artificial intelligence will drive increasing levels of consumption by offering more personalised products and by increasing the free time of consumers.

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2.2

IMMERSIVE TECHNOLOGIES

MERGING THE PHYSICAL AND THE VIRTUAL WORLD TO TRANSFORM EXPERIENCES

DESCRIPTION:

Immersive technologies can enable a deeply engaging, multisensory, digital experience. **Augmented reality (AR)** overlays digitally created content on the user's real-world environment. **Virtual reality (VR)** creates a fully rendered digital environment that replaces the user's real-world environment. **Mixed reality (MR)** seamlessly blends the user's real-world environment with digitally created content in a way that allows both environments to coexist and interact. Extended reality (XR) is an umbrella term that encompasses AR, VR and MR.
Examples of augmented technology devices include projections from phone devices, windshields on cars, and glasses. Examples of virtual reality technology devices include headsets for a fully immersive virtual reality experience.

Immersive technologies depend on the following key components:

- **On-body sensors** track and identify users and their limb movements, as well as the objects around them.
- **Off-body sensors** allow for more precise recreation of elements of the physical world in virtual spaces.
- **Haptic devices** convey the sense of touch to the user with vibrations to augment virtual experiences.
- **Holograms and volumetric video** diffract light across multiple wavefronts to display high-quality 3D representations that can be seen without using a headset.
- **Electromyography** is a neurotechnology that detects and records electrical activity from muscles to control movement and manipulates objects in virtual spaces.
- **Microelectromechanical systems (MEMS)** use midair ultrasonic waves to allow users to physically feel tactile experiences without any wearables.

Applications of immersive technologies can be broadly categorised as follows:

- **Product design and development:** Digital reality can offer knowledge workers access to specific information at the exact moment they need it and at any stage of the design and development lifecycle. For example, by wearing augmented reality glasses, construction engineers can see a detailed description of a project's electrical and plumbing parts on-site.

- **Collaboration and cooperation:** Immersive technologies can make it possible for workers to engage with, share information with, and support colleagues in other locations. For example, engineers sitting in a regional office will be able to see what field workers see.
- **Learning and training:** Immersive technologies can place trainees in lifelike situations that would be too expensive or logistically impossible to recreate in real life. Variations include treating psychological issues such as post-traumatic stress disorder and phobias.
- **Enhanced consumer experience:** Use cases of immersive technologies are emerging across the retail, travel-hospitality-leisure, and real estate sectors to bring potential customers closer to the respective products, services and experiences.

In the near term, augmented reality could exist mostly as a proof of concept, constrained within narrowly defined environments and only overlaying low-fi visuals over the real world. In the middle term, consumer augmented reality could gain wider adoption and more demanding industrial use cases could be implemented. In the longer term, consumer augmented reality sets shrink and use cases proliferate, with a seamless digital layer acting as an overlay to the real world.

In the near term, virtual reality offers limited virtual worlds and is manipulated using external peripherals that limit immersion. In the medium term, high-fidelity and comfortable virtual reality is available at scale. In the long term, virtual worlds in virtual reality are almost indistinguishable from real life and haptics have improved to give a realistic sense of feeling across the body.

The development of immersive technologies is driven by significant funding from the commercial sector. Further social and technological factors driving this trend include the increased use of smartphones and connected devices, the rising adoption of 5G networks and the need for more collaboration platforms to enable remote work.

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

The table below summarises the functions that are generally provided by the use of immersive technologies, which impact metrics for these functions are expected to improve and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF IMMERSIVE TECHNOLOGIES	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
PRODUCT DESIGN AND DEVELOPMENT	• COST SAVINGS. • INCREASED EFFICIENCY. • NEW METHODS TO ANALYSE DATA AND GENERATE INSIGHTS.	• IMPLEMENTATION FOR THE DESIGN OF A NEW SATELLITE. • DIGITAL TWINS OF PRODUCTS FOR VIRTUAL WALKTHROUGHS.
COLLABORATION AND COOPERATION	• IMPROVED PRODUCTIVITY. • REDUCED RISK. • CROSS-GEOGRAPHIC	• FIELD-WORKER ASSISTANCE. • SHARED VIRTUAL WHITEBOARDS FOR BRAINSTORMING.
LEARNING AND TRAINING	• STRONGER RETENTION OF MATERIALS. • REDUCED RISK. • COST SAVINGS. • IMPROVED THERAPEUTIC OUTCOMES.	• IMMERSIVE SEARCH AND RESCUE TRAINING. • DRIVING LESSONS.
ENHANCED CONSUMER EXPERIENCE	• BETTER CUSTOMER ENGAGEMENT. • INCREASED MARKETING OPPORTUNITIES. • INCREASED SALES	• VIRTUAL CONFERENCES AND EVENTS. • VIRTUAL SHOPPING MALL.

Below, we will discuss the impact and the main uncertainties and challenges of immersive technologies for each category:

— SOCIO-CULTURAL:

- **Impact:** New products and services will be introduced by immersive technologies, engaging consumers in new ways and enhancing customer experiences. For example, immersive technologies might become the leading platform for video streaming, with the attendant impacts on existing platforms. Immersive technologies might affect social interactions, further digitising increasingly larger parts of them.
- **Main uncertainties and challenges:** Will immersive technologies drive the current trend further towards remote work? What will be the

— TECHNOLOGICAL:

- **Impact:** Immersive technologies can increase production efficiency in various ways. Virtual rapid prototyping, for example, can make early-stage design amendments possible. Digital twins can enable virtual walkthroughs of products under development. In general, the production process can be improved through early-warning-detection mechanisms, improved quality assurance, etc. Analytics applied to collected user data can further improve product design.
- **Main uncertainties and challenges:** Will augmented technology ideas remain at the proof-of-concept stage or will they begin to break through to scale? How will complementing technologies (e.g. miniaturisation, ruggedness, sensor advances, data storage, connectivity) that are required to achieve scale effects in immersive technologies evolve? Which applications will achieve wider acceptance and use? How can complex security vulnerabilities (e.g. cyber threats, data protection) be mitigated?

— ECONOMIC:

- **Impact:** Costs can be reduced by effective product development, improved processes and improved training, all enabled by immersive technologies. New products and services can engage consumers in new ways and enhance customer experiences, thus increasing sales and consumption. Analytics applied to user-collected data can also be used to drive advertising.
- **Main uncertainties and challenges:** How can a cost reduction that is required to make more applications commercially viable and scalable be achieved? Are there any feasible business models?

— ENVIRONMENTAL:

- **Impact:** Further advancements in immersive technologies will require a significant amount of computing power to establish the environments. This will have a potentially large impact on energy use and therefore a significant environmental impact.
- **Main uncertainties and challenges:** Will immersive technologies make it to market before energy optimisation takes place? How will the energy efficiency of computing hardware and infrastructure used for immersive technologies evolve?

— (GEO)POLITICAL, REGULATORY:

- **Impact:** Immersive technologies could potentially expand into the political domain and enable more direct and experiential participation. They also have many potential defence applications, for example in training, logistics and on the battlefield.
- **Main uncertainties and challenges:** How will the use of sensitive user data collected by augmented reality devices be regulated? How can novel forms of harm, scams and crime be enabled by augmented realities? To what extent can immersive reality facilitate the spread of false information?

WEAK SIGNALS:

› **Kentucky Fried Chicken** places employees in a virtual escape room where they must successfully complete a five-step chicken preparation process before they are released.

› The startup **Sophia Technologies** aims to establish a metaverse-based "educational city", catering to students globally from grades 1 to 12.

› **Johns Hopkins University** and **NVIDIA** are collaborating on a 3D reconstruction algorithm to reconstruct object shapes from smartphone videos without any additional input, promising applications in virtual reality.

› Researchers at **Virginia Polytechnic Institute** have introduced tools to safeguard bystander privacy in real-time sensor data by employing eye tracking, near-field microphones and spatial awareness.

INTERACTIONS WITH OTHER TRENDS:

› **Data science & AI:** Virtual and augmented reality sets will generate a significant amount of rich data that can be further exploited. AI generative methods could be useful for the generation of virtual objects and worlds in virtual and augmented reality.

› **Quantum technologies:** Quantum technologies could conceivably find a role in immersive technology applications, for example, to ensure data safety via quantum cryptography.

› **Sensor technologies:** Novel, more capable, small, and ubiquitous sensors could form part of nearer and longer-term immersive technology applications.

› **New space technologies:** Immersive technologies could become crucial for specific space applications, such as astronaut training and rich robotic teleoperation.

› **New materials and digital production:** Immersive technologies could be a cornerstone of future digital production approaches, in particular for product design and collaborative work. Further, novel materials could enable lighter and more efficient augmented and virtual reality sets.

› **Renewable energy and resilience:** Due to the very high computational demands anticipated of immersive technologies, they could have a significant negative impact on energy use and thus the environment.

› **Human enhancement technologies:** Human enhancement technologies such as brain-computer interfaces could be a key component of longer-term immersive technology applications.

› **Cyber technologies:** Immersive technologies would arguably be an attractive target for malicious cyber attacks, for example, due to the considerable amount of personal data they capture.

› **Digital communication:** 5G and other digital connectivity technologies are central to the further development of immersive technologies due to their assumed need for very fast and capable connectivity.

› **Robotic and autonomous systems:** Immersive technologies could be a central aspect of human-robotic cooperation and interaction, as well as of rich robotic teleoperation.

INTERACTIONS WITH MEGATRENDS:

› **Changing nature of work:** Immersive technologies could have a huge impact on the nature of work, for example enabling rich teleworking.

› **Diversification of education and learning:** Immersive technologies have the potential to disrupt education and learning by offering remote and immersive learning experiences. It could also offer access to extremely personalised and immersive worlds, potentially triggering a retreat into these by an increasing number of people.

› **Growing consumption:** Immersive technologies could offer new ways to buy and consume existing and novel products and services, for example through immersive virtual shopping.

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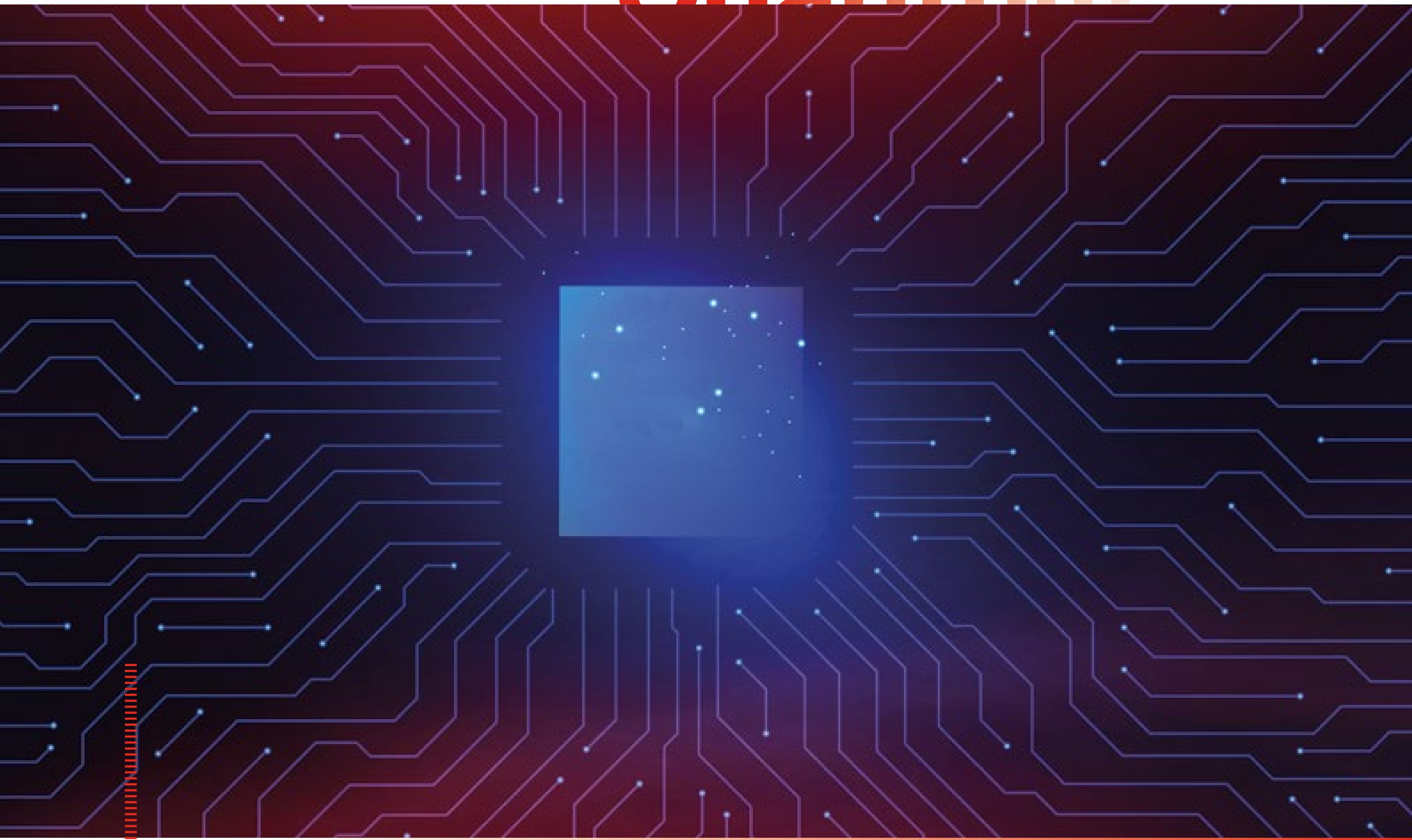

2.3 QUANTUM TECHNOLOGIES

USING QUANTUM PHYSICS TO ACHIEVE UNPRECEDENTED CAPABILITIES

DESCRIPTION:

Quantum technologies exploit quantum physics and associated phenomena at an atomic and sub-atomic level, in particular quantum entanglement and superposition. Engineers are now beginning to be able to create several types of devices that take advantage of these effects to far exceed the capabilities of existing devices. Quantum technologies are often grouped into three broad categories: quantum sensing, quantum communication and quantum computing.

Quantum sensing and metrology refers to the ability to use quantum mechanics to build extremely precise sensors. One category of sensing technology includes probes that can perform highly sensitive measurements of elapsed time, acceleration, rotation, vibrations or electric, magnetic and gravitational fields. Highly precise clocks could have commercial applications, such as verifying high-frequency financial trades and dynamically regulating a smart electrical grid. Sensitive gravitometers could be used for seismographic predictions of earthquakes and volcano eruptions. Quantum magnetometers could also have biomedical applications, for example for improving magnetic resonance imaging. Improved accelerometers could allow for self-contained inertial navigation systems, allowing accurate positioning and navigation for very long periods of time in environments where GPS is not available. A sensitive gravitometer or magnetometer could also be used for GPS-less positioning and navigation by taking precise measurements of the local fields and comparing them with preexisting maps of the Earth’s gravitational and magnetic anomalies. Another category of sensing technology is quantum imaging. Two of the most promising applications are known as ghost imaging and quantum illumination. Ghost imaging uses the unique quantum properties of light to detect distant objects using very weak illumination beams. Quantum illumination is conceptually similar, but could provide an even greater improvement in sensitivity. It can achieve a performance measurably higher than the best apparatus theoretically possible that does not make use of quantum mechanics. One proposed use case for this technology is a quantum radar. Furthermore, quantum lidar technology promises improved signal-to-noise-ratio values and images in the near future. In addition to entanglement, this requires highly sensitive photon detectors and machine learning methods.

Quantum communication methods include applications to ensure security against eavesdroppers by taking advantage of quantum effects to make it physically impossible to eavesdrop undetected. Quantum-secure communication is sometimes referred to as "unhackable", although technical subtleties could lead to vulnerabilities. A longer-term application of quantum communication, known as quantum networks (or sometimes a quantum internet), could be very secure and could enable distributed quantum sensing and computing, among other applications that are difficult to predict today.

Quantum computing methods could, in theory, perform certain computations considerably quicker than is fundamentally possible with a standard, traditional computer, for specific classes of analytical problems (e.g. optimisation and simulation). This computational leap would, for example, enable us to efficiently solve the mathematical problems underlying classic public key cryptography, potentially (but not necessarily) rendering current cryptographic methods obsolete[3]. This would pose a serious security risk for all of the encryption and password protection methods currently in use. Other applications take advantage of an improvement in the speed of brute-force searches of large databases, as well as numerical optimisation. Quantum computers could also potentially lead to massive improvements in the machine-learning algorithms used in artificial intelligence, with possible applications of quantum computers for machine learning. A final, lesser-known potential application of quantum computers is for the scientific simulation of advanced materials and biochemistry, including drug discovery. Since quantum-mechanical effects explain the underlying physics of these materials, computers that use quantum mechanics are uniquely well suited to simulate them computationally.

The performance and engineering difficulty facing a given quantum technology is quantified by a simple (though technical) unifying measure, known as quantum entanglement. In quantum computing, entanglement is used to create qubits that are connected. When one qubit is manipulated, it affects the others it is «linked» with. This allows quantum computers to perform complex calculations incredibly fast, because they can explore many possibilities at once. Speed, operating power and also the complexity of realisation increase with more sustained entanglement. The most powerful potential applications of quantum technology all require sustained entanglement between multiple particles.

Applications that require smaller degrees of controlled entanglement are therefore more likely to be implemented sooner. Most quantum sensing applications require very little controlled entanglement and are thus considered the closest to deployment. Quantum communication is an intermediate case, because some protocols use entanglement and some do not. The simplest forms of quantum communication have already been deployed, but the most advanced and useful forms are still many years away. Quantum computing is the most technologically challenging case, because it requires a high degree of entanglement. Some niche applications of quantum computers are being explored and these may become useful within the next few years. However, the most important applications are further away.

Technological developments in quantum technologies are driving forward the abovementioned quantum technologies in the relevant fields of quantum mechanics, quantum computing, quantum communication and quantum sensing. This trend is mainly being driven by commercial interest, however the more security-oriented applications are also being driven by geopolitical competition.

[3] Public key cryptography is used for digital signatures, establishing a secret key via an insecure channel and for encrypting data, among other things. Cryptographic procedures with symmetric keys (secret key cryptography) are only affected to the extent that the search for the correct key experiences a maximum quadratic acceleration. Doubling the length of the key compensates for this advantage, making symmetric procedures quantum-resistant.

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

The table below summarises the functions that are generally provided by the use of quantum technologies, which impact metrics for these functions are expected to improve and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF QUANTUM TECHNOLOGIES	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
QUANTUM SENSING	ENHANCED SENSITIVITY SENSING FOR: • TIME. • ACCELERATION. • MAGNETIC FIELDS. • ELECTROMAGNETIC RADIATION. • ROTATIONS. • VIBRATIONS. • PHOTONS.	• INERTIAL NAVIGATION SYSTEMS AND MAGNETOMETRY SYSTEMS FOR NAVIGATING IN ENVIRONMENTS IN WHICH GPS IS NOT AVAILABLE. • IMPROVED LIDAR AND RADAR FOR RECONNAISSANCE. • FULL-RANGE RADIO-FREQUENCY DETECTORS. • TUNNEL AND BUNKER DETECTION.
QUANTUM COMMUNICATION	USE OF THE QUANTUM PROPERTIES OF LIGHT FOR: • INCREASED SECURITY. • EAVESDROPPING DETECTION[4].	• SECURE COMMUNICATIONS THAT ARE DIFFICULT TO INTERCEPT. • NETWORKING OF QUANTUM SENSORS AND COMPUTERS.
QUANTUM COMPUTING	IMPROVED COMPUTATIONAL POWER FOR SPECIFIC PROBLEMS SUCH AS: • ATTACKS ON TRADITIONAL PUBLIC KEY CRYPTOGRAPHY. • OPTIMISATION. • SIMULATIONS. • CLASSIFICATION. • FACTORISATION.	• DESIGN OF ADVANCED MATERIALS. • BIOCHEMISTRY. • DRUG DESIGN. • NUMERICAL OPTIMISATION (E.G. FOR LOGISTICS). • BREAKING TRADITIONAL PUBLIC KEY CRYPTOGRAPHY.

[4] Since there are currently no authentication mechanisms that are secure based on quantum properties, authentication is still based on traditional approaches. Hence, if traditional authentication can be broken, eavesdropping would be simple. Quantum communication can therefore be seen to be generally as secure as the weakest link – traditional authentication.

Below, we will discuss the impact and the main uncertainties and challenges of quantum technologies for each category:

— SOCIO-CULTURAL:

- **Impact:** In some conceivable cases, quantum sensing and computing could contribute to the loss of expectation of privacy in specific scenarios. The new capabilities of quantum technologies could support a significantly improved quality of life, for example by assisting in climate change mitigation, drug design and social planning and decision-making.
- **Main uncertainties and challenges:** Will quantum technologies such as sensing and decryption/encryption have a privacy-enhancing or reducing net effect? What will the magnitude of this effect be?

— TECHNOLOGICAL:

- **Impact:** The applications discussed above will have a wide-ranging impact in a variety of sectors. Quantum remote sensing and positioning, navigation and timing can offer dramatic improvements compared to the current capabilities. This could be a game changer, for example for security and military applications (e.g. for navigating in environments in which GPS is not available or for very sensitive reconnaissance). Quantum communications could potentially offer safer communications, with applications in secure high-frequency trading, for example. Quantum computing could make traditional public key cryptography obsolete and at the same time offer increased security quantum encryption. Any application that relies on traditional public key cryptography would be significantly affected. Quantum optimisation would make the solving of previously intractable problems feasible, with applications for example in complex logistics decision-making problems. Quantum simulations would allow the simulation of aspects of material design, chemical reactions, climate and weather that are currently only able to be studied in the lab or through observation. The impact of this on the relevant sectors would be tremendous.
- **Main uncertainties and challenges:** Are high-entanglement quantum applications feasible? Will more than the present few algorithms for quantum computers be developed?

— ECONOMIC:

- **Impact:** Quantum sensing and navigation can offer some economic benefits in specific applications; however, it's arguably used mainly for military and security applications. Nevertheless, quantum remote sensing can provide an impressive increase in the wealth of data generated by remote sensing, thus providing significant economic benefits. Quantum sensors will likely not be less cost-effective than their non-quantum counterparts. The latter will remain prevalent for generic applications, with quantum sensors being used in more targeted applications such as those mentioned above. Quantum communication will offer significant benefits in transporting quantum information between quantum computers. Quantum computing has the potential to offer dramatic returns by replacing a large part of the physical research needed, for example for material or drug development, with a new class of accurate simulations. New optimisation methods enabled by quantum computing could dramatically improve operations in all sectors. In the longer term, quantum computers could offer a further jump in artificial intelligence capabilities, with all the attendant economic benefits. The applications of quantum computing-relevant decryption/encryption could potentially further disrupt many sectors. However, a smooth transition towards "quantum-immune" encryption will likely occur, which will minimise this impact.
- **Main uncertainties and challenges:** What is the economic feasibility of quantum technologies, especially when it comes to wider application and not exclusively to use in a limited set of specific use cases? What will be the net economic impact of the decryption/encryption capabilities of quantum technologies?

— ENVIRONMENTAL:

- **Impact:** Ultra-sensitive quantum sensors can conceivably be used for environment and climate-relevant measurements. More importantly, the advanced simulation capabilities of quantum computing can offer impressive insights in climate and environmental science, as well as much more reliable weather predictions.
- **Main uncertainties and challenges:** To what extent will the deployment of quantum technologies impact the environment? In particular, what will be the energy footprint of quantum computing?

— (GEO)POLITICAL, REGULATORY:

- **Impact:** Quantum sensing and navigation are potentially strategically significant capabilities, including the negation of the ability to "hide" any military asset. The combination of quantum communications and computing can offer more secure communications and encryption methods for use in security applications, but quantum decryption could also become destabilising if decryption capabilities are made available before the relevant encryption capabilities.
- **Main uncertainties and challenges:** Will quantum technologies such as sensing and decryption/encryption have a strategically stabilising or destabilising net effect?

WEAK SIGNALS:

› **Kentucky Fried Chicken** places employees in a virtual escape room where they must successfully complete a five-step chicken preparation process before they are released.
› **Multiverse Computing** is collaborating with **Oxford Quantum Circuits** and **Moody's Analytics** to enhance flood risk assessment through quantum technology, aiming to overcome the limitations posed by the computational complexity in current methods.
› **Quantagonia**, has introduced a cloud-native service, facilitating the execution of conventional and quantum algorithms for artificial intelligence, simulation and optimisation, streamlining development and providing an accessible gateway to quantum computing.
› Researchers at **NASA's Jet Propulsion Laboratory** have created a detector capable of measuring individual photons at high rates, potentially revolutionising high-speed quantum communication.
› **Quantinuum** and **HSBC** announced a series of exploratory projects that exploit the potential near- and long-term benefits of quantum computing for banking with specific projects in cybersecurity, fraud detection and natural language processing.

INTERACTIONS WITH OTHER TRENDS:

› **Data science & AI:** Data generated by quantum sensing could serve as input for data science and artificial intelligence. Advanced quantum computing can be used to generate even more capable artificial intelligence. Conversely, data science and artificial intelligence could be used in the research and design of quantum technologies.
› **Immersive Technologies:** Quantum sensing and computing can conceivably enhance immersive technology, e.g. by potentially contributing towards making a synthetic environment completely realistic.
› **Robotic and autonomous systems:** Quantum sensors can be applied, for example, for the navigation of autonomous systems in environments in which GPS is not available. Quantum computing can be used, for example, to optimise the operation of large-scale robotic and autonomous systems.
› **Sensor technologies:** Quantum sensing is an important class of new sensing capabilities.
› **New space technologies:** Space often serves as the platform for quantum remote sensing and secure quantum communications.
› **New materials and digital production:** Quantum sensing can be useful in the factory of the future. Quantum computing can be a central aspect in the design of new materials and the operational optimisation of production via advanced quantum simulation and optimisation.
› **Renewable energy and resilience:** Quantum computing simulations can be used to study previously intractable climate, weather prediction and energy system operations problems.
› **Human enhancement technologies:** Quantum computing simulation and optimisation capabilities can be used in the design and operation of human enhancement capabilities.
› **Cyber technologies:** Quantum sensing, communications and computing infrastructure, as well as these three combined into the "quantum internet" could be a central part of the cyber domain in the future.
› **Digital communication:** Quantum communications can form a part of the digital communication domain in the future.

INTERACTIONS WITH MEGATRENDS:

› **Changing nature of work:** Quantum technologies can offer higher security communications and encryption, but also ultra-sensitive remote sensing and potentially disrupting decryption capabilities, although a transition to quantum-secure encryption is already underway.
› **Climate change and environmental degradation:** Quantum computing can offer potentially groundbreaking capabilities for climate simulation, thus helping with climate change study and mitigation.
› **Shifting health challenges:** Quantum computing simulation can help in the design of new drugs, materials and medical devices.

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2.4 SENSOR TECHNOLOGIES

CAPTURING DATA TO MAKE SMARTER DECISIONS AND TO ENHANCE EFFICIENCY

DESCRIPTION:

A **sensor** generally refers to a device that converts a physical measurement into a signal that is read by an observer or an instrument.
Sensors can measure a wide variety of inputs, including mechanical, optical, chemical and biological. Sensors vary by how they interface with the sample or measurand:
- **Contact sensors** require contact with the input sample.
- **Non-contact sensors** allow indirect or remote sample sensing.
- **Sample-based sensors** require an invasive collection of the object under analysis.

Sensors can be passive and simply respond to inputs, or active and have additional components that interact with the input sample to enable a sensor response.

Modern sensors are often found as part of an integrated package. These smart sensors usually comprise of one or more sensors along with an integrated set of modules, for example for energy storage and harvesting, communications or data processing.
Sensor technologies are advancing along three general paths of improvement:
- **Enhanced sensing performance** in terms of, for example, accuracy[5], sensitivity[6], precision[7] or the ability to operate in different environmental conditions.
- **Miniaturisation** of the sensors themselves as well as the connected electronics in the case of smart sensors.
- **Distribution, networking and connectivity**, with increasingly larger numbers of sensors distributed more densely and/or widely, as well as being better networked.

A non-exhaustive and exemplary list of advanced sensor technologies that offer improvements along one or more of these paths by using different approaches is discussed below.

[5] The maximum difference that will exist between the actual value and the indicated value at the output of the sensor.
[6] The minimum input of physical parameters that will create a detectable output change.
[7] The reproducibility of a measurement: if exactly the same value was measured a number of times, an ideal sensor would output exactly the same value every time.

MEMS sensors (sensors based on microelectromechanical systems) have been the main contributor to the changes in the scale and functionality of sensors over the last decade. The use of MEMS sensors in smartphones marked a turning point in MEMS sensor production and technology advancements. As a result of the MEMS revolution, there has been a significant reduction in the size, cost and power usage of common sensors, which has had a profound impact on the kinds of sensing formats and architectures available. Today, MEMS and the associated technologies are used in advanced sensing platforms and instruments whose capabilities are much more advanced than human senses and perception.

Nanotechnology-enabled sensors may offer significant advantages over conventional sensors. The unique properties of nanoscale materials make them ideal for sensing, offering impressive improvements in performance. For example, the sensitivity may be increased due to tailored conduction properties, the limits of detection may be lowered and infinitely small quantities of samples can be analysed. At the extreme nanoscale limit, there exists the potential to even detect a single molecule or atom. The benefits of nanotechnology can be further leveraged to manufacture highly miniaturised sensors, for example, nanoparticles can be used as sensitive biological sensors.

Printed and flexible sensors include flexible, stretchable and generally mechanically adaptable sensors. They can withstand mechanical deformation without degrading their performance or being destroyed. Flexible sensors enable measurements on dynamic and/or shape-changing objects and large-area non-flat surfaces where rigid sensors typically struggle. Flexible sensors are lightweight thanks to the use of organic materials and/or thin-film form factors, thus potentially enabling improved integration, distribution and application. Furthermore, some flexible sensors can be manufactured using low-cost materials and large-scale processes such as printing.

Bioinspired sensors take inspiration from basic concepts behind sensory physiology. They do so either by direct (emulating the biological functions closely) or analogous (in a more abstract form) mimicry. Examples include chemical sensors mimicking the human tongue and optical neuromorphic sensors mimicking the morphology of the human eye and the neurological behaviour of human visual processing, Benefits include increased performance and reduced power use.

Optical fibre sensors use optical fibre either as the sensing element (intrinsic sensors) or as a means of relaying signals to the processing electronics (extrinsic sensors). Their attractive characteristics include immunity to electromagnetic interference, low power consumption, a small size and high levels of sensitivity.
Lab-on-chip sensors perform various, often complex and demanding, laboratory operations on a miniaturised scale. Their size can range from a few millimetres to a few square centimetres.

Hyperspectral remote sensors collect image data simultaneously in dozens or hundreds of narrow, adjacent spectral bands. In contrast, common multispectral remote sensors produce images with a few relatively broad wavelength bands. This rich hyperspectral image data can be compared with field or laboratory-derived data to recognise and map surface materials such as particular types of vegetation or minerals associated with ore deposits.

Smart dust comprises smart sensors that can be packed into a cubic-millimetre mote (a small particle or speck) to form the basis of integrated, massively distributed sensor networks. Due to its small size, substantial functionality, connectivity and anticipated low cost, smart dust could be used to provide more information from more places less intrusively.

The evolution of these sensor technologies in the future will offer progress along the three paths mentioned above, offering increasingly capable, small, distributed and networked sensors. The level at which a sensor technology will have to satisfy one or more of these metrics and at what levels will depend on the use case.

Sensors are central to many key activities in practically every sector. Advancements in sensor technologies are thus driven by the increasing performance and cost demands of these activities.

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

The table below summarises the functions that are generally provided by the use of sensor technologies, which impact metrics for these functions are expected to improve and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF SENSOR TECHNOLOGIES	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
MEMS SENSORS	• REDUCTION IN SIZE, COST AND POWER USAGE.	• INDUSTRIAL ROBOTICS. • AUTONOMOUS VEHICLES. • MICROPHONES. • NAVIGATION SENSORS.
NANOTECHNOLOGY-ENABLED SENSORS	• INCREASED SENSOR PERFORMANCE. • INCREASED MINIATURISATION.	• BIOMEDICAL SENSING. • HIGH-PRECISION ENVIRONMENTAL MONITORING.
QUANTUM COMPUTING PRINTED AND FLEXIBLE SENSORS	• IMPROVED INTEGRATION ON FLEXIBLE SURFACES. • LOWER COST.	• WEARABLE HEALTH MONITORING. • SMART PACKAGING. • STRAIN GAUGES.
BIOINSPIRED SENSORS	• IMPROVED PERFORMANCE. • REDUCED POWER USAGE.	• LOW POWER, HIGH-FREQUENCY OPTICAL SENSING FOR FAST ROBOTICS. • "ARTIFICIAL NOSES" FOR WASTE SORTING.
OPTICAL FIBRE SENSORS	• REDUCED POWER USAGE. • INCREASED SENSOR PERFORMANCE. • IMMUNITY TO ELECTROMAGNETIC INTERFERENCE.	• STRUCTURAL HEALTH MONITORING. • TELECOMMUNICATIONS SIGNAL QUALITY MONITORING. • ACOUSTIC SENSORS FOR PERIMETER SURVEILLANCE.
LAB-ON-CHIP SENSORS	• INTEGRATION OF COMPLEX LABORATORY FUNCTIONS ON A MINIATURISED CHIP.	• MEDICAL TESTING AND DIAGNOSTICS IN REMOTE SETTINGS. • CLINICAL CHEMISTRY MINIKITS.
HYPERSPECTRAL REMOTE SENSORS	• NOVEL SENSING CAPABILITIES.	• MINERAL EXPLORATION. • PRECISION AGRICULTURE.
SMART DUST	• INCREASED MINIATURISATION. • REDUCED POWER USAGE. • INCREASED DISTRIBUTION AND CONNECTIVITY.	• SECURITY AND DEFENCE-RELEVANT SURVEILLANCE. • DISASTER MONITORING. • DIGITAL TWIN OF THE ENVIRONMENT, BATTLEFIELD REPRESENTATION.

Below, we will discuss the impact and the main uncertainties and challenges of sensor technologies for each category:

— SOCIO-CULTURAL:

- **Impact:** Sensors can make technology personal by being included in numerous everyday objects, consumer electronics and wearable devices. Sensors further increase safety in all aspects of social life, from leisure activities such as driving to working in an industrial setting. Finally, sensors enable scientists to study environments, materials, biological systems and the universe itself in greater detail than ever before.
- **Main uncertainties and challenges:** To what extent will society accept widespread sensor deployment and what are the ethical implications? How can concerns about privacy, data ownership and surveillance be addressed?

— TECHNOLOGICAL:

- **Impact:** The performance, miniaturisation and connectivity of sensor technologies are enabling them to have a huge impact in a large number of sectors. In the automotive industry, for example, modern vehicles are packed with sensors for safety and performance. Sensors have also revolutionised the capabilities of modern consumer electronics and are indispensable for monitoring and controlling industrial processes. The growth of low-cost microsensors has enabled the internet of things, allowing connectivity and the exchange of data between billions of objects and devices.
- **Main uncertainties and challenges:** How will sensor performance and miniaturisation evolve? How will the secondary capabilities of smart sensors (power, communications, computing) evolve? Will novel sensor technologies be able to be produced and deployed on a large-scale basis?

— ECONOMIC:

- **Impact:** Automation and process optimisation enabled by sensors can improve speed, precision and efficiency within manufacturing technology, healthcare, agriculture and other domains. This in turn increases productivity levels and the economic potential. The vast amount of rich data collected by such sensors can also be fed into a "data economy", producing value for the numerous stakeholders participating in it.
- **Main uncertainties and challenges:** Will there be adequate demand for specific specialised types of sensors? Which new data-based business models could emerge based on novel sensors?

— ENVIRONMENTAL:

- **Impact:** Environmental sensors can continuously monitor air and water quality, pollution levels, greenhouse gases and other environmental parameters.
- **Main uncertainties and challenges:** How will the energy and resource efficiency of sensors evolve? How will sensor deployment and disposal impact ecosystems (e.g. pollution)?

— (GEO)POLITICAL, REGULATORY:

- **Impact:** The proliferation of sensors could conceivably be useful in the monitoring of the adherence to various types of laws and regulations, both national and international.
- **Main uncertainties and challenges:** How can questions about data ownership, consent and responsible use be addressed? How should the privacy of data recorded by sensor technologies be regulated? How would geopolitical tensions affect the technological and resource inputs needed for the further development of sensor technologies?

WEAK SIGNALS:

› Researchers from the **University of Chicago**, the **US Department of Energy** and the **University of Wisconsin-Milwaukee** have created a method for the mass production of graphene-based sensors that detect lead, mercury and E. coli in water.
› Researchers at **Penn State University** have devised an electronic tongue that uses graphene-based chemitransistors as taste buds to recognise gas and chemical molecules.
› **Kaunas University of Technology** researchers have devised gravimetric sensors to detect greenhouse gases such as carbon dioxide and methane, offering greater sensitivity and lower energy consumption than electrochemical sensors.
› Canadian space data company **Wyvern** intends to launch a satellite programme, employing hyperspectral imaging to provide farmers with real-time high-resolution data on soil moisture, plant growth and weather-induced damage.

INTERACTIONS WITH OTHER TRENDS:

› **Data science & AI:** An increased number of more capable and distributed sensors in the future could produce a trove of data relevant to data science and AI.
› Immersive technologies: Certain types of sensors, such as flexible sensors or MEMS, are key components of immersive technologies.
› **Quantum technologies:** Quantum sensing is used in a number of sensing technologies, mainly photonics.
› **New space technologies:** Certain sensors are mounted on spacecraft, either as payloads (e.g. hyperspectral imagers) or to provide assistance in spacecraft operations (e.g. MEMS accelerometers).
› **New materials and digital production:** Sensors are a central component of digital production approaches.
› Renewable energy and resilience: Miniaturised, networked and capable future sensors could be instrumental in environmental monitoring.
› **Human enhancement technologies:** Sensor technologies (e.g. flexible biometric sensors) play a large role in human enhancement technologies.
› **Cyber technologies:** Future networks of smart sensors could form an important part of cyberspace.
› **Digital communication:** Future networks of smart sensors will make use of several connectivity technologies, such as 5G.
› **Robotic and autonomous systems:** Sensors could be mounted on robots, either as payloads (e.g. hyperspectral imagers) or to provide assistance in operations (e.g. MEMS accelerometers).

INTERACTIONS WITH MEGATRENDS:

› **Aggravating resource scarcity:** Sensor technologies can help with the search for and identification of scarce resources or minerals.
› **Changing security paradigm:** Sensor technologies can be used for surveillance or defence applications.
› **Continuing urbanisation:** Sensor technologies provide data for numerous smart city applications.
› **Climate change and environmental degradation:** Sensor technologies can be used for important applications in environmental monitoring (e.g. smart dust).
› **Shifting health challenges:** Sensor technologies can play an important role in medical applications, for example via flexible wearable sensors, nanosensors for biosensing, and nanomedicine.

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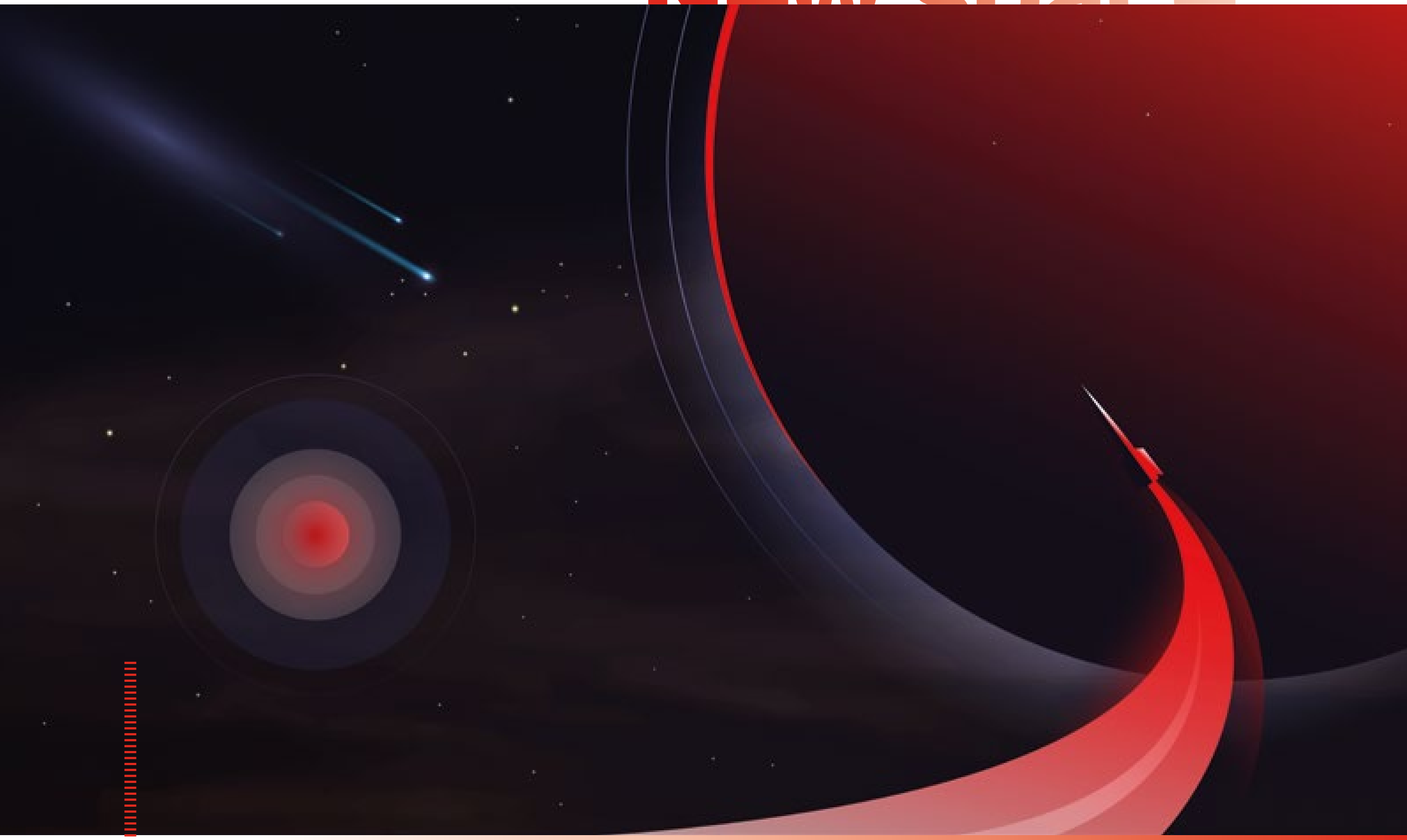

2.5 NEW SPACE TECHNOLOGIES

DESCRIPTION:

Space is generally considered to begin 90–100 km (the Kármán line) above sea level. Space technologies exploit the unique operational environment of space, including the freedom of action, the global field of view, speed and the freedom of access. However, space technologies must also be content with the unique operational environment of space, including near-vacuum, micro-gravity isolation and extreme environments (temperature, vibration and sound during launch, and pressure).

In the **near term** (multiple years to a decade), advances in space technology can enable groundbreaking applications in a multitude of sectors on Earth. Examples include:

- Positioning, navigation and timing to support autonomous vehicles.
- **Earth observation** systems to provide real-time input to advanced agriculture.
- **Satellite constellations** offering **connectivity** to enable the internet of things.

In the longer term (the next couple of decades), the infrastructure may be deployed to enable the sustainable presence of humanity in space. Such capabilities would include:

- **Resource extraction in space** could be used to "feed" a space-based economy, or to return to Earth.
- **Space-based manufacturing** could take advantage of conditions in space, for example microgravity to enable the production of advanced products that cannot be otherwise manufactured on Earth easily, or even common products for use in space.

A complex and populous space-based ecosystem could be established, comprising different satellites, habitats, research facilities, in-orbit refuelling stations and factories.

In the **even longer term** (within this century), such infrastructure and ecosystems could enable **humanity to truly establish itself and expand in space** and provide abundance on Earth.
This increasing viability of space applications is enabled by disruptive changes in the space domain driven by technological and other factors. These factors include decreasing launch costs and increasing ease of access to space, advances in miniaturisation, standardisation and production at a scale that enables the deployment of mega-constellations and swarms, autonomous systems and robotics to facilitate the operation and utilisation of these advanced space systems, and the introduction of technologies from adjacent fields (e.g. artificial intelligence, advanced manufacturing, quantum communications, etc.).

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

The table below summarises the functions that are generally provided by the use of new space technologies, which impact metrics for these functions are expected to improve and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF NEW SPACE TECHNOLOGIES	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
POSITIONING, NAVIGATION AND TIMING	• INCREASED NAVIGATION ACCURACY. • INCREASED SERVICE AVAILABILITY.	• PRECISION AGRICULTURE. • THE INDUSTRIAL INTERNET OF THINGS.
EARTH OBSERVATION	• INCREASED SPATIAL, TEMPORAL AND SPECTRAL RESOLUTION OF DATA. • BETTER INSIGHT EXTRACTION FROM DATA. • INCREASED AVAILABILITY OF DATA.	• REAL-TIME MONITORING OF ECONOMIC AND INDUSTRIAL ACTIVITY. • PREDICTIVE MODELS THEREOF.
COMMUNICATIONS	• INCREASED AVAILABILITY. • BETTER AFFORDABILITY. • INCREASED SECURITY.	• GLOBAL INTERNET. • "UNBREAKABLE» QUANTUM COMMUNICATIONS FOR FINANCIAL APPLICATIONS.
RESOURCES AND MANUFACTURING	• THE CAPABILITY TO EXTRACT RESOURCES AND MANUFACTURE PRODUCTS IN SPACE FOR USE IN SPACE OR TO RETURN TO EARTH.	• ASTEROID MINING FOR KEY METALS. • SPACE-BASED SOLAR POWER TO PROVIDE POWER TO EARTH. • MANUFACTURING OF ELECTRONICS IN MICROGRAVITY.
RESOURCES AND MANUFACTURING EXPLORATION AND SETTLEMENT	• ESTABLISH (SEMI-) PERMANENT SETTLEMENT IN SPACE.	• ORBITAL HOTELS. • LUNAR BASES.

Below, we will discuss the impact and the main uncertainties and challenges of new space technologies for each category:

— **SOCIO-CULTURAL:**

• **Impact:** Space can become a new field of human expansion and cultural activity, from space tourism in the near term to the permanent settlement of space in the longer term.
• **Main uncertainties and challenges:** Will there ever be enough social "demand" for more than the practical applications of space?

— **TECHNOLOGICAL:**

• **Impact:** Any technology that depends on the above functions will be impacted. An increase in the positioning, navigation and timing performance will for example enable precision agriculture and the industrial internet of things. The spatial and temporal resolution of Earth observation data as well as its availability will increase. This, in conjunction with artificial intelligence approaches to take advantage of this data, will enable many geo-data-relevant applications, from agriculture to climate change mitigation, and weather forecasting. This combination can even result in the creation of predictive models. Communication constellations will offer truly global, permanent, and affordable connectivity. This will enable capabilities such as global access to cheap internet and the industrial internet of things. In combination with quantum technologies, this may enable "unbreakable" communications, for example for financial applications.
• **Main uncertainties and challenges:** Will the required space technologies ever become competitive enough to enable these applications, especially relative to Earth-based alternatives?

— **ECONOMIC:**

• **Impact:** Improved space services such as the ones mentioned above will have a large positive economic impact by improving specific economic activities on Earth, such as agriculture, mining, manufacturing, and finance. Space services can also help to mitigate the effects of climate change, thereby reducing the economic harm they cause. In the longer term, space can offer a new field of economic activity, e.g. the use of space-based resources or even the settlement of cis-lunar space and other celestial bodies. for the numerous stakeholders participating in it.
• **Main uncertainties and challenges:** Will space-based use cases ever become financially competitive, especially relative to Earth-based alternatives? How important will "new space" companies and start-ups become and will "old space" companies become more or less important (or even maintain the status quo)?

— **ENVIRONMENTAL:**

• **Impact:** Improved Earth observation capabilities as described above can offer a tool for monitoring and mitigating the effects of climate change.
• **Main uncertainties and challenges:** To what extent will new space activities impact the environment (e.g. the effect of launch exhaust on the upper atmosphere)?

— **(GEO)POLITICAL, REGULATORY:**

• **Impact:** Improved Earth observation capabilities as described above can offer a tool for ensuring compliance with various laws and regulations. Space might become a domain of conflict in an increasingly contested geopolitical environment.
• **Main uncertainties and challenges:** Will space remain a relatively stable and peaceful domain or will it become a field of conflict? What will be the effect of increasing conflict in space on its civilian use? Will aspects of space use, e.g. space debris, ever be adequately regulated?

WEAK SIGNALS:

› **Prada** and **Axiom Space** are designing a space suit.
› **Varda Space Industries** is set to develop a production platform in space in order to manufacture semiconductors, pharmaceuticals and fibre optics.
› **SpaceData Inc.** is using AI methods to create Earth's digital twin based on satellite data.
› **NASA** successfully tested 3D-printed rocket engine parts.

INTERACTIONS WITH OTHER TRENDS:

› **Data science & AI:** Data from space (earth observation, geodata) can be used as input for machine-learning algorithms, e.g. for image analysis and predictive purposes.
› **Immersive technologies:** Immersive technologies can be useful in many parts of the space production chain, e.g. during design or training.
› **Quantum technologies:** Space is the platform on which quantum communications will take place and will thus be indispensable for them.
› **Sensor technologies:** Space offers a platform for new and advanced sensors. Increasing access to space will make the deployment of such advanced sensors easier.
› **New materials and digital production:** New materials can enhance space applications. Space research can be key in developing new materials. Space communications can enable the industrial internet of things. Digital production can reduce the costs of operating in space.
› **Renewable energy and resilience:** Space-based solar power is a "sci-fi" space-based energy solution. Space is key to informing climate policy.
› **Human enhancement technologies:** Human enhancement can enable space exploration.
› **Cyber technologies:** Space platforms are part of the cyber domain.
› **Digital communication:** Space is a key platform for digital communication.
› **Robotic and autonomous systems:** Autonomy can enable many space applications. Space can enable robotics on Earth, e.g. through the industrial internet of things.

INTERACTIONS WITH MEGATRENDS:

› **Climate change and environmental degradation:** Space is key for climate-relevant Earth observation activities. And in a very distant future, humanity could relocate to space after Earth becomes uninhabitable.
› **Aggravating resource scarcity:** Space-based resources, including for example rare minerals and space-based solar power, might alleviate the need for resources and climate change mitigation on Earth.
› **Changing security paradigm:** Space might become a domain of active conflict between nations.
› **Expanding influence of East and South:** Geopolitical tensions could rise as well as the race for space discovery and exploitation.

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2.6

NEW MATERIALS AND DIGITAL PRODUCTION

TRANSFORMING HOW THINGS ARE MADE

DESCRIPTION:

Advanced (novel) materials are artificial materials with unique and novel properties. These materials may have desirable characteristics, including extreme heat resistance, high strength, energy harvesting and storage, superconductivity, embedded sensing and other exotic properties such as stealth, self-adaptability, and self-healing. **Digital manufacturing** (also often referred to as Industry 4.0) encompasses the digitisation of the entire manufacturing value chain to enable unprecedented levels of real-time monitoring, control and optimisation. This level of digitisation moves beyond production to also include the entire ecosystem of partners, suppliers and end users with the aim of gathering and sharing data that can be used to optimise designs, manufacturing processes, operations and through-life support.

"New materials" can be divided into the following categories: metals (hard, ductile and heat and electrically conductive, e.g. copper as well as high-entropy alloys and shape memory alloys), polymers (widely variable, often soft and flexible, e.g. many plastics), ceramics (hard, brittle, resistant to corrosion, electrically non-conductive, e.g. concrete, porcelain) and composites (made from two or more constituent materials, merged to create a material with properties unlike the individual elements). A further "exotic" category is quantum materials, which is an umbrella term for materials with interesting or useful quantum properties resulting from electronic interactions beginning at the atomic and subatomic level.

Advanced materials within these categories are used with the aim of improving performance in various areas, such as:

- **Weight:** Lightweight metal alloys such as aluminium alloys and titanium alloys, as well as composite materials such as fibreglass and carbon fibre composites, are being developed to reduce weight while retaining or improving strength.
- **Strength and durability:** Materials such as carbon fibre and advanced ceramics are being developed to outperform traditional materials in terms of strength and durability.

• **Stability and efficacy:** A material's stability can allow it to retain its original characteristics and properties throughout its intended use, whereas efficacy is the ability to produce a desired or intended result, for example for drug delivery.
• **Self-healing and mimicking ability:** Self-healing materials can recover/repair any damage they sustain automatically and autonomously, and electronic skin can mimic the sensory capabilities of human skin.
• **Processing:** Advanced materials such as graphene, nanowires and quantum dots can improve the performance of electronic devices by increasing speed, reducing power consumption and improving memory capacity.

As materials technology advances, the improvements in these and other properties will become more and more impressive, potentially even achieving properties that seem unnatural. Metamaterials, for example, could achieve electromagnetic properties that do not occur naturally, such as negative index of refraction or electromagnetic cloaking. Nanomaterials could combine unique optical, electronic, thermo-physical and mechanical properties.

The acquisition lifecycle of a product is often broken down along the CADMID cycle, defined in six phases: Concept, Assessment, Demonstration, Manufacture, In-Service and Disposal/Termination.

Digital production aims to digitise more and more elements of this chain, including production, as well as the whole ecosystem of partners, suppliers and end users. The aim is to gather and share data that can be used to optimise designs, manufacturing processes, operations and through-life support. A "digital twin" of each new product could be established and continuously updated using real-world data at all stages of the CADMID cycle. This data would be used to generate real-time updates to industrial machinery to improve the efficiency of manufacturing processes, as well as feeding predictive models that would be used to simulate the performance of the product. In doing so, the insights gained from live operations could be used to provide information to maintenance and support based on predictive modelling, rather than on the mean times between failure. In turn, real-world data on system and sub-system performance could be fed back into the design process.

Additive manufacturing or 3D printing is a novel manufacturing method at the heart of digital production. It creates three-dimensional solid objects of virtually unlimited shape from digital models and a wide variety of metals, plastics and resins. Successive layers of material are laid down in different forms and, in some cases, different material compositions. It can be used for rapid prototyping, on-the-spot production and repair, as well as for the production of precision, custom and unique parts or very complex shapes that can result in the number of parts required in systems being reduced.

As this trend advances, an increasing part of the value chain will be digitised, providing increasing gains from this digitisation. Digital production is an umbrella term that includes most of the technology trends studied in AnticipaTech. As more of these relevant enabling technologies mature, they will be implemented increasingly for digital production. This implementation will happen at different rates and at different levels of implementation depending on the nature of a given sector.

New materials technologies are driven by rapid technological advances in a wide range of materials research and development fields. Digital production advancements are driven by developments in many enabling fields, such as the rise of data and connectivity, analytics, human-machine interactions and improvements in robotics. A further driving force are the synergistic effects of integration efforts already happening in businesses for non-technological reasons.

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

In the table below, we summarise which functions are generally provided by the use of new materials and digital production, which impact metrics for these functions are expected to improve and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF NEW MATERIALS AND DIGITAL PRODUCTION	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
NEW MATERIALS	IMPROVEMENTS E.G. IN: • WEIGHT. • CONDUCTIVITY. • HEAT AND STRENGTH RESISTANCE. • NANOMATERIALS • SELF-HEALING AND SHAPE MEMORY MATERIALS • "EXOTIC" PROPERTIES.	• LOW-WEIGHT, HIGH-STRENGTH MATERIALS. • ROOM TEMPERATURE SUPERCONDUCTORS. • CLOAKING COATINGS. • BUILDING MATERIALS FOR REDUCED CO2 PRODUCTION.
DIGITAL PRODUCTION	BENEFITS THROUGHOUT THE VALUE CHAIN, INCLUDING: • LOWER OPERATIONAL COSTS. • HIGHER EFFICIENCY, LOWER WASTE. • INCREASED ADAPTABILITY OF DESIGNS. • INCREASED ADAPTABILITY OF MATERIAL PROPERTIES.	• INTEGRATED VALUE CHAIN FROM CONCEPT TO PRODUCTION, TO USE FOR A WIDER RANGE OF PRODUCTS AND SECTORS.

Below, we will discuss the impact and the main uncertainties and challenges of new materials and digital production for each category:

— **SOCIO-CULTURAL:**

• **Impact:** Specific new materials could potentially pose new health hazards. Digital production would transform manufacturing and have an impact on the social aspect of the workplace in this sector as well as in adjacent sectors. Novel capabilities, for example the on-demand customisation of a product, could change how products are produced and consumed.

• **Main uncertainties and challenges:** How will the transition to digital production impact the demand for workforce skills? Do specific materials have any negative health effects?

— **TECHNOLOGICAL:**

• **Impact:** New materials and digital production could have a large impact on a wide variety of sectors. The wide-ranging improvements offered by new materials can open up many types of applications in different sectors. Some examples are the energy sector, with carbon fibre composites for wind turbines, electronics with the advent of superconductors that can operate near room temperatures, or healthcare, with new drug delivery systems. Digital production will change the face of every step in the manufacturing industry and thus will have an impact on the production of all types of products, from miniaturised everyday electronics to complex aerospace vehicles.

• **Main uncertainties and challenges:** Will specific key new materials be able to be produced on a large-scale basis? How can technical challenges for digital production be overcome, such as limitations as regards the product size, precision, and quality, and the potential need for post-fabrication processing?

— **ECONOMIC:**

• **Impact:** The economic relevance of new materials and digital production will be massive. New materials will increase the quality and performance of a very large number of products and services, and thus their economic value. Digital production methods have the potential to increase production efficiency along the entire value chain in practically every sector and can have a significant economic impact.

• **Main uncertainties and challenges:** How will the high up-front costs of digital production methods affect adoption? Which sectors will be more amenable to digital production methods? Which parts of the value chain can be more efficiently digitised? Will specific new materials be economically viable?

— **ENVIRONMENTAL:**

• **Impact:** Both new materials and digital production methods aim to increase efficiency in the production and use of a product, and thus can have a significant impact on the reduction of the environmental and climate footprint of production. New building materials could emit less CO2 during production or even have CO2 absorbing capabilities. Specific new materials could potentially pose new environmental hazards.

• **Main uncertainties and challenges:** How will resource and energy efficiency evolve in the production of new materials? Will the new materials generate new environmental threats?

— (GEO)POLITICAL, REGULATORY:

- **Impact:** New materials could have a positive or negative impact on the demand for resources. Novel production methods and the related interconnections and integration might make new regulations and laws necessary.
- **Main uncertainties and challenges:** How will perceived risks surrounding cyber and data security as well as intellectual property affect the adoption of digital production? How should the production of new materials be regulated to reduce health and environmental impacts?

WEAK SIGNALS:

› **UC San Diego** researchers created a non-invasive neural implant with graphene electrodes to monitor deep brain activity from the surface.
› **Argonne National Laboratory** researchers achieved a temperature record for superconductors, enabling superconductivity at minus 23 degrees Celsius under high pressure.
› **Siemens** and **Nvidia** are developing an "industrial metaverse", enabling digital twins and internet-of-things applications.
› **University of Michigan** researchers employ a unique 3D printing method to create thin, curved and resilient concrete walls, allowing recycled materials to be used and in turn reduce the impact on the environment.

INTERACTIONS WITH OTHER TRENDS:

› **Data science & AI:** AI can be used in the design of new materials and in the design and operation of digital production capabilities. Data science is central to the latter.
› **Immersive technologies:** Immersive technologies will play a key role in the human-machine cooperative operation of digital production capabilities.
› **Robotic and autonomous systems:** Robotic and autonomous systems are a central technology for digital production. New materials can be useful for future robots.
› **Sensor technologies:** Distributed sensing throughout the value chain, but mainly in production facilities will be central for digital production.
› **New space technologies:** Space is a platform for the key positioning, navigation and timing capabilities that are necessary for digital production.
› **Quantum technologies:** Quantum capabilities, such as optimisation and simulation, could significantly enhance and enable the production of new materials as well as the large-scale optimisation of digital production.
› **Renewable energy and resilience:** New materials and digital production can significantly decrease the environmental and climate impact of a large number of sectors.
› **Human enhancement technologies:** New materials would be necessary e.g. bio-compatible human enhancements and implants.
› **Cyber technologies:** Digital production will play a significant part in the cyber domain.
› **Digital communication:** Digital communication approaches, such as 5G, will be one of the main technologies needed for digital production.

INTERACTIONS WITH MEGATRENDS:

› **Aggravating resource scarcity:** New materials and digital production can ease this scarcity via increases in efficiency.
› **Changing nature of work:** New digital production approaches throughout the value chain could significantly disrupt the nature of work.
› **Changing security paradigm:** Advances in metamaterials, particularly electromagnetic coatings, can pose new security risks such as invisibility and advancing stealth technology.
› **Growing consumption:** New materials and production capabilities could enhance the efficiency of the production and use of many new products.
› **Shifting health challenges:** Exotic properties of new materials can be used in new medical devices and for treatments of diseases, as well as in drug development and nanomedicine.

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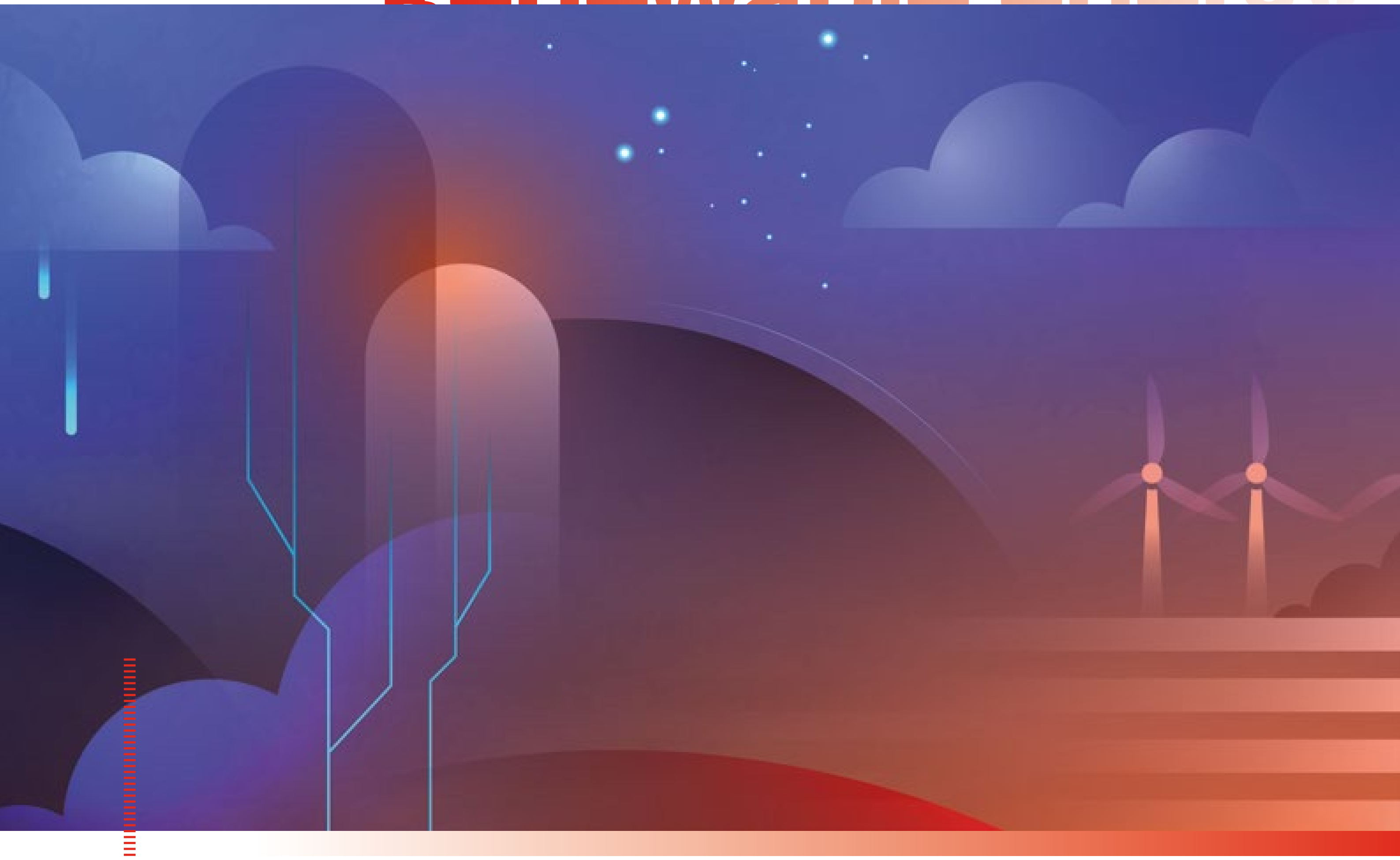

2.7

RENEWABLE ENERGY AND RESILIENCE

POWERING A CLEAN AND SUSTAINABLE FUTURE

DESCRIPTION:

Renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed. In contrast to fossil fuel-based energy, renewable energy produces very low greenhouse gas emissions, such as carbon dioxide, over its life cycle. Renewable energy sources generally depend on energy flows through the Earth's ecosystem, such as from the insolation of the sun and the geothermal energy of the Earth. **Resilience** in energy systems is defined as the ability to withstand threats, both natural (e.g. drought, earthquake, flood and storm, surge, hurricane, ice storm, tornado, tsunami) and man-made (e.g. cyber attack, physical attack, intentional electromagnetic pulses and major operation errors).

Renewable energy sources include **solar** (e.g. direct heating, photovoltaics), **wind**, **hydropower** (dams), **marine** (e.g. wave energy, current energy), geothermal and biomass. Nuclear fission plants are not typically considered renewable, as fission material depends on non-renewable sources and due to the issue of nuclear waste. Longer-term solutions include futuristic energy production methods, such as **nuclear fusion** (fusing light atomic nuclei to form heavier ones, releasing vast amounts of energy in the process) and **space-based solar power** (collecting solar power in space which is then transmitted to the ground).

Renewable energy sources can have significant benefits concerning resilience, including:

- **Low reliance on fuel supply**, and low sensitivity for example to volatile price spikes or unexpected changes in fuel availability.
- Reliance on naturally occurring, free and self-replenishing sources of fuel such as sunlight and wind.
- **Smaller, decentralised power generation**, which could conceivably be deployed in much smaller units than traditional power generation methods.
- **Rapidly deployable** in comparison to traditional generation using fossil fuels or nuclear energy.

They also suffer from potential drawbacks in terms of resilience, including:

- The inherent **variability of the energy supply** makes it challenging to use renewables as a baseline energy supply in an energy system. High-performance energy storage solutions are needed; however, these are not technologically mature enough.
- Many renewables rely on f**inite supplies of specific key elements** for their construction, for example, rare earth materials needed to manufacture photovoltaics.
- Their **resilience** is particularly **vulnerable to climate change**, as this may worsen extreme weather events and increase power outages. Integrating renewables could thus add a degree of uncertainty to power systems.

The goal of managing the effects of climate change is the main driver for transitioning to a low or zero-emissions economy as currently envisioned by many governments. The European Commission's plan to transition to a net-zero greenhouse gas emission economy by 2050 offers a clearly formulated roadmap is applied as an example in this report[10].

The European Commission's vision outlines seven main strategic building blocks:

1. Maximise energy efficiency, including zero-emission buildings;
2. Maximise the deployment of renewables and the use of electricity to fully decarbonise Europe's energy supply;
3. Embrace clean, safe and connected mobility;
4. Use the circular economy as a key enabler to reduce GHG emissions;
5. Develop smart network infrastructure and interconnections;
6. Use the bioeconomy and create essential carbon sinks;
7. Develop and deploy Carbon Capture and Storage (CCS) technologies to remove excess carbon from the atmosphere.

Using these levers, the EU has met its 2020 goals. The new 2030 targets for energy efficiency and renewable energy should enable the EU to reduce its emissions by around 45% if fully implemented. This is all with the aim of achieving a zero-emission economy by 2050.

Beyond 2050, it is conceivable that futuristic solutions such as fusion energy and space-based solar power will offer additional alternative sources of clean power, offering further benefits such as reduced land usage.

Climate change is the main driver behind the need for renewable energy. Only by limiting the global temperature increase to 1.5°C could the world avoid some of the worst climate impacts. This limit is typically considered as a tipping point below which some of the worst climate impacts of climate change could be avoided and the likelihood of extreme weather events could be reduced. The resilience benefits offered by low emissions energy systems are also another key driver. On the technological side, advances in the last decade have made renewable energy sources very competitive, with photovoltaics and wind turbines dramatically dropping in cost and increasing in efficiency, for example

[10] Switzerland's Federal Council decided in August 2019 that Switzerland should aim for net-zero greenhouse gas emissions by 2050. The net-zero target is thus enshrined in law in Switzerland (link: https://www.fedlex.admin.ch/eli/fga/2022/2403/de)

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

In the table below, we summarise which functions are generally provided by the use of new materials and digital production, which impact metrics for these functions are expected to improve using renewable energy and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF RENEWABLE ENERGY AND RESILIENCE	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
ENERGY PRODUCTION	• HIGHER PERCENTAGE OF RENEWABLE POWER IN THE ENERGY MIX. • INCREASED RESILIENCE TO ECONOMIC AND STRATEGIC EFFECTS. • DECREASED RESILIENCE TO CLIMATE EFFECTS.	• LOW TO ZERO EMISSIONS ENERGY PRODUCTION.
ENERGY DISTRIBUTION AND MANAGEMENT	• DECREASED FOSSIL FUEL USE. • INCREASED USE OF RENEWABLE ENERGY CARRIERS. • IMPROVED GRID MANAGEMENT METHODS. • INCREASED RESILIENCE TO DISRUPTIONS.	• ELECTRIFIED MOBILITY. • SMART ENERGY GRID. • RENEWABLE ENERGY AS BASELOAD.
ENERGY USE	• INCREASE IN EFFICIENCY OF USE.	• HIGH-EFFICIENCY HEATING FROM GEOTHERMAL. • HIGH-EFFICIENCY ELECTRONICS. • ELECTRIFIED MOBILITY.

Below, we will discuss the impact and the main uncertainties and challenges of renewable energy systems are discussed for each category:

— **SOCIO-CULTURAL:**

• **Impact:** Renewable energy and its positive effects on energy resilience will have significant positive social effects. By mitigating the most extreme effects of climate change, it can dramatically increase the quality of life and life expectancy of a large number of people. Its positive effects on employment and job quality will further accentuate these effects. At the same time, the side effects of renewable energy, such as increased land usage, might have a disrupting effect on local and agricultural societies.

• **Main uncertainties and challenges:** Will social acceptance significantly impede the use of renewable sources? What will be the net effect of the transition to a renewable energy system on employment? How is the shift to renewable energy systems related to social justice concerns?

— **TECHNOLOGICAL:**

• **Impact:** The transition to renewable energy systems is set to significantly change several key sectors. It will, for example, decarbonise and electrify transportation, manufacturing and other sectors.
• **Main uncertainties and challenges:** Will established (solar, wind) renewable technologies continue developing at the same impressive pace? How will other renewable technologies develop, and will they become competitive in comparison with established technologies? What role will long-term technologies such as nuclear fusion play? What role will developments in non-renewable, non-fossil energy sources such as advanced fission play? How will technology on the energy demand side (e.g. transportation) develop?

— **ECONOMIC:**

• **Impact:** In the shorter term, the price of energy generated by renewable systems might increase in comparison with fossil fuel-based systems. This will have knock-on effects on the economy. Renewable energy sources are becoming more competitive each year, and they will likely catch up or surpass fossil fuel-based sources in economic efficiency in the longer term. It has been estimated that the renewable energy transition will have a net positive impact on the economy and facilitate job growth. In the long term, the switch to a clean energy system will have benefits, such as preventing damage from climate change and additional benefits such as improved air quality. The transition will arguably decouple emissions from economic growth and help to develop new industries, jobs and technical innovations.
• **Main uncertainties and challenges:** What will be the net economic effect of the transition to renewable energy systems? Is a shift to renewable energy systems financially feasible?

— **ENVIRONMENTAL:**

• **Impact:** The environmental impact of renewable energy will be immense, mitigating the effects of climate change to prevent severe negative effects on human health and the environment. Some environmental degradation might still occur due to the increased land usage required by renewable energy sources and/or because of the extraction of elements required for their manufacture.
• **Main uncertainties and challenges:** Will the climate response to the reduced emissions energy systems be sufficient to achieve the stated temperature rise goals? To what extent will renewable energy sources impact the environment, for example with respect to land use and resource extraction? How will climate change affect the deployment and operation of renewable energy systems?

— **(GEO)POLITICAL, REGULATORY:**

• **Impact:** Energy security has been a driving force behind geopolitical conflict in the past. The transition to renewable energies has the potential to significantly ease these pressures and contribute towards individual nations achieving energy self-sufficiency and resilience. New sources of conflict might arise around the key resources, such as rare earth elements, needed for the hardware in new renewable energy systems.
• **Main uncertainties and challenges:** How will the transition to renewable energy systems affect global geopolitics? Which regulations will drive forwards the spread of renewable energy systems?

WEAK SIGNALS:

› **Lawrence Livermore National Laboratory** researchers achieved a breakeven by producing more energy in a fusion reaction than was used to ignite it. A key milestone for nuclear fusion was thus reached.
› **Greenlytics**, a Swedish start-up, is integrating AI, meteorology and data analysis to predict electricity production and demand, enabling advanced and efficient methods for energy distribution and management.
› India and the UK are collaborating to create a global solar grid spanning 140 countries to efficiently connect solar producers to consumers, and to reduce the need for extensive energy storage.

INTERACTIONS WITH OTHER TRENDS:

› **Data science & AI:** AI and data-based methods can offer smart methods for the efficient management of energy production, distribution and consumption.
› **Immersive technologies:** Immersive technologies could offer improved methods for the training and education of personnel working in the fields of renewable energy technologies, design and visualisation of energy infrastructure planning, and remote monitoring and maintenance of renewable energy systems.
› **Quantum technologies:** Quantum computing might offer a method for addressing previously untraceable problems in meteorology, climate and energy-related decision-making.
› **Sensor technologies:** Distributed, ubiquitous, miniaturised and affordable sensors will play a central role in renewable energy systems.
› **New materials and digital production:** New materials and production methods can improve the efficiency of energy production, distribution and consumption.
› **New space technologies:** Space-generated data can assist in energy management.
› **Human enhancement technologies:** None.
› **Cyber technologies:** Novel renewable energy systems will play a part in the cyber domain.
› **Digital communication:** Digital communication can be an important component of renewable energy systems, in all aspects of production, distribution and consumption.
› **Robotic and autonomous systems:** Robotic and autonomous systems can be helpful in every aspect of the renewable energy system life cycle, from manufacturing to management and maintenance.

INTERACTIONS WITH MEGATRENDS:

› **Aggravating resource scarcity and growing consumption:** Renewable energy will some resources (e.g. fossil fuels) less scarce, but may aggravate the scarcity of others (e.g. rare earth minerals).
› **Climate change and environmental degradation:** Renewable energy will be key in addressing climate change and environmental degradation.
› **Changing security paradigm:** Renewable energy will generally have a net positive effect on international conflict by reducing the need for resources and increasing energy resilience.
› **Continuing urbanisation:** Renewable energy will satisfy the increasing need for clean energy for cities.
› **Shifting health challenges:** Renewable energy will contribute very positively to health challenges related to climate change and environmental degradation.

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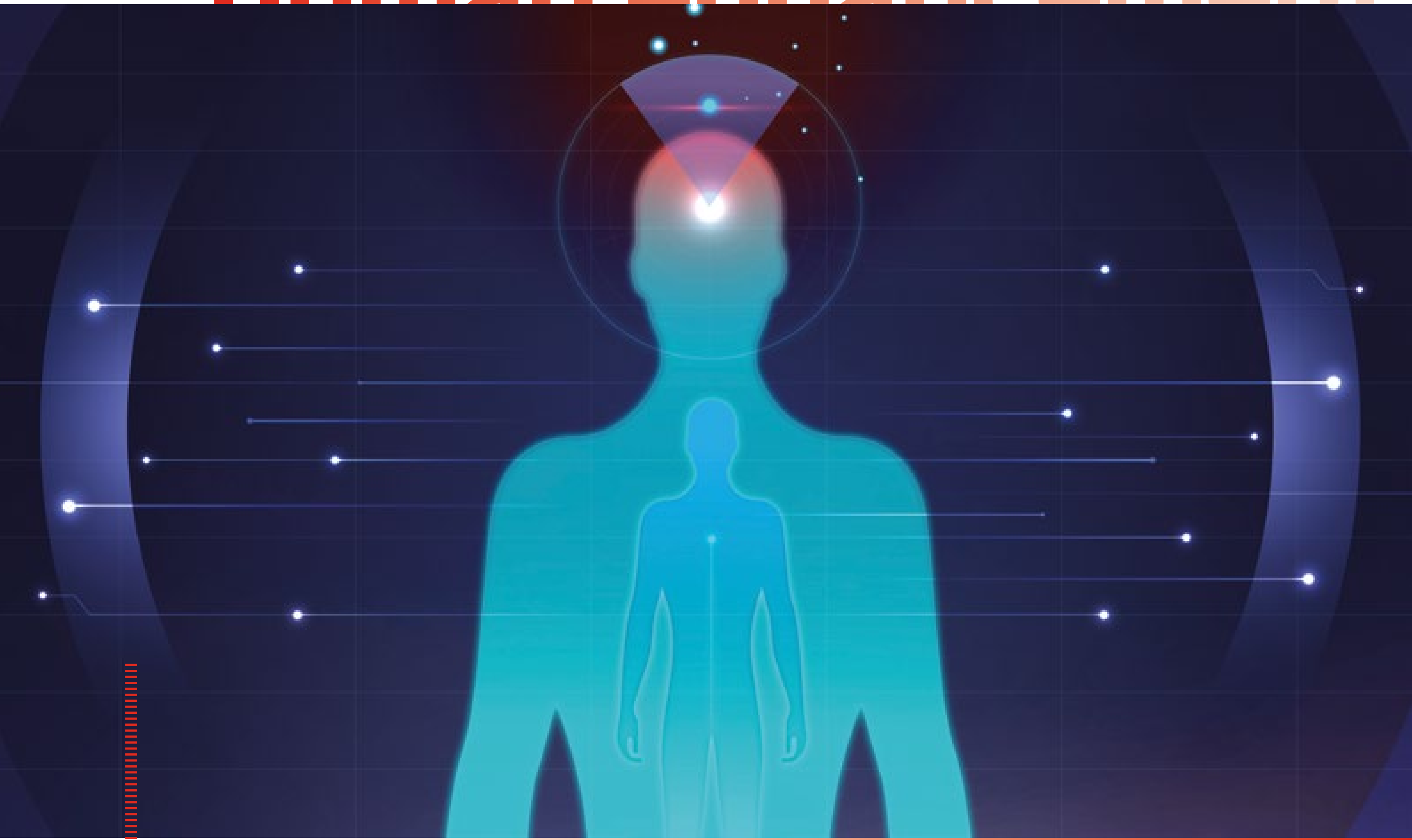

2.8

HUMAN ENHANCEMENT TECHNOLOGIES

TAKING HUMAN PERFORMANCE TO NEW LEVELS

DESCRIPTION:

Human performance enhancement is the use of science and technologies to enhance human performance beyond the limits of our biological potential and can include additional capabilities beyond those innate to humans. Human performance enhancement is a subset of human augmentation, defined as the application of science and technologies to improve human performance temporarily or permanently.

Conceptualising the human as a platform is fundamental to thinking about human augmentation. The following key elements collectively represent the human platform:

- **Physical performance** is the capability to affect the physical environment and move within it. Key components include strength, dexterity, speed and endurance.
- **Psychological performance** comprises cognition, emotion and motivation. Cognition is the mental action or process of acquiring knowledge and understanding. Emotion describes the subjective human experience and is closely linked with motivation, which is the force that energises, activates and directs behaviour.
- **Social performance** is the ability to perceive oneself as part of a group and the readiness to act as part of the team.

Four core human augmentation technologies can be identified – genetic engineering, bioinformatics, brain interfaces and pharmaceuticals. These will be discussed in detail below.

Genetic engineering refers to the modification of reproductive cells (germline engineering), or cells in the grown organism (somatic modification). Germline modification affects all cells in the organism and the change is passed on to the next generation. Somatic modification affects only the target cells and those cells descended from them.

Recent developments in genetic engineering are beginning to offer significant potential:

- *Greater range:* Gene editing can now add, delete and alter specific elements of DNA in the target genome.
- *Increased specificity* and integration: Specific regions of DNA can be targeted by cutting tools so that changes are more precise and safer. There are still off-target effects, but newer techniques such as prime editing are improving the targeting process.

- *Improved duration of effect:* Being able to target the genome rather than simply depositing DNA into cells means that edits are reproduced as the cell divides and the effect is spread.
- *Easier production:* New production techniques are often easier, cheaper and faster to develop and perform.

Genetic engineering could be used to prevent inheriting incurable diseases and represents the first step towards precision medicine based on an individual's biology.

Bioinformatics is an interdisciplinary field that applies computation and analysis tools to capture and interpret large sets of biological data. The processing of such large volumes of data available for exploitation and assessment has enabled a much greater understanding of biological, biochemical, physiological cognitive and social behaviours. In turn, this has supported new technological developments in medicine, genetics and biology.

Brain interfaces, also known as neural interfaces or brain-computer interfaces, enable direct communication between the brain and the computer. They can be one-way (e.g. to understand brain function) or two-way (e.g. to create a control and feedback system). The hearing aid is an example of a one-way interface. Thought-speech translation in people is an example of a two-way interface.

External/non-invasive brain interfaces rely on direct, non-invasive measurements of brain activity. Internal/invasive brain interfaces aim to develop a high-bandwidth data connection between the brain and the computer by implanting electrodes under the scalp via surgery for communicating brain signals. Such approaches, however, come with their own challenges.

Neurostimulation can be used to change brain function. Non-invasive methods of neurostimulation, such as transcranial magnetic stimulation, use electrical means to increase or decrease the excitability of areas of the brain. This potentially affects mental processes such as neural plasticity and memory, attention and creativity.

Brain interfaces could enhance concentration and memory function, leading to new forms of collaborative intelligence. In some very ambitious applications, they could allow new skills and knowledge to be simply "downloaded", and the physical world to be manipulated using your own thoughts alone, for example, flying a plane from anywhere in the world.

Pharmaceuticals play a role in many important forms of augmentation, including physical, cognitive, emotional, motivational and sensory processes. Most performance-enhancing pharmaceuticals have their origins in medicines or are attempts to enhance the presence of naturally occurring chemicals in the human body or nature in general. However, their use as enhancements lacks a sufficient level of understanding, and they often come with side effects that negate the potential gains.

Cognition-enhancing pharmaceuticals range from caffeine to stimulants such as amphetamines. These typically affect simple, low-level functions such as alertness and memory rather than high-level intelligence. Other types of cognitive augmentation include the modulation of blood glucose and hormones, such as adrenaline and testosterone. Pharmaceuticals that enhance physical performance include anabolic steroids. Performance gains can be impressive, but the side effects can be severe and include even death.

Currently, pharmaceuticals have only limited use in human augmentation. Developments in biotechnology, nanotechnology and bioinformatics could, however, allow new pharmaceuticals to be designed that have more powerful and precise effects.

Additional technologies of interest include exoskeletons, sensory augmentation and social media. These will be discussed below.

Exoskeletons are external, removable structures capable of supporting the human musculoskeletal system and have been in development for decades. Passive exoskeletons can ease the load on the body and reduce the risk of chronic occupational injuries. Active exoskeletons amplify the user's normal movement and can even translate brain signals into movement or provide restorative or enhanced mobility and strength. Exoskeletons are being developed for therapeutic reasons, but industrial and military applications are becoming increasingly common. Prosthetic limbs can be seen as a subcategory of exoskeletons. The most advanced prosthetics use implanted microelectrodes to provide a two-way interface.

Sensory augmentation aims to extend the sensory range or acuity either by using wearables or sensors mounted or implanted on the body to "translate" external information for the human senses or by the modification of innate senses. This could allow the user, for example, to "see" through walls, sense vibrations and detect airborne chemicals.

Social media and social networks may be best understood as a means for human social augmentation, and they have in some cases been highly successful[11].

[11] They can also influence individuals, reducing their field of perception and becoming factors in the move towards diminished humans.

Performance optimisation technologies aim to improve human performance up to the limit of our biological potential without adding new capabilities. They include, among others, physical and cognitive training, sleep optimisation and optimised hydration.

Less invasive and ambitious human enhancement applications will be the first implemented. As the various significant health impact, technological, and regulatory challenges are addressed and as the social acceptance of human enhancement technologies grows, more and more ambitious and complex applications will be implemented. Eventually, integrated human-machine symbiotes of unparalleled capabilities may potentially be able to be created.

Advances in materials, information systems and the human sciences are laying the foundations for the significant enhancement of human physiological, cognitive and social capabilities. Development in these areas is enabled by rapid parallel developments in adjacent areas, such as robotic and autonomous systems, data science and artificial intelligence, miniaturisation, and innovative materials and manufacturing. These developments are further driven primarily by substantial national investments and increasing commercial interest.

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

In the table below, we summarise which functions are generally provided by the use of human enhancement technologies, which impact metrics for these functions are expected to improve using renewable energy and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF HUMAN ENHANCEMENT TECHNOLOGIES	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
PHYSICAL	• IMPROVED CAPABILITY TO AFFECT THE PHYSICAL ENVIRONMENT AND MOVE WITHIN IT.	• EXOSKELETONS FOR INDUSTRIAL AND MILITARY APPLICATIONS. • PERFORMANCE-ENHANCING PHARMACEUTICALS WITH REDUCED SIDE EFFECTS.
PSYCHOLOGICAL	• IMPROVED COGNITION, EMOTION AND MOTIVATION.	• AUDITORY ENHANCEMENT FOR PERSONAL PROTECTION. • MEMORY ENHANCEMENT VIA NEUROSTIMULATION.
SOCIAL	• IMPROVED COMMUNICATION SKILLS. • ENHANCED COLLABORATION AND TRUST. • IMPROVED GROUP COHESION.	• NEW, INTENSE WAYS TO CONNECT (E.G. VIA LINKED BRAIN-MACHINE INTERFACES).

Below, we will discuss the impact and the main uncertainties and challenges of human enhancement technologies for each category:

— **SOCIO-CULTURAL:**

• **Impact:** Human enhancement technologies are likely to be more easily available to the rich or otherwise privileged. Alternatively, it is conceivable that such potentially risky technologies will be reserved for the underprivileged in some societies. Without intervention, human augmentation is likely to exacerbate inequality and could lead to societal tensions. Furthermore, it may challenge or offend philosophical, religious and other views, and result in polarisation, social tension and, conceivably, conflict. Interest in self-enhancement, particularly in a world of increasing individualism and competitiveness, might also drive social tensions.

• **Main uncertainties and challenges:** To what extent will human enhancement technologies be socially accepted? How will factors, including the technologies' purpose, effectiveness, and safety, affect social acceptance? What philosophical issues will arise, for example about what it means to be human, who should, can and must receive enhancement, and how to deal with the possible inequality?

— **TECHNOLOGICAL:**

• **Impact:** The potential applications of human enhancement technologies are staggering. In the medical field, genetic engineering could be used for precision personal medicine. Brain interfaces could cure paralysis and treat Alzheimer's disease. A huge impact is anticipated for human-machine interfacing, which is a key aspect of the operation of many future technologies, such as transportation and manufacturing.

• **Main uncertainties and challenges:** How can the numerous technological challenges faced by genetic engineering be addressed (e.g. new vehicles to carry the genetic code, better understanding of the unintended side effects)? How can the huge knowledge gap surrounding the human brain be bridged? How can neurostimulation technologies achieve more complex functionality, or target specific areas of the brain? Will it be possible to capture complex signals from deep brain functions without the insertion of electrodes? How to deal with the possibility of brain interface hacking? How can exoskeletons and prosthetics achieve better speed and range of movement?

— **ECONOMIC:**

• **Impact:** Human enhancement technologies have the potential to improve productivity and workforce health while mitigating disabilities. Human augmentation will help people to live even longer and better lives, thus either alleviating the pressure placed on social and healthcare systems by improving health and productivity in old age or exacerbating it. Personalised medicine will reduce the level of infrastructure needed to provide healthcare services and the associated costs. The preventative interventions enabled will be cheaper and more effective than at present, which means that less strain will be placed on the economy.

• **Main uncertainties and challenges:** Will consumers widely accept this technology? What will be the economic impact of human enhancement, if human labour is widely replaced by robotics anyway?

— **ENVIRONMENTAL:**

• **Impact:** Human enhancement has been argued as being a long-term solution that will help humans adapt to a changing environment, for example for dealing with the effects of climate change.onitoring and mitigating the effects of climate change.

• **Main uncertainties and challenges:** What, if any, will be the net environmental and climate effect of the entire chain from design to production, implementation and the operation of human enhancements?

— **(GEO)POLITICAL, REGULATORY:**

• **Impact:** Human augmentation is founded on very personal biological data. Significant challenges and threats could thus result in safety, security and privacy concerns. Nations might get involved in an "arms race" for human augmentation technologies, considering their significant potential applications in defence and security.

• **Main uncertainties and challenges:** How can the large number of important regulatory, legal and governance challenges be addressed? How should challenging applications be dealt with (e.g. do-it-yourself enhancements, genetic engineering of humans, and "designer babies")? How should human enhancements in war be regulated? Will human enhancements be eventually considered a human right, or will they be left to be self-regulated by the market?

WEAK SIGNALS:

› **Neuralink**, a neurotechnology company founded by Elon Musk, has developed a neurosurgery robot capable of implanting flexible polymer threads into the brain that feed into a small, low-powered implant. This implant amplifies and digitises brain signals for broadband-speed streaming between the brain and technological devices.
› **The University of Utah** has developed a prosthetic arm that uses 100 microelectrodes to provide an interface with the user's nervous system. Combining robotics and electrode arrays for the first time has enabled the user to experience tactile sensations that are crucial when manipulating delicate objects.
› **The University of Grenoble** enabled a paralysed patient to walk again by using two wireless implants to interpret brain signals into robotic movements.
› **The MoleculArXiv** exploratory programme led by the CNRS is developing new data storage devices based on DNA and artificial polymers.

INTERACTIONS WITH OTHER TRENDS:

› **Data science & AI:** Data science and AI are key aspects of bioinformatics, and a central aspect of many other applications, e.g. in drug design.
› **Immersive technologies:** Human enhancement technologies and immersive technologies go hand-in-hand, with the latter widely considered a subset of the former.
› **Quantum technologies:** Quantum simulations may promote research on advanced human enhancement technologies.
› **Sensor technologies:** Miniaturised bio-compatible sensors could be a key part of human enhancement technologies. Biosensors are a novel category of sensors.
› **New space technologies:** Human enhancement technologies may be central to the potential long-term settlement and adaptation of humans to space.
› **New materials and digital production:** Advanced materials are a main component of human enhancement technologies. Digital production methods, such as 3D printing, have significant applications within human enhancement technologies (e.g. human organ printing).
› **Renewable energy and resilience:** In the long term, advanced human enhancement technologies could be used to help humankind adapt to a planet that has been made less hospitable by climate change.
› **Cyber technologies:** With human enhancement technologies, the human body itself becomes part of the cyber domain.
› **Digital communication:** Digital communication technologies are a main component of human enhancement technologies.
› **Robotic and autonomous systems:** Human enhancement technologies can enable seamless and rich human-robot interfaces, also for complex applications. Robotics can improve human enhancement technologies, for example, prosthetic limbs.

INTERACTIONS WITH MEGATRENDS:

› **Changing nature of work:** Human enhancement technologies could improve many work-relevant abilities and increase productivity by enhancing many physical, cognitive and social capabilities.
› **Changing security paradigm:** Human enhancement technologies could find significant applications in defence and security by improving the key relevant attributes e.g. in soldiers.
› **Diversification of education and learning:** Human enhancement technologies could improve many learning-relevant mental attributes and thus enhance learning.
› **Widening inequalities:** Human enhancement technologies are likely to exacerbate inequalities due to there being unequal access to them between the rich and the poor.
› **Shifting health challenges:** Human enhancement technologies could have a groundbreaking impact on life quality and length, with all the attendant benefits.

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2.9 CYBER TECHNOLOGIES

PROTECTING OUR INCREASINGLY DIGITAL WAY OF LIFE

DESCRIPTION:

Cyberspace can be defined as the virtual and physical space of all information technology systems linked at the data level on a global scale. The basis for cyberspace is the internet as a universal and publicly accessible connection and transport network that can be complemented and further expanded by any number of additional data networks. **Cyber technology** can be defined as the study of the hardware, software, services and connections that make up cyberspace. The overarching focus of cyber technologies is on how to defend against and mitigate threats to cyberspace. Cybersecurity, also referred to as information technology security, focuses on protecting computers, networks, programs and data from unintended or unauthorised access, change or destruction.

Critical infrastructures are composed of public and private institutions in key sectors, including agriculture, public health, emergency services, government, information and telecommunications, energy, transportation, banking and finance. Cyberspace is their nervous system – the control system of society. Cyberspace comprises a large number of interconnected computers, servers, routers, switches, cables and wireless connections that allow these critical infrastructures to work. Thus, the healthy functioning of cyberspace is essential to society.

Cybersecurity can be broken down into five broad categories, each of which includes several subcategories, as is discussed below.

Attack and defence aspects include the following:

- *Malware and attack technologies* focus on discovering and taking advantage of exploits and developing distributed malicious systems, as well as applying the associated discovery and analysis approaches.
- The study of *adversarial behaviours* includes the motivations, behaviours and methods used by attackers. These include malware supply chains, attack vectors and money transfers.
- *Security operations and incident management* focus on the configuration, operation and maintenance of secure systems. This includes the detection of and response to security incidents and the collection and use of threat intelligence.
- *Forensics* focuses on the collection, analysis and reporting of digital evidence in support of incidents and criminal events.

Systems security aspects include the following:

- *Cryptography* focuses on the main mathematical cryptographical principles as well as emerging algorithms and the protocols that use them.
- *Operating systems and virtualisation security* involve protection mechanisms for operating systems, implementing the secure abstraction of hardware and the sharing of resources. These include isolation in multiuser systems, secure virtualisation and security in database systems.
- *Distributed systems security* involves security mechanisms relating to larger-scale coordinated distributed systems. This includes peer-to-peer systems, clouds, multitenant data centres and distributed ledgers.
- *Authentication, authorisation and accountability* involve all aspects of identity management and authentication technologies as well as architectures and tools to support authorisation and accountability in both isolated and distributed systems.

Software and platform security aspects include the following:

- *Software security* focuses on categories of programming errors resulting in security bugs, and techniques for avoiding these errors, both through coding practice and improved language design. This also includes tools, techniques and methods for the detection of such errors in existing systems.
- *Web and mobile security* aims to overcome issues related to web applications and services distributed across devices and frameworks. This includes the diverse programming paradigms and protection models.
- *Secure software lifecycle* applies security software engineering techniques in the whole systems development life cycle, resulting in software that is secure by default.

Infrastructure security aspects include the following:

- *Network security* focuses on networking and telecommunication protocols, including the security of routing, network security elements and specific cryptographic protocols used for network security.
- *Hardware security* involves security in the design, implementation and deployment of general-purpose and specialist hardware, including trusted computing technologies and sources of randomness.
- Cyber-physical systems security aims to address security challenges in cyber-physical systems, such as the internet of things and industrial control systems, as well as to study the security of large-scale infrastructures.
- *Physical layer and telecommunications security* addresses security concerns and the limitations of the physical layer, such as aspects of radio frequency encodings and transmission techniques, and interference.

Human, organisational and regulatory focus on non-technical aspects such as governance, regulation, human factors and privacy.

Cyberspace, as defined above, is predicted to undergo expansion as adjacent technology fields mature in the future. For example, cyberspace will be expanded to various types of objects and devices via the internet of things, and even to the human body itself through human enhancement technologies such as brain interfaces. The attendant requirements for cybersecurity will thus become more and more demanding. The advancement of further adjacent technologies (e.g. artificial intelligence) will increase the sophistication of other cybersecurity technologies themselves (e.g. attack and defence methods).

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

The table below summarises the functions that are generally provided by the use of cyber technologies, which impact metrics for these functions are expected to improve and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF CYBER TECHNOLOGIES	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
ATTACKS AND DEFENCES	• FULLY AUTOMATED DISCOVERY OF COMPLEX SEMANTIC VULNERABILITIES. • FULLY AUTOMATED GENERATION OF EXPLOITS FOR NON-TRIVIAL VULNERABILITIES. • NEXT-GENERATION MALWARE: UNDETECTABLE BACKDOORS IN MACHINE LEARNING MODELS. • IMPROVED DETECTION OF AND RESPONSE TO ATTACKS.	• AUTOMATED VULNERABILITY DISCOVERY IN SOFTWARE AND SYSTEMS. • AUTONOMOUS HACKING BOTS AND ARMIES WITH LITTLE OR NO HUMAN INVOLVEMENT. • AUTOMATED DEFENCE OF SYSTEMS.
SYSTEMS SECURITY	• ADOPTION OF TRUSTED EXECUTION ENVIRONMENTS. • PASSWORD-LESS AUTHENTICATION, E.G. BASED ON BIOMETRIC DATA. • GLOBAL DATA PROCESSING POLICIES SIMILAR TO THE EU'S GDPR AND AI ACT.	• PLATFORM-AGNOSTIC SYSTEMS (ON-PREM VS. CLOUD IRRELEVANT). • POST-QUANTUM CRYPTOGRAPHY. • CONSOLIDATION OF SECURITY SERVICE PROVIDERS (E.G. WITH SASE).
SOFTWARE AND PLATFORM SECURITY	• IMPROVED SECURITY IN SOFTWARE DEVELOPMENT THROUGH AUTOMATION. • AI-SUPPORTED SOFTWARE ENGINEERING (CODE ASSISTANT) • WIDESPREAD USE OF BOMS (BILL OF MATERIALS)	• SECURE CODING APPROACHES. • SOFTWARE ENGINEERING FOR "DUMMIES" THROUGH THE USE OF LLMS.
INFRASTRUCTURE SECURITY	• FRAGMENTATION OF NETWORKS. • WIDESPREAD USE OF TRUSTED COMPUTING ENVIRONMENTS. • REGULATION OF IOT AND INDUSTRIAL CONTROL SYSTEM SECURITY.	• ZERO-TRUST NETWORK ARCHITECTURES. • AUTOMATION OF TESTED INFRASTRUCTURE DEPLOYMENTS. • TRUSTED EXECUTION OF SOFTWARE. • ROBOTS REPLACE HUMANS FOR SOME TASKS.

Below, we will discuss the impact and the main uncertainties and challenges of cyber technologies for each category:

— **SOCIO-CULTURAL:**

- **Impact:** Cybersecurity approaches could enhance trust in data and communications security, among other things, and thus have a dramatic impact on the social adoption of the many adjacent technologies that depend on these (e.g. data and artificial intelligence, human enhancement). Alternatively, if malicious approaches prevail, they could have the opposite effect.
- **Main uncertainties and challenges:** How will cyber technologies affect social attitudes towards security and privacy? How will the current drive towards digitisation develop?

— **TECHNOLOGICAL:**

- **Impact:** Cybersecurity technologies will enable the protection of sensitive information, thus assisting many applications and technologies that rely on the use of such data. They can also enhance secure communication and data exchange over networks, ensuring the confidentiality, integrity and authenticity of transmitted information, once more facilitating the operation of many future applications depending on these capabilities.
- **Main uncertainties and challenges:** To what extent will artificial intelligence affect cyber technologies? How will the assumed groundbreaking impact of quantum cryptography and computing affect cyber technologies? What will the timelines be for such disruption?

— **ECONOMIC:**

- **Impact:** Cyber attacks on the infrastructure of the future (power grids, transportation systems and healthcare facilities) could have devastating economic effects, both directly and indirectly (knock-on economic effects), and even human casualties. Cybersecurity technologies used to either attack or defend such infrastructure and functions that are critical to the economy will then have an outsized impact.
- **Main uncertainties and challenges:** How can organisations ensure return on investment on cybersecurity technologies? How can the economic benefits of cybersecurity technologies be quantified? How can the rising need for cybersecurity specialists be met?

— **ENVIRONMENTAL:**

- **Impact:** Defensive cybersecurity approaches could deter cyber attacks that could have negative environmental consequences, for example attacks on dams or energy plants. Some cyber technologies are inherently very resource-intensive (e.g. for training large language models) and may have a negative environmental effect.
- **Main uncertainties and challenges:** How will the resource and energy efficiency of the software, hardware and infrastructure required to implement cyber technologies evolve?

— **(GEO)POLITICAL, REGULATORY:**

- **Impact:** In a world of increasing geopolitical tension, cyberspace will become another contested domain. Cyber technologies will offer increasingly sophisticated tools in this competition. Such "weaponised" cyber tools might require regulation, for example by cyber "arms control" treaties.
- **Main uncertainties and challenges:** How will the dynamic regulatory environment (laws, regulations, compliance requirements at national and international levels) surrounding cybersecurity evolve? To what extent will regulatory developments impact cybersecurity practices? What will be the "strategic balance" between offensive and defensive cyber weapons? What global standards should be developed to assist in the regulation of cyber technologies?

WEAK SIGNALS:

› **Safe Security** has developed a platform for the fast estimation of business cyber risks for the purposes of insurance.
› The US government has issued a "**Space Policy Directive**" for cybersecurity in space, encouraging public and private space actors to think about cybersecurity from the earliest phases of spacecraft development.
› Researchers from **MIT** have developed a method of quantitatively evaluating cybersecurity methods. The framework analyses how probable it is for attackers to overcome specific weaknesses and steal secret information.
› **Renewable energy and resilience:** Cybersecurity approaches can help safeguard future energy infrastructure and make it more resilient to cyber attacks.
› **Human enhancement technologies:** Impressively, through human enhancement technologies, the human body and even the brain could become part of cyberspace, thus potentially making humans vulnerable to cyber-attacks.
› **Robotic and autonomous systems:** Autonomous and robotic systems will form a significant part of the cyber domain.
› **Digital communication:** Novel digital communication methods will further increase connectivity within cyberspace as well as enable its dramatic expansion.

INTERACTIONS WITH OTHER TRENDS:

› **Data science and AI:** Novel artificial intelligence methods will play a critical role in the development of both novel offensive and defensive cyber tools.
› **Immersive technologies:** Cyber technologies and security are key building blocks for ensuring that immersive technologies are established on solid foundations.
› **Quantum technologies:** Quantum computing has the potential to significantly disrupt cybersecurity by rendering current cryptography approaches obsolete, as well as by proving new quantum-based cryptography methods.
› **Sensor technologies:** Novel sensors could form a part of extended networks within cyberspace. The potential dramatic increase in the number of sensors could significantly increase the "attack surface" for potential cyber attacks.
› **New space technologies:** Space is increasingly becoming part of cyberspace and it is also in need of more sophisticated cybersecurity solutions.
› **New materials and digital production:** Novel digital production approaches (e.g. internet of things) will expand cyberspace dramatically.

INTERACTIONS WITH MEGATRENDS:

› **Changing security paradigm:** A changing security and geopolitical paradigm will increase competition and conflict in the cyber domain, as well as the need for more sophisticated cyber security solutions.
› **Continuing urbanisation:** The ongoing smartification of cities depends on cyber technologies; thus, infrastructure is exposed to the significant security risk of cyber attacks.
› **Changing nature of work:** There will be an increase in demand for security experts in all digitally driven industries.
› **Increasing influence of new governing systems:** The threats of cyber attack-induced manipulation hinder the further digitisation of elections and the governmental participation of citizens, as well as the complete digitisation of public services.
› **Shifting health challenges:** With personal health data being transferred and stored in cyberspace, the risk of this data being hacked or intercepted increases.

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2.10 DIGITAL COMMUNICATION

ENHANCING CONNECTIVITY AND ENABLING SEAMLESS COMMUNICATION GLOBALLY

DESCRIPTION:

Digital communication is defined as the transfer of digital information between different points. Most communication systems used for transferring information today are either digital or are being converted from analogue to digital. Such communications can be either wired or wireless. **Digital connectivity** encompasses digital networks, from mobile and fixed structures to the internet, including cables and satellites. We will treat the terms "digital communications" and "digital connectivity" as synonymous for the purposes of this report.
Existing connectivity technologies are penetrating more broadly across geographies and domains. At the same time, the latest standards are making them more robust. Advanced connectivity technologies are enabling new use cases.

Fibre optic networks offer reliable, high-throughput[12], low-latency[13] connectivity provided through a physical wire. They have seen rapid growth in the past and provide millions of people with high-speed internet. Fibre optic networks continue to expand.

Next-generation Wi-Fi (Wi-Fi 6) aims to improve speeds while supporting many additional connected devices. It has the potential to make the biggest difference in crowded environments such as airports, apartment buildings and stadiums. Due to its performance and security characteristics, it is also suitable for industrial applications.

[12] A measure of how many units of information a system can process in a given amount of time.
[13] The delay in network communications.

Mobile cellular networks are being upgraded from the current 4G infrastructure to 5G. Low- to mid-frequency 5G networks can offer significant improvements in speed and latency, all while supporting a greater density of connected devices. High-band, also known as millimetre-wave or standalone, 5G networks represent a jump in performance. Designed to be the most ultra-fast mobile option, high-band 5G promises to achieve first-class speed, latency, reliability, and security performances, expanding upon what mobile devices can do. However, there is a significant amount of effort and costs involved in upgrading the infrastructure required for high-band 5G. Beyond the current approaches, 6G systems are the next frontier in wireless communications. Such systems aim to create an omnipresent wireless network that is intelligent, reliable, scalable, secure and incorporates both terrestrial and space communications.

Wireless personal area network technologies include Bluetooth, NFC (near-field communication), and RFID (radio frequency identification). RFID enables one-way contactless communication between devices, while NFC is a newer form that can support close-range two-way communication. Bluetooth enables data exchanges between fixed and mobile devices using radio waves and building personal area networks.

Low-power wide-area networks (LPWANs) provide connectivity over broader areas and longer ranges. Since LPWANs require less power from the devices they connect, they could enhance the devices' battery lifespan (e.g. by several years or more). Different protocols exist in this realm (e.g. LoRa, NB-IoT and SigFox). These standards are designed from the ground up to optimise internet of things devices.

Low Earth orbit satellites aim to deliver a breakthrough in the breadth of coverage. They target areas in which laying fibre or building tower networks would be too expensive. This is achieved by deploying constellations of numerous satellites in a low orbit around Earth, with each satellite orbiting simultaneously. These constellations also provide significantly reduced latency in comparison with existing satellite offerings.

In the future, the above solutions will be developed to offer global, ubiquitous, high-performance and secure connectivity. Additionally, they will evolve to cover the many and increasingly challenging use cases of connectivity.

The advancement of wireless technologies will be mainly driven by two technological factors: cloud computing and the internet of things:

- *Cloud computing* refers to a network model in which applications reside on network servers and are accessed from the end client, for example via a personal computer. Cloud computing is expected to increase in popularity. This trend places enormous strain on the communications infrastructure and the technology must be able to deal with the combined challenges of growing user mobility and more mobile computing.
- The *internet of things* pertains to the pervasive inclusion of internet connectivity, typically wireless, in common everyday objects. Currently, tens of billions of devices are connected to the internet and this number is projected to grow exponentially. Wireless technology will be a key enabler in realising this vision.

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

The table below summarises the functions that are generally provided by the use of digital communication, which impact metrics for these functions are expected to improve and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF DIGITAL COMMUNICATION	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
OPTICAL FIBRE (TERRESTRIAL WIRED)	• HIGHER THROUGHPUT. • LOWER LATENCY. • LOWER MAINTENANCE COSTS.	• BACKBONE OF MODERN TELECOMMUNICATIONS NETWORKS. • INTERNAL DATA CENTRE COMMUNICATIONS.
LOW-POWER WIDE-AREA (TERRESTRIAL WIRELESS)	• MORE CONNECTED DEVICES. • HIGHER ENERGY EFFICIENCY. • EXTENDED COVERAGE. • LOWER CONNECTIVITY COST.	• ASSET TRACKING AND LOGISTICS. • CONNECTIVITY FOR SMART CITIES.
WI-FI 6 (TERRESTRIAL WIRELESS)	• IMPROVED SPEED, RANGE AND SECURITY. • MORE SUITABLE FOR INDUSTRIAL APPLICATIONS.	• CONNECTIVITY FOR INDUSTRIAL INTERNET OF THINGS. • HIGH-PERFORMANCE INTERNET CONNECTIVITY FOR CROWDED ENVIRONMENTS.
5G/6G CELLULAR (TERRESTRIAL WIRELESS)	• HIGHER THROUGHPUT. • MORE CONNECTED DEVICES. • HIGHER SPECTRUM EFFICIENCY. • BETTER QUALITY OF SERVICE. • HIGHER SECURITY. • LOWER LATENCY.	• ULTRA-HD VIDEO STREAMING. • REMOTE SURGERY AND TELEMEDICINE. • 6G NON-TERRESTRIAL NETWORKS.
LOW-EARTH ORBIT SATELLITE CONSTELLATIONS (EXTRATERRESTRIAL WIRELESS)	• INCREASED COVERAGE. • LOWER LATENCY (COMPARED TO OTHER SPACE-BASED SOLUTIONS).	• MARITIME AND AVIATION CONNECTIVITY. • GLOBAL CONNECTIVITY FOR AUTONOMOUS VEHICLES.

Below, we will discuss the impact and the main uncertainties and challenges of digital communications for each category:

— **SOCIO-CULTURAL:**

- **Impact:** Overall quality of life could be enhanced with ubiquitous connectivity and significantly higher quality of service. This enables individuals, for example, to work remotely, access bandwidth-heavy services and stream higher-quality content. Connectivity will furthermore be a major asset in the treatment of chronic diseases, enabling monitoring at home with connected medical devices. Finally, a large proportion of the global population could receive access to the internet for the first time thanks to new connectivity technologies.
- **Main uncertainties and challenges:** To what extent will the dramatic increase in connectivity have a social and cultural impact, also for people that did not have internet access before?

— **TECHNOLOGICAL:**

- **Impact:** Digital connectivity is a key enabler for revolutionary capabilities reliant on high-quality connectivity. For example, edge and cloud computing technologies, coupled with advanced connectivity, will unlock the full benefits of next-generation computing for consumers and industry. Using the internet of things, logistics providers could track and trace products, and thus optimise supply chains and improve overall operational efficiency. High-quality network access could enable self-driving connected vehicles equipped with features even in remote locations.
- **Main uncertainties and challenges:** How can the dual challenge of too many signals in the crowded electromagnetic spectrum and increased demand for wireless communications be overcome? How might the technical architecture of computing systems evolve thanks to connectivity technologies (e.g. cloud, edge)? Which aspect of use cases should be addressed by advanced connectivity methods (5G, 6G, space), and which use cases can be satisfied by more cost-efficient legacy approaches (e.g. 4G)?

— **ECONOMIC:**

- **Impact:** As a key enabler of numerous emerging technologies, digital connectivity could have an outsized economic impact. It has been estimated that it can add a GDP value of $1.2 trillion to $2 trillion in the sectors of mobility, healthcare, manufacturing and retail alone. The enabled internet of things solutions further contribute by increasing productivity, lowering energy consumption and reducing overall costs in factories.
- **Main uncertainties and challenges:** How will the fragmented nature of demand across many small use cases affect the economic viability of digital connectivity offerings? How will the capital intensiveness of some advanced connectivity methods (e.g. 5G, 6G, space) affect the same economic viability? Which types of new actors might become connectivity providers (e.g. telecom operators versus tech companies)?

— **ENVIRONMENTAL:**

- **Impact:** The internet of things solutions enabled by digital connectivity technologies could increase efficiency levels and decrease energy consumption throughout the value chain in a multitude of sectors, thus providing a significant positive environmental impact.
- **Main uncertainties and challenges:** What will the net climate impact of connectivity technologies be in terms of the resources needed for the production of connectivity technologies compared to the energy savings and efficiency increases they offer?

— **(GEO)POLITICAL, REGULATORY:**

- **Impact:** Countries from the global south stand to benefit significantly from advanced connectivity technologies and cheap global coverage in the future.
- **Main uncertainties and challenges:** How can concerns about data privacy, confidentiality, integrity and security be dealt with? Can the wide variety of stakeholders (e.g. public infrastructure agencies, automotive industry, tech industry) cooperate adequately to ensure the necessary regulation and standardisation?

WEAK SIGNALS:

› **Deere & Co.** is collaborating with SpaceX to offer internet connectivity in rural USA and Brazil via Starlink.
› **GM** has partnered with **AT&T** to equip several vehicle models with 5G mobile communications with the aim of enhancing transmission speeds for improved software performance, navigation and media streaming.
› **Dreamworld AR**, a US start-up, is creating a lightweight headset with enhanced resolution and 5G connectivity, making it able to connect to various devices easily.
› Ukrainian start-up nect **World** is introducing a thin, portable modem offering fast internet anywhere.
› **Omnispace** and **Lacuna** have announced a collaboration to deliver a global LoRaWAN® internet of things service.

INTERACTIONS WITH OTHER TRENDS:

› **Data science and AI:** Increased connectivity will contribute to the future exponential increase of generated data. AI methods can be used to enhance 6G services, for example, by means of smart networks and spectrum use management.
› **Immersive technologies:** Digital connectivity is a key enabler for cloud-based immersive technologies, for example portable, high-definition immersive technology headsets.
› **Quantum technologies:** None. Quantum encryption and decryption (quantum computing) technologies could offer security improvements and pose security hazards.
› **Sensor technologies:** Digital connectivity is a cornerstone technology for future ubiquitous sensor networks.
› **New space technologies:** Space-based services are a main component of digital connectivity technologies. Digital connectivity methods could also prove useful in space applications (e.g. exploration).
› **New materials and digital production:** Digital connectivity is a cornerstone technology for digital production methods, such as the industrial internet of things.
› **Renewable energy and resilience:** Digital connectivity can enable smart energy grids. It can also reduce energy use for example in industrial settings that make use of it.
› **Human enhancement technologies:** Digital connectivity is key for human enhancement technologies in which communications and networking play a role.
› **Cyber technologies:** Digital connectivity technologies are arguably the most important part of cyberspace, as they provide the means for connection between its parts.
› **Robotic and autonomous systems:** Connectivity is key in robotic applications where more than one robot is involved (e.g. robotic swarms).

INTERACTIONS WITH MEGATRENDS:

› **Changing nature of work:** Improved connectivity could further accelerate current trends such as remote working.
› **Changing security paradigm:** Increased connectivity could pose data security risks.
› **Continuing urbanisation:** Digital connectivity could be key for smart city infrastructure.
› **Diversification of education and learning:** Digital connectivity could enable novel education and learning approaches, such as remote augmented or reality learning.
› **Expanding influence of East and South:** Countries from the global south stand to benefit significantly in the future from advanced connectivity technologies and cheap global coverage.
› **Shifting health challenges:** There are significant applications of connectivity in the medical sector, for example, connected medical devices can monitor chronic diseases in real time.

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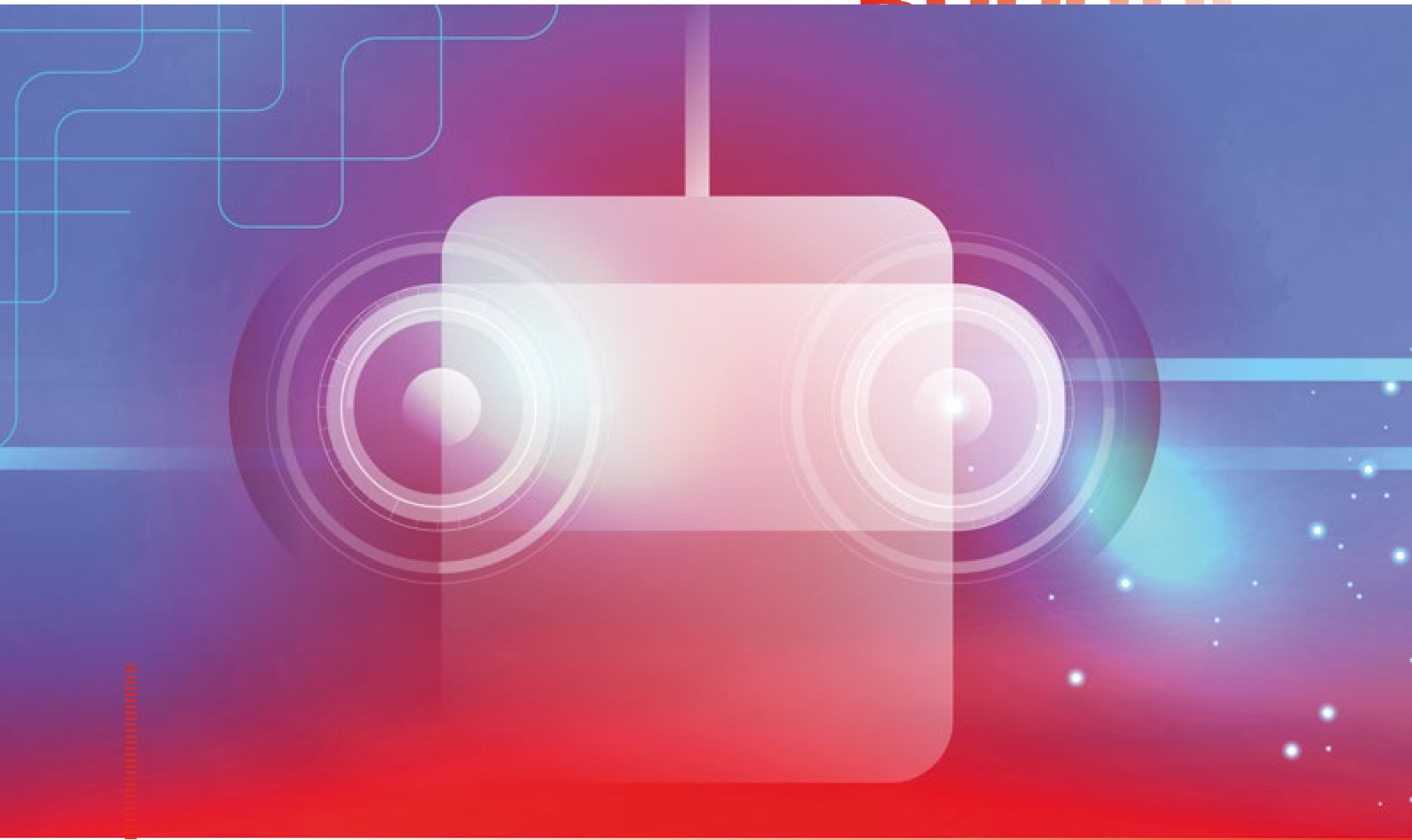

2.11 ROBOTIC AND AUTONOMOUS SYSTEMS

SMART MACHINES WORKING FOR AND WITH HUMANS

DESCRIPTION:

Autonomy is the ability of a system to respond to uncertain situations by independently composing and selecting from different courses of action to accomplish goals based on knowledge and a contextual understanding of the world, itself and the situation. Autonomy is characterised by degrees of self-directed behaviour (levels of autonomy), ranging from fully manual to fully autonomous. **Robotics** is the study of designing and building autonomous systems spanning all levels of autonomy (including full human control).

Robotic and autonomous systems are mainly deployed to take on dull, dirty and dangerous, and dear tasks (the four D's of robotisation).

Dull tasks include repetitive and tedious tasks. These can range, for instance, from manufacturing to data input and logistics. The use of autonomous vehicles in logistics and warehouses as well as in agricultural tasks are good examples. Using robotics and autonomous systems for these types of tasks reduces the need for human labour and the attendant costs.

Dirty and dangerous tasks involve the handling of hazardous substances, exposure to unsanitary conditions and in general tasks that put the integrity or health of humans at risk. In factories, for example, autonomous robots can take over tasks that involve handling toxic or hazardous materials. Autonomous robots can also explore underground tunnels for minerals and perform rescue tasks in disaster areas.

Dear tasks are those where one cannot afford to err. If done well, robotic and autonomous systems can eliminate human error in these tasks, while also reducing cost and increasing efficiency levels. Such tasks include autonomous means of transportation, defence and security, and medical operations, for example robotically performed surgery.

Robotic functions can be categorised in the general categories of sense (e.g. sensing and perceiving), plan (e.g. sense making, decision making, control), and act (e.g. actuation, manipulation, locomotion). Autonomous and robotic systems can perform these tasks with various levels of autonomy. Robotic autonomy can be categorised along a spectrum, depending on which of these functions are automated and at what level. A typical framework categorises five levels of autonomy:

- **Remotely controlled** with a human in the loop, making all the decisions.
- **Simple automation** with some automation techniques to reduce operator workload.
- **Remotely operated** with an operator allowing onboard systems to do the controlling and only deciding where to go, when and what to do once there.
- **Highly automated** or semi-autonomous systems perform complex tasks, understand the environment, adjust their mission dynamically, require limited human supervision and adapt to failures and changes.
- **A fully autonomous** system executes tasks from high-level objectives with extensive situational awareness, prognostics and decision-making authority without human intervention.

In the future, an ever-increasing number of challenging tasks from the four D categories will be performed at higher and higher levels of autonomy. The level of autonomy for each task in each use case will depend on the mission requirements, technical capabilities and limitations, and the legal/policy constraints. Human-machine collaboration will be a key element of such systems.

The increasing viability of robotic and autonomous systems is driven by technological factors and other factors in all three key functions of robotics: cheaper and smaller sensors, more agile, capable, small, and cheaper actuators, and advances in computing, autonomy and artificial intelligence. These developments allow for better autonomous decision making, sense making and planning by robots.

IMPACT AND THE MAIN UNCERTAINTIES AND CHALLENGES:

The table below summarises the functions that are generally provided by the use of robotic and autonomous systems, which impact metrics for these functions are expected to improve and a number of example applications that these improvements would enable.

HIGH-LEVEL CATEGORISATION OF ROBOTIC AND AUTONOMOUS SYSTEMS	POSSIBLE FUTURE IMPROVEMENTS	EXAMPLE APPLICATIONS ENABLED
DULL FUNCTIONS	• DECREASE OF AMOUNT OF LABOUR. • INCREASE OF PRODUCTION FLEXIBILITY.	• MANUFACTURING. • WAREHOUSE LOGISTICS. • GUARD DUTY.
DIRTY AND DANGEROUS FUNCTIONS	• DECREASE IN RISK TO HUMAN LABOUR. • DECREASE OF ASSOCIATED COSTS. • ENABLING PREVIOUSLY UNFEASIBLE USE CASES.	• SEARCH AND RESCUE. • UNDERGROUND PROSPECTING AND MINING.
DEAR FUNCTIONS	• DECREASE OF HUMAN ERROR IN COSTLY APPLICATIONS. • DECREASE OF RISK TO HUMAN LIFE.	• MANUFACTURING. • MEDICAL APPLICATIONS E.G. AUTOMATED SURGERY. • SECURITY AND MILITARY APPLICATIONS. • LAB AUTOMATION.

Below, we will discuss the impact and the main uncertainties and challenges of obotic and autonomous systems for each category:

— SOCIO-CULTURAL:

- **Impact:** Robotic and autonomous systems will disrupt the employment market. Demand for dull, dirty, dangerous and dear labour is expected to be reduced over time, while new jobs are created in robotic and autonomous systems-related jobs, such as in programming, design and system maintenance. Collaborative work with robotic and autonomous systems will change how work is carried out. Overall, robotic and autonomous systems can yield high-potential social advantages such as increased safety, a better quality of life and cost savings.
- **Main uncertainties and challenges:** What will be the net effect of robotic and autonomous systems on employment? How will any of the social benefits of robotic and autonomous systems be socially distributed? How can issues surrounding human-machine collaboration (e.g. increased cognitive load, the need for training, a change of working habits) be overcome? What ethical challenges may arise, for example for defence and security applications, and how can they be overcome?

— TECHNOLOGICAL:

- **Impact:** A wide variety of sectors will be affected by advancements in robotic and autonomous systems. Industrial robots are already being widely deployed in a wide range of manufacturing industries. More capable robots will be able to replace human labour, for example in agriculture. Automated driving is poised to disrupt the transportation and logistics sectors, also considering advances towards more reliable autonomy. In healthcare, applications include surgery assistance, hospital logistics, patient rehabilitation and long-term care. In military applications, robotic and autonomous systems can have an impact on the battlefield (e.g. providing assistance to soldiers, targeting and as weapons platforms) on operational support (e.g. logistics and planning) as well as on intelligence and reconnaissance.
- **Main uncertainties and challenges:** Will the very high reliability of automated and autonomous systems required be achieved for specific applications (e.g. transportation)? What level of autonomy will be necessary for many of these applications, and what will the role of humans be within them?

— ECONOMIC:

- **Impact:** The above improvements will have a dramatic impact. By taking care of dull tasks, overall labour costs could be dramatically reduced and human labour could be freed up to take care of more productive tasks. When performing dirty and dangerous jobs, they safeguard human capital and the associated costs of mitigating and treating the risks associated with these activities. When carrying out dear tasks, they reduce the costs associated with critical errors that humans would make and add value by allowing the performance of more of these dear tasks.
- **Main uncertainties and challenges:** Will specific use cases for robotic and autonomous systems be competitive, and at what levels of autonomy? How will tech companies disrupt incumbent companies in their respective sectors?

— ENVIRONMENTAL:

- **Impact:** Autonomous and robotic systems will affect the environmental footprint in different sectors in different ways. Autonomous systems can have significant benefits for some environmental issues, for example cleaning microplastics from the oceans and monitoring and putting out forest fires. Alternatively, the increased demand for resources and energy to support these systems could have a negative net impact.
- **Main uncertainties and challenges:** How will the energy and resource efficiency of robotic and autonomous systems evolve? Are there feasible and practical use cases

— (GEO)POLITICAL, REGULATORY:

- **Impact:** Robotic and automated systems in the military and security sector could have a strong impact on strategic stability, making war more or less likely. More autonomous vehicles and platforms will tend to collect a growing amount of user data, raising implications for privacy and data security.
- **Main uncertainties and challenges:** How will data collection, privacy and security be regulated? How will varying degrees of regulation affect the viability of some use cases?

WEAK SIGNALS:

› Automotive manufacturers and tech companies are collaborating on self-driving technology.
› The Chinese startup **Unitree** is developing a ChatGPT-based robot dog.
› **Airbus** is developing a pilot system designed to aid in in-flight emergencies.
› **BotBuilt**, a US start-up, is creating pioneering technology to automate house construction.
› **University of North Carolina at Chapel Hill** is developing an autonomous robotic needle for medical use.

INTERACTIONS WITH OTHER TRENDS:

› **Data science and AI:** Increased use of intelligent, widely distributed, ubiquitous, cheap, interconnected sensors and autonomous entities (physical or virtual) will lead to volumes of data. Data science and artificial intelligence methods can both take advantage of this wealth of data, as well as enable its analysis.
› **Immersive technologies:** Immersive technologies will be a central building block of any human-robotic collaboration interface and effort.
› **Quantum technologies:** Quantum computing might become relevant to planning, decision-making and optimisation problems in robotics and autonomy.
› **Sensor technologies:** New robotic and autonomous platforms will host widely distributed, ubiquitous, cheap, interconnected sensors, thus enabling many applications.
› **New space technologies:** New space technologies are critical for the infrastructure needed for key robotic and autonomous systems applications, such as positioning, navigation and control to enable for example the industrial internet of things. Robotic and autonomous systems in space can make many key use cases possible, such as in-orbit servicing and orbit debris removal.
› **New materials and digital production:** Robotic and autonomous systems are central to future manufacturing methods and concepts, such as for Industry 4.0. Novel materials can enable more novel use cases for robotic systems.
› **Renewable energy and resilience:** Highly autonomous processes can be used, for example, to increase efficiency in the management of energy production and distribution. Robotic systems can be useful throughout the life cycle of renewable energy systems, from production and operation to maintenance.
› **Human enhancement technologies:** Robotic and autonomous systems are expected to play a central role as auxiliary systems for human enhancement technologies. The latter will also serve as a key technology for robotic-human interface methods.
› **Cyber technologies:** Autonomous and robotic systems are part of the cyber domain.
› **Digital communication:** Digital communication will play a central role in communications e.g. in distributed robotic systems and systems for remote operations.

INTERACTIONS WITH MEGATRENDS:

› **Aggravating resource scarcity and Growing consumption:** Robotic and autonomous systems will enable growth in the production of products and resources.
› **Changing nature of work:** Robotic and autonomous systems are a key driver of this megatrend and will require that the workforce be retrained or upskilled.
› **Changing security paradigm:** Robotic and autonomous systems will play a key role in the security paradigm of the future by augmenting surveillance capabilities, facilitating rapid threat responses and introducing new challenges such as cybersecurity risks and ethical dilemmas.
› **Continuing urbanisation:** Autonomous transportation will be key for increasingly urbanised societies.
› **Widening inequalities:** The replacement of many jobs by robotic and autonomous systems, and the increasing part that machinery plays in production over labour, might feed into this trend.
› **Increasing influence of new governing systems:** Robotic and autonomous systems might be used for repression.
› **Shifting health challenges:** Novel medical and care robotics might help in addressing these challenges.

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3 Megatrends

While technological advancements offer glimpses of possibilities, broader societal or environmental shifts paint a more complex picture. Megatrends are powerful forces that exert a long-term influence on this picture. These factors together shape the direction in which global development is heading. They represent fundamental shifts in behaviour, values and norms, influencing multiple aspects of human life, geopolitics and organisational operations. Understanding these megatrends is crucial for strategic planning. Unlike micro-trends (fashions or passing interests), megatrends are more enduring and interconnected. They act as the underlying currents shaping the future.

Scenario planning benefits greatly from incorporating megatrends. By considering these long-term forces, a wider range of possible futures can be explored. This allows businesses to gain the foresight to navigate not just the most likely path ahead, but also potential disruptions and unforeseen challenges that could radically alter their operating environment.

This section has categorised the European Commission's megatrends hub for reference. Accelerating technological change and hyperconnectivity was dismissed, as the technology trends section covers a wider range than that megatrend. Woke culture is a megatrend identified from the Trendone Trend Manager macrotrends repository. It has been renamed to diversity-aware culture, due to the controversial connotation of the term "woke". Therefore, the concluding number of megatrends discussed is fourteen.

The megatrends can be grouped into three broad categories:

- Socioeconomic trends: These megatrends encompass shifts in demographics, education, work and inequality.
- Environmental trends: These megatrends address resource scarcity, climate change and environmental degradation.
- Geopolitical trends: These megatrends reflect changes in the global landscape. They include the emergence of new powerful countries and the growing importance of migration.

For the discussion of the megatrends, a simplified version of the technology trend report format was used. A definition and description of the trend is provided. A discussion on the possible future development of the trend is provided for the relative near and long term. The relevance and impact, as well as the uncertainties and challenges surrounding a given megatrend, are discussed in the form of the STEEP framework (Sociological, Technological, Economical, Environmental and Political). Finally, the weak signals occurring for the respective megatrend are described.

It should be remembered that these are only a starting point. The real power comes from exploring these megatrends and how they interact, also in combination with the discussed technology trends.
The following sections contain a report for each of the megatrends.

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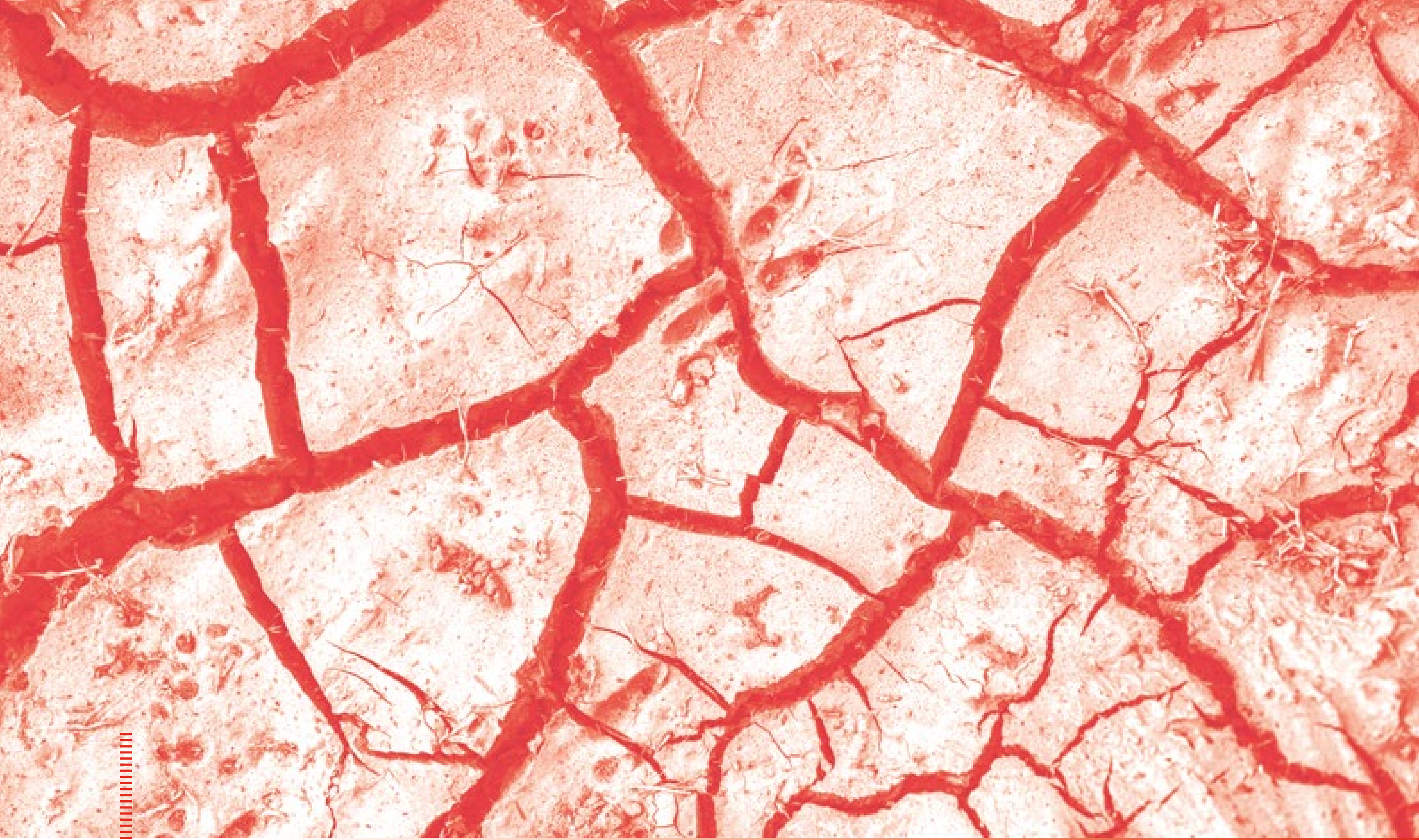

3.1 AGGRAVATING RESOURCE SCARCITY

A DISCONNECT BETWEEN HUMAN CONSUMPTION AND THE PLANET'S FINITE RESOURCES

DESCRIPTION:

The need for essential resources like water, food, energy, land and minerals is growing quickly. This growth is causing these resources to become scarcer and more expensive and this scarcity is in turn causing problems worldwide. These include water shortages, food scarcity and energy crises. Human well-being depends on certain resources. However, the Earth has a limited capacity and is struggling to keep up with increasing demands. This situation is pushing us beyond planetary boundaries and raises concerns for our long-term survival. This trend has been noticeable for many decades and has sped up recently, thus highlighting the need to quickly improve how we manage resources.

In the near term (multiple years to a decade), the world will be facing problems brought about by a rising global population and economic growth. This situation is causing a higher need for resources. In particular, the US and the EU-28 are greatly increasing global excess material use, stressing the importance of sharing natural resources more equally. This otherwise bears the potential to cause political instability, as countries compete for access to limited resources. Human activities have already changed 75% of the land and 66% of the sea. This exceeds the planetary boundaries, raising concerns for the ecosystem's long-term sustainability. Water scarcity will become increasingly acute in regions already facing stress, leading to conflicts over access and allocation. Food production will face challenges from climate change and land degradation, threatening the food security for vulnerable populations. Energy demands will continue to rise, with implications for energy access, affordability and environmental sustainability. Efforts to address these issues will require innovative solutions and greater collaboration across sectors and nations.

In the long term, the sustainable use of natural resources will be pivotal for humanity's survival. Critical resources could become scarce, calling for technological breakthroughs and advancements in material science. International cooperation is required to effectively manage and address inequalities in access. This will help prevent major geopolitical tensions over resources.

Below, we discuss the impact of aggravating resource scarcity for each category:

— **SOCIO-CULTURAL:**

In the realm of socio-cultural dynamics, the intensifying scarcity of resources may prompt shifts in societal values. Individuals might actively engage in shaping policies and behaviours to prioritise environmental impact over excess. However, this also disproportionately affects marginalised communities. The impact of aggravating resource scarcity is felt across societies globally.

— **TECHNOLOGICAL:**

Emerging technologies such as blockchain and artificial intelligence offer potential solutions to manage resources more efficiently. Innovations in urban farming and vertical agriculture demonstrate new approaches to resource management. Additive manufacturing and recycling are pivotal in fostering more sustainable production practices. However, technological advancements must be coupled with broader societal changes to address resource scarcity effectively.

— **ECONOMIC:**

More than 50% of the global gross domestic product relies directly on nature. Rising resource prices due to increased demand affect economic growth and global trade patterns. This underlines the importance of using resources sustainably and sharing them fairly. To deal with resource shortages and to meet the demand for sustainability, companies are adopting environmental, social and governance criteria in their operations. A push for sustainable economic

— **ENVIRONMENTAL:**

Human activities have already exceeded the planetary boundaries, leading to concerns about long-term ecosystem sustainability. Over 90% of extracted materials are wasted, with only 8.6% remaining in the circular economy. Climate change and land degradation pose significant challenges to food production and water availability, exacerbating resource scarcity. Efforts to protect biodiversity and transition to resilient energy sources demonstrate a commitment to sustainability despite regulatory and economic obstacles.

— **(GEO)POLITICAL, REGULATORY:**

Global governance is evolving to address resource issues, which has been evident from discussions at forums such as the United Nations focusing on equitable resource use globally. Geopolitical events impacting fossil fuel availability often highlight the importance of resource and energy efficiency. These elements are vital for geopolitical strategies, as competing for scarce resources could increase tensions and conflicts, highlighting the importance of international cooperation.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

How will changing societal attitudes towards consumption and sustainability impact resource management practices? Will there be widespread adoption of sufficiency-oriented behaviours, or will consumption patterns continue to drive resource depletion?

— **TECHNOLOGICAL:**

What role will emerging technologies play in mitigating resource scarcity and how quickly can they be implemented on a global scale? What are the potential unintended consequences or limitations of relying on technological solutions to address resource scarcity?

— **ECONOMIC:**

What economic shifts are necessary to promote sustainable consumption and equitable resource distribution? How will businesses balance profitability with environmental and social responsibility in addressing resource scarcity?

— **ENVIRONMENTAL:**

How will ecosystems adapt to increasing resource depletion and environmental degradation? What long-term consequences will failing to stop depleting resources have on biodiversity and ecosystem services?

— **(GEO)POLITICAL, REGULATORY:**

What geopolitical tensions might arise from competition over scarce resources and how can international cooperation mitigate these tensions? What regulatory frameworks are needed to incentivise sustainable resource management practices and how can they be implemented effectively across different regions and sectors?

WEAK SIGNALS:

There are signs of a major trend of worsening resource scarcity. More industries are adopting environmental rules and sustainability standards. This shows a rising awareness of the importance of saving resources and cutting down on waste. The increase in urban farming and vertical agriculture is demonstrating new ways of managing resources in order to form self-sufficient cities.

Consumers are changing their behaviour, showing a shift towards sufficiency. They are demanding products or services that promote low waste and long use, e.g. in the fashion industry. These should be based on circularity and reuse. Business ventures are meeting these customer demands. They are doing this by focusing on ESG, which stands for environmental, social and corporate governance. This means they evaluate their operations based on these criteria.

Furthermore, the rising prices of essential resources coupled with growing demand from emerging economies are escalating resource scarcity globally. Communities at the municipal level are focusing on protecting biodiversity and ecosystems in their construction plans. Meanwhile, state governments are moving towards more resilient energy sources by using renewables. These initiatives show a dedication to sustainability and using resources wisely, despite being confronted with obstacles such as regulatory rules and economic restraints. Collaboration and proactive efforts are essential to addressing resource scarcity effectively.

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3.2 CHANGING NATURE OF WORK

DESCRIPTION:

The Changing nature of work is about how jobs, career paths and company structures change. This happens because of new technology, global connections and changes in society and the economy. This transformation could be an enabler of increased flexibility, decentralised work and a healthier work-life balance. It is driving the normalisation of the gig economy and is also causing job displacements in some industries.

In the near term (multiple years to a decade), we expect to see a continued rise in remote, flexible, purpose-driven work arrangements. These are demanded by new generations entering the workforce. New generations entering the workforce, coupled with older generations working longer, contribute to this dynamic. Technological advancements will change job roles and the skills needed. There will be a big focus on IT and programming skills, which can be attributed to automation and digital transformation. The gig economy and freelancing will continue to grow, providing alternative employment models. The digital transformation and technologies enhancing automation are presenting both challenges and opportunities that reshape jobs and the necessary skill sets. Skill shortages in certain sectors are likely, as the demand for new technical skills outpaces the supply.

In the longer term, the transformative grip of technology on industries and labour could encourage the discussion universal basic income. This will be necessary to address the impact of AI and automation. Furthermore, governmental taxes on algorithms that displace human labour could be needed to maintain government revenue. Work could change from traditional models, with individuals potentially having multiple jobs. This will lead to a gig economy of self-employment. The first generation growing up with AI, called "AI Alphas", find it easy to use smart technologies from a young age. They learn how to shape these technologies.

Below, we discuss the impact of aggravating resource scarcity for each category:

— **SOCIO-CULTURAL:**

Societal and cultural shifts are altering the demands for a work-life balance and job satisfaction, with an increased desire for flexible, independent and meaningful roles. These changes in work dynamics are influencing the societal norms around employment and career trajectories, with a marked shift towards remote work, a work-life balance and individual autonomy. The rise of the gig economy also underscores a move away from traditional employment models towards project-based tasks and self-employment.

— **TECHNOLOGICAL:**

Automation and digital transformation are changing job roles. This change is raising the demand for information technology and programming skills due to the technological progress made, which creates innovation opportunities. However, it is also causing problems such as job displacement and skill mismatches. There's a growing need for upskilling, especially in IT and programming, in order to adapt to these changes. Additionally, there have been advancements in communication technology support remote work, allowing for collaboration without any physical constraints.

— **ECONOMIC:**

The gig economy and freelancing offer alternative work opportunities, transforming traditional employment and affecting the economy broadly, from income distribution to job market functioning and social welfare sustainability. These models also demand innovative approaches to retaining top talent, while providing economic flexibility for individuals and organisations. Yet, they may lead to skill shortages in areas where the demand for new technical skills exceeds supply, potentially affecting economic productivity and growth.

— **ENVIRONMENTAL:**

Remote work and flexible schedules can help lower carbon emissions by reducing commuting needs. Moreover, companies are now focusing more on sustainability and social responsibility, incorporating environmental sustainability into their core values.

— **(GEO)POLITICAL, REGULATORY:**

Governments and regulatory bodies may need to update labour laws to accommodate new work models, address job insecurity and reduce income inequality. The discussion surrounding universal basic income as a response to AI and automation's effects on jobs may grow. Additionally, it could be important to regulate algorithms that are displacing human work in order to maintain government revenue and promote social equity.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

How will society adapt to the increasing prevalence of remote work and non-traditional employment models? Will there be a cultural shift towards valuing flexibility and autonomy over job security?

— **TECHNOLOGICAL:**

What will be the long-term impact of automation and digital transformation on job roles and the overall labour market? How will individuals and organisations cope with the rapid pace of technological change and the need for continuous upskilling?

— **ECONOMIC:**

What measures can be taken to address skill shortages in critical sectors and ensure equitable access to opportunities in the digital economy? How will the growth of the gig economy impact traditional employment structures and economic stability?

— **ENVIRONMENTAL:**

How can remote work and sustainable employment practices be further incentivised to maximise environmental benefits? What role can governments and businesses play in promoting environmentally conscious work practices?

— **(GEO)POLITICAL, REGULATORY:**

What policies and regulations are needed to ensure fair treatment and protection for workers in the gig economy? How can governments balance the need for innovation and technological advancement with the preservation of jobs and social stability?

WEAK SIGNALS:

Signals show that the way in which organisations arrange their workforce and manage employment is changing significantly. First, more organisations are adopting remote work policies and flexible schedules. This change is driven by technological advancements and lessons from the COVID-19 pandemic. This trend reflects a growing recognition of the benefits of remote work in terms of flexibility, productivity and work-life balance. Additionally, the expansion of the gig economy and freelance platforms marks a major change in employment models. More people are choosing non-traditional, project-based work arrangements. This shift towards gig work highlights a desire for autonomy and flexibility among workers, as well as the emergence of new opportunities in the digital economy. Furthermore, companies are now focusing more on sustainability and meaningful work. This is seen in their values and mission statements. It shows a larger change in society towards ethical and socially responsible business actions. Companies are now understanding how important it is to share the same values as their employees and customers. This has caused them to start programs that focus on environmental sustainability and social impact. These manifestations collectively indicate a fundamental reimagining of work and employment structures. Organisations and individuals are embracing new ways of working that prioritise flexibility, purpose and social responsibility.

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3.3 CHANGING SECURITY PARADIGM

DESCRIPTION:

The changing security paradigm reflects a shift in how societies perceive and address security challenges. Traditionally, security focused primarily on military threats between nations. This megatrend covers a wide range of security issues. It includes both traditional and non-traditional threats. Non-traditional threats include cyberattacks, conflicts caused by climate change, and terrorism. They are driven by various factors, including technological advancements, evolving geopolitical landscapes and social changes. This shift impacts not only governments and military institutions, but also businesses, communities and individuals.

The global security scene is changing deeply. New players, technologies and geopolitical trends are driving this change. This shifting paradigm is characterised by the emergence of hybrid threats. Cyberspace is increasingly vulnerable to attacks, particularly on vital infrastructure. At the same time, outer space is seeing more military activity.

Advanced technologies are changing international relations and political power. These include artificial intelligence, autonomous weapons, big data, biotechnologies, hypersonic glide vehicles and quantum technologies.

In the near term (multiple years to a decade), traditional warfare is evolving. Hybrid threats, cyber warfare and the militarisation of outer space are becoming more common. Hybrid warfare, which blends conventional and political warfare, poses a challenging defence scenario, necessitating innovative security approaches. Cyberspace, now a crucial war domain, attracts extensive state investment and anticipates intensified cyberattacks. The race for space supremacy has been revived, potentially transforming space into a field of geopolitical conflict. Moreover, societal changes, including increased connectivity and migration, will further shape the security landscape.

In the long term, emerging technologies could enable unprecedented surveillance capabilities, raising concerns about privacy and civil liberties. There is a deepening reliance on technological innovations and unconventional tactics in security strategies. As hypersonic glide vehicles and quantum technologies develop, they will likely be added to military arsenals, which will shape how future conflicts unfold.

Additionally, environmental degradation and resource scarcity may exacerbate conflicts, necessitating innovative approaches to address climate-induced security challenges. The role of international cooperation and governance mechanisms in managing global security threats will become increasingly crucial.

Below, we discuss the impact of the changing security paradigm for each category:

— **SOCIO-CULTURAL:**

Cyberattacks are becoming more common, exposing weaknesses in crucial infrastructure. This trend erodes public confidence in digital systems. People's opinions on security are shifting, with a growing focus on privacy, surveillance, and activism. The conflict in Ukraine has broken the trust in a secure Europe. Moreover, climate disasters, terrorism and global violence are making people feel less safe.

— **TECHNOLOGICAL:**

Artificial intelligence, the internet of things and blockchain technologies are evolving quickly. They are revolutionising security through enhanced threat detection and better surveillance. Additionally, quantum computing offers advanced surveillance but raises ethical concerns about privacy and potential misuse by authoritarian governments. The militarisation of cyberspace and outer space represents new warfare and security fronts.

— **ECONOMIC:**

The evolving security landscape requires considerable investments in cybersecurity and defence technology, affecting economic priorities and resources. Security spending could boost the economy by funding defence, cybersecurity and infrastructure safeguarding. On the other hand, economic disparities and competition for resources may spark security challenges. They could disrupt trade, destabilise markets and increase defence spending at the expense of social and development projects. Furthermore, hybrid threats and cyber warfare present challenges for businesses, impacting supply chains, intellectual property and economic stability.

— **ENVIRONMENTAL:**

Environmental degradation, climate change and natural disasters are worsening security by exacerbating resource scarcity, triggering conflicts and displacing populations. These issues are amplifying social tensions and are threatening stability, leading to migration and food shortages. They are heightening conflicts over territories and resources, necessitating innovative solutions and global cooperation for effective crisis management.

— **(GEO)POLITICAL, REGULATORY:**

Geopolitical shifts and regulatory frameworks influence alliances, defence policies and international cooperation. Rising nationalism, land conflicts and power shifts affect security plans and trade ties. This impacts the stability of regions and worldwide security cooperation. Trends in geopolitics and power dynamics are driving military expansion into space. Meanwhile, territorial and resource tensions are underscoring the need for international collaboration and governance in addressing global security challenges.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

How will changing views on privacy and security affect the use of surveillance technologies? How will they influence government interference? How do rising public awareness and activism about security and privacy issues affect policymaking and governance?

— **TECHNOLOGICAL:**

What are the ethical dilemmas and regulatory issues stemming from developing and deploying advanced military technology such as autonomous weapons and quantum technologies? How will the integration of emerging technologies into security strategies affect the balance of power and international relations?

— **ECONOMIC:**

What are the economic implications of escalating cybersecurity threats and the need for significant investments in defence technologies? How will companies adjust to changes in security, specifically regarding supply chain resilience and intellectual property safety?

— **ENVIRONMENTAL:**

How will environmental degradation and resource scarcity exacerbate conflicts and influence security priorities and resource allocation? What innovative approaches are needed to address climate-induced security challenges? How will climate-induced security challenges impact economic and geopolitical dynamics?

— **(GEO)POLITICAL, REGULATORY:**

How will international cooperation and governance mechanisms address global security threats amid increasing geopolitical tensions and territorial disputes? How will hybrid threats and non-state actors influence global regulatory frameworks and security strategies?

WEAK SIGNALS:

Early indicators of the changing security paradigm are multifaceted and encompass various domains. Cyberattacks are becoming more common. One example is the SolarWinds Supply Chain Attack on governmental computer systems in the US in 2020. This shows that critical infrastructure is vulnerable to digital threats.

At the same time, both governments and non-government groups are using hybrid warfare strategies and are also developing advanced military technologies. This shows how conflicts and security threats are changing. Moreover, the growth in military activities in space by new actors is highlighting a change in the range of global politics. Both military and civilian surveillance operations are being deployed in space.

Additionally, growing geopolitical tensions over territorial disputes and resource extraction are contributing to the complex security environment. The rise of non-state actors and terrorist organisations exploiting societal grievances further complicates security dynamics. Heightened public awareness and activism on security and privacy issues reflect evolving societal attitudes towards security measures. Social media also plays a role in shaping public perception through propaganda, underscoring the importance of digital security and critical thinking in modern conflict.

Furthermore, the use of new technologies for monitoring and forecasting crime shows how tech improvements are being incorporated into security plans. Together, these manifestations emphasise the need for proactive measures and strategic foresight to address emerging security challenges effectively.

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3.4

CLIMATE CHANGE AND ENVIRONMENTAL DEGRADATION

DESCRIPTION:

Climate change and environmental degradation are two of the most pressing challenges facing humanity today. Climate change is caused by continued unabated, anthropogenic pollution and the release of greenhouse gases into the atmosphere. Environmental degradation is the destruction or damage of natural environments. Both climate change and environmental degradation have a significant impact on human health, livelihoods and ecosystems. Since the Industrial Revolution, human-induced global warming has escalated, causing rising temperatures, melting ice caps and extreme weather. The need to deal with this major trend comes from wanting to lessen its bad effects. These effects hurt ecosystems, economies and people's well-being. Urgent environmental action is necessary to mitigate the harm and avoid the worst effects of climate change and environmental degradation.

In the near term (multiple years to a decade), efforts to combat climate change and environmental degradation are expected to intensify. Governments, businesses and individuals will adopt more measures, aiming to reduce greenhouse gas emissions and promote sustainability. Additionally, they will adjust to changing environmental conditions. Regulatory frameworks will become tougher, which will encourage eco-friendly practices and punish environmental negligence.

Technological innovations in renewable energy, sustainable agriculture and waste management will play a crucial role in this transition. By 2030, emission-reducing solutions might be cost-effective and could be used in areas responsible for 70% of the world's emissions, including transportation, energy, buildings, agriculture and land use.

In the long term, without significant steps being taken to reduce climate change and environmental harm, serious damage will be caused to the planet. Continued advancements in technology and policy interventions will be essential for mitigating the most severe impacts of climate change. Depending on our actions, potential scenarios range from catastrophic environmental breakdowns to successful transitions to sustainable societies.

Below, we discuss the impact of Climate change and environmental degradation for each category:

— **SOCIO-CULTURAL:**

Awareness of environmental issues is increasing. This rise in awareness boosts demand for sustainable practices and products. It influences consumer choices, with preferences shifting towards sustainability, showing a higher demand for environmental accountability. Climate events such as disasters and resource shortages worsen social inequalities, fuelling displacement, conflict and migration.

— **TECHNOLOGICAL:**

Renewable energy advancements, including solar and wind, provide fossil fuel alternatives, cutting greenhouse gas emissions and boosting energy independence. Carbon capture and storage technologies capture and store carbon dioxide from industrial and power sources, lessening the environmental impacts. CRISPR-Cas9 genetic engineering innovations enhance crop resilience, tackling agricultural issues worsened by climate change.

— **ECONOMIC:**

Extreme weather and natural disasters are putting a lot of pressure on the infrastructure, agriculture, and insurance. Investing in renewable energy and improving energy efficiency, alongside adapting to a low-carbon economy, is necessary. Regulatory measures such as carbon pricing are aligning economic incentives with environmental goals, promoting a collective effort to combat climate change. Moreover, growing investment in renewable technologies and sustainable industries signals a shift towards a more environmentally conscious economy.

— **ENVIRONMENTAL:**

Biodiversity loss, habitat destruction and pollution are threatening ecosystems and essentials such as clean air, water and soil. Increasing temperatures and changing weather patterns are exacerbating environmental problems, leading to more droughts, wildfires and floods. The surge in greenhouse gas emissions and global temperatures calls for urgent climate action.

— **(GEO)POLITICAL, REGULATORY:**

International agreements such as the Paris Agreement aim to reduce emissions via global cooperation, but geopolitical tensions and national interests may obstruct these climate objectives. Domestic regulations significantly influence sustainable industries by incentivising renewable energy use and penalising environmental harm, affecting corporate strategies and investments. Regulations are anticipated to strengthen, promote eco-friendly practices and penalise environmental negligence, increasing pressure on governments for enforcement. Moreover, global cooperation and geopolitical tensions could arise in response to resource scarcity, climate-driven migration and the distribution of climate action responsibility.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

In what ways might cultural norms shape environmental trends in different regions? How will societal values evolve in response to climate change? What uncertainties surround the effectiveness of communication and education in raising awareness and driving behavioural change towards environmental issues? How do social inequalities and cultural barriers influence fair participation in climate action efforts, potentially exacerbating vulnerabilities and disparities?

— **TECHNOLOGICAL:**

What breakthroughs are needed to achieve widespread adoption of renewable energy and sustainable practices? How will emerging technologies impact the trajectory of climate change and environmental degradation? How does the rapid pace of technological innovation affect the development of solutions to environmental challenges? What uncertainties surround the long-term effectiveness of innovative technologies in mitigating environmental risks?

— **ECONOMIC:**

How do the economic risks associated with climate disasters and environmental damage impact decision-making regarding the transition to a low-carbon economy? What challenges arise in conducting cost-benefit analyses and making investment decisions amidst the resulting economic uncertainties? How do economic disparities hinder fair global cooperation and the equitable distribution of resources for climate action? What economic challenges will arise during the transition to a more sustainable economy?

— **ENVIRONMENTAL:**

What challenges will arise in predicting the scale and timing of environmental impacts due to feedback loops, tipping points and threshold effects? How do uncertainties in climate models and projections complicate efforts to assess and mitigate environmental risks? What uncertainties surround the responses and resilience of ecosystems in the face of environmental changes and cascading effects?

— **(GEO)POLITICAL, REGULATORY:**

How do the political will and enforcement capacity influence the success of regulatory frameworks in promoting sustainability and penalising environmental violations? What uncertainties exist in the stability and effectiveness of international agreements and treaties aimed at addressing environmental challenges? What geopolitical tensions may arise due to competition for resources or disagreements over climate policies? How will international agreements and treaties evolve to address the complex challenges of climate change and environmental degradation? Additionally, how will regulatory frameworks adapt to emerging technologies and evolving environmental threats?

WEAK SIGNALS:

Escalating greenhouse gas emissions and global temperatures highlight the urgent need for immediate climate action. Increasingly severe extreme weather events underscore the tangible impacts of climate change, necessitating a multi-stakeholder response. Innovations such as CRISPR/Cas genetic engineering offer potential solutions by enhancing crop resilience.

Shifting consumer preferences towards sustainability and regulatory measures, such as carbon pricing, reflect a growing societal demand for environmental accountability. These interventions align economic incentives with environmental goals, fostering a shared commitment to fighting climate change. The identification of tipping elements by the Potsdam Institute for Climate Impact Research emphasises the irreversible nature of some environmental changes.

Additionally, global protests, youth-led movements, and calls for policy action demonstrate heightened public awareness and activism. Growing investment in renewable technologies and sustainable industries signals a shift towards a more environmentally conscious economy. Moreover, climate-related litigation and corporate accountability efforts hold polluters and governments accountable, further promoting environmental responsibility.

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3.5 CONTINUING URBANISATION

A CITYSCAPE SHIFT – FROM CONCRETE JUNGLES TO SUSTAINABLE HUBS

DESCRIPTION:

People are moving from rural areas to cities all around the world. They are seeking better job opportunities, services and education. This movement is part of the continuing trend of urbanisation. Over the last forty years, this phenomenon has doubled the number of people living in cities. It is projected that by 2050, more than 68% of the world's population will reside in urban areas. Rapid urbanisation will lead to technological innovation. It will also boost economic growth. Additionally, it will cause social change. All of these factors will shape the future of life and governance in urban areas.

In the near term (multiple years to a decade), urbanisation is expected to continue at an accelerated pace. By 2050, the number of people living in cities is expected to hit 5 billion. This increases productivity and GDP. However, it also worsens problems, including environmental degradation, public health issues, housing shortages, congestion and inequalities. New digital technologies are aiding cities in addressing these challenges, fostering citizen engagement and transforming city services.

In the long term, urbanisation is expected to further intensify, particularly in developing regions. Cities will become even more vital centres of economic activity and innovation. Sustainable urban planning and governance are essential, as they will ensure that cities can survive and remain liveable. This is important due to emerging challenges such as climate change and geopolitical tensions.

Below, we discuss the impact of Continuing urbanisation for each category:

— SOCIO-CULTURAL:

Urbanisation will affect cultural identities, social dynamics and community interactions by fostering cultural diversity and new urban cultures. It can enhance social cohesion but might also lead to socio-economic inequalities, cultural conflicts and issues such as social fragmentation and gentrification. Addressing these issues is crucial for ensuring social inclusion and maintaining cohesive urban communities.

— TECHNOLOGICAL:

Urbanisation will boost technology in transport, infrastructure, energy systems and public services. Smart city tech and data-driven decisions will boost infrastructure efficiency, sustainability and quality of life. Yet, data privacy, the digital divide and tech dependency concerns may affect urban future and governance.

— ECONOMIC:

Urbanisation offers chances for economic growth by turning cities into centres for innovation, entrepreneurship and investment. Yet, it also poses challenges, such as straining resources and infrastructure, causing economic and social inequalities. While boosting growth by gathering resources, labour and capital, it raises issues like income inequality, housing affordability and urban poverty. Thus, it calls for inclusive economic strategies and social programs to mitigate disparities.

— ENVIRONMENTAL:

Environmental degradation, climate change and natural disasters are worsening security by exacerbating resource scarcity, triggering conflicts and displacing populations. These issues are amplifying social tensions and are threatening stability, leading to migration and food shortages. They are heightening conflicts over territories and resources, necessitating innovative solutions and global cooperation for effective crisis management.

— (GEO)POLITICAL, REGULATORY:

Urbanisation requires regulations for land use, transportation, sustainability and infrastructure investments. Local governments will be key in managing urban challenges and enforcing rules. Urbanisation could impact geopolitical dynamics through its influence on cities' economic and political significance. This includes issues of resource allocation, territorial disputes and migration, requiring cooperative strategies and diplomacy for sustainable urban development.

Main uncertainties and challenges:

— SOCIO-CULTURAL:

How might diverse populations be effectively integrated while preserving cultural identities in urban settings? What measures can be taken to enhance social cohesion, community resilience and inclusivity in rapidly evolving urban environments?

— TECHNOLOGICAL:

How will emerging technologies be adopted and integrated into urban environments and what are the uncertainties surrounding this process? What are the potential impacts of rapid technological innovation on job markets and societal norms in urban areas? How can cities navigate the challenges of balancing technological advancement with societal needs and concerns? What are the potential ethical implications and social consequences of pervasive surveillance, artificial intelligence and automation in urban environments?

— ECONOMIC:

What strategies can be implemented to ensure the equitable distribution of resources and opportunities in urban settings? How might economic disparities and income inequality be addressed as urbanisation continues to accelerate? What potential consequences could widening economic gaps pose for social cohesion and economic stability in cities?

— ENVIRONMENTAL:

In what ways might environmental considerations shape future urban planning and development initiatives? What strategies can cities implement to mitigate urban sprawl, biodiversity loss and climate change impacts while ensuring sustainable development and resource efficiency? How can urban development practices be made more sustainable and what uncertainties exist regarding their long-term ecological impact?

— (GEO)POLITICAL, REGULATORY:

What challenges do regulatory policies and governance mechanisms face in effectively managing urban growth and development? How might geopolitical tensions and competing interests among stakeholders hinder collaborative efforts to address urban challenges?

WEAK SIGNALS:

Early indicators offer insights into the potential of urbanisation trends, highlighting avenues for sustainable development and inclusive growth. Cities are now adopting sustainable designs that focus on being suitable for humans. This includes using green infrastructure and sustainable building methods. Cities mix different types of land use and also use renewable energy. The goal is to make cities better places for people to live. New city concepts are emerging with a focus on not using cars, making cities inclusive and sharing infrastructure. These concepts also aim to use space efficiently with flexible designs.

Secondly, local groups and movements are pushing for fair access to housing, transportation and public services. They highlight the need for citizens to take part in planning city development. Technological innovations are crucial for smart city solutions, as they help make data-driven decisions. Furthermore, they encourage people to participate in city governance.

Lastly, cities can work together through international collaborations and knowledge-sharing platforms. These platforms allow them to share their best practices in urban development, resilience and sustainability. They highlight how important global cooperation is in solving urban challenges. Early signals are resulting in a major change in how cities develop. They focus on protecting the environment, fairness for all people and using new technology. This will shape the cities of the future.

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3.6

DIVERSIFICATION OF EDUCATION AND LEARNING

UNLEASHING LEARNING POTENTIAL: THE TRADITIONAL CONCEPT OF EDUCATION NEEDS TUTORING

DESCRIPTION:

The world is rapidly changing, and the way in which people learn is changing with it. New technologies are changing education, new educational methods are being introduced And new generations of learners are coming up. Together, they are making education and learning more diverse. The connection between education and formal schools may become weaker. Instead, casual, and unplanned learning could become more valued. The phrase "I don't know" is becoming obsolete. Advancements in cognitive sciences and the availability of information are enabling a wide range of interests and learning methods.

In the near term (multiple years to a decade), the education landscape will witness a shift from traditional classrooms to exploration, customisation and coaching. Schools are changing. Previously, they used to just provide knowledge; Now, they are becoming active learning centres and are adjusting to changes in society and technology. Teaching will shift its focus more towards learning. This shift will require new content and will also need different types of learning spaces and various learning methods. Additionally, educators are taking on new roles as facilitators of learning, rather than just disseminators of knowledge. Peer-to-peer learning, blended learning and the integration of technology are becoming increasingly prevalent.

In the long term, the trajectory of the diversification of education and learning is likely to continue, albeit with the further integration of emerging technologies and pedagogical approaches. Education may become even more personalised and adaptive, catering to individual learning styles and preferences. Change will happen quickly. People will need to keep learning all their lives. They must become adaptable and good at teaching themselves.

Below, we discuss the impact of Diversification of education and learning for each category:

— SOCIO-CULTURAL:

Education is becoming more diverse. It now focuses on lifelong learning and adaptability. It also highlights the importance of individuality and self-improvement. This change is challenging the traditional idea that education is just formal schooling. It encourages inclusivity and makes knowledge more accessible to diverse groups.

— TECHNOLOGICAL:

Education has been changed by technology. It allows for personalised learning and the use of virtual and augmented reality in teaching. This has resulted in better access to education and more engaging learning experiences through AI tutors and mixed-reality environments. These innovations foster a diversified and interconnected educational ecosystem, promoting immersive and interactive experiences. However, there are worries about digital skills, data privacy and ethics.

— ECONOMIC:

Redirecting education towards skill-based, lifelong learning can enhance workforce productivity and adaptability, potentially increasing economic growth. Diversified education can boost innovation, creativity and skills development, contributing to economic competitiveness. Tailoring to different learning styles improves workforce efficiency and meets evolving market needs. Moreover, new educational models and platforms offer opportunities for entrepreneurship and investment in the education sector. Nevertheless, unequal access to high-quality education may exacerbate existing inequalities.

— ENVIRONMENTAL:

By encouraging remote learning, decreasing physical infrastructure needs and enhancing digital literacy, the carbon footprint linked with conventional education can be reduced. Additionally, the focus on experiential learning and interdisciplinary methods can promote environmental consciousness and responsibility, leading to a mindset geared towards sustainability.

— (GEO)POLITICAL, REGULATORY:

Policymakers need to update regulations for new educational models and technologies, ensuring high-quality and equitable access. Geopolitical issues can affect the global flow of educational resources and the collaboration and mobility of international students. Overcoming regulatory and geopolitical challenges is essential for promoting innovation and collaboration in education.

Main uncertainties and challenges:

— SOCIO-CULTURAL:

How will societal attitudes towards traditional education systems evolve in response to the increasing diversification of learning methods? Will there be equitable access to diversified education opportunities across different socio-economic backgrounds and geographic regions? How will cultural values and beliefs influence the acceptance and adoption of emerging educational technologies and pedagogical approaches? What challenges are posed by societal biases and how can inclusivity be ensured within evolving educational practices?

— TECHNOLOGICAL:

What are the potential ethical implications of the widespread adoption of AI-powered tutors and personalised learning assistants in education? How resilient are current technological infrastructures in supporting the scalability and accessibility of diversified learning platforms, especially in underserved areas? How can educational systems address the challenges posed by technological advancements while leveraging their benefits?

— ECONOMIC:

How will the cost-effectiveness of diversified education models compare to traditional educational systems, especially in terms of infrastructure investments and resource allocation? How will the evolving job market demand and skill requirements impact the economic viability of diversified education programs and their graduates?

— ENVIRONMENTAL:

What are the environmental implications of the increased reliance on electronic devices and digital resources for learning? How can environmental sustainability be integrated into the curriculum and practices of diversified education systems?

— (GEO)POLITICAL, REGULATORY:

How will regulatory frameworks adapt to ensure quality assurance and accreditation of diverse learning experiences, especially in the absence of traditional institutional structures? What geopolitical tensions may arise from disparities in access to diversified education resources and opportunities across different regions? How might geopolitical tensions and regulatory disparities impact international collaboration in education and the exchange of best practices? What strategies can be employed to navigate diverse cultural and regulatory landscapes in global education initiatives, particularly amidst regulatory inconsistencies?

WEAK SIGNALS:

Early indicators of the diversification of education and learning are becoming increasingly apparent. Schools are evolving into dynamic learning hubs where experimentation and diverse forms of education are embraced. This shift is exemplified by the emergence of extended schooling models, the outsourcing of educational services and the concept of learning-as-you-go. Additionally, the roles of educators are changing. New learning agents are stepping into various roles in the education ecosystem.

Mixed realities are also being integrated into learning environments, offering immersive and interactive educational experiences. These early signs paint a vivid picture of the evolving education landscape. Traditional boundaries are being blurred and new opportunities for personalised and experiential learning are emerging. Micro-learning platforms, personalised learning apps and online courses reflect a trend towards tailored knowledge delivery. This caters to individual preferences and needs. The emergence of AI-powered tutors and personalised learning assistants further highlights the potential for truly individualised learning experiences. Alternative learning communities, such as Massive Open Online Courses, offer flexibility and diverse perspectives beyond traditional schooling. Additionally, there is a growing interest in experiential learning, maker spaces and gamification. These developments emphasise hands-on and engaging educational experiences. These trends look promising. However, the extent to which they will affect education and society over time is still unclear.

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3.7 WIDENING INEQUALITIES

DESCRIPTION:

Inequalities are growing, i.e. the richest and poorest people in society are growing further apart. This is happening even though progress is being made in reducing extreme poverty. Inequality is ongoing. These disparities extend across various facets of life, including education, employment, health and wealth distribution. It affects people differently depending on their gender, age, ethnicity, social class, migration status and where they live. These differences impact who has access to important opportunities for a prosperous life. The COVID-19 pandemic has exacerbated existing inequalities, emphasising the urgency for policymakers to prioritise addressing the issue of widening inequalities.

In the near term (multiple years to a decade), efforts to mitigate widening inequalities should focus on implementing policies that promote equitable access to education, employment and healthcare. Initiatives aimed at bridging the gap between the affluent and marginalised groups must be prioritised. These include focused social welfare programs and economic policies that include everyone. Additionally, addressing structural barriers is crucial for social cohesion and sustainable development. These barriers include discriminatory practices in the labour market and the unequal distribution of resources, which perpetuate inequality.

In the long term, sustained efforts to combat widening inequalities are crucial for ensuring a fair and inclusive society. Policies and interventions must focus on systemic factors that cause inequality. These include biases in institutions and unequal opportunities. It is crucial to adopt a comprehensive approach. This approach should combine social, economic and environmental factors. Doing so is essential for ensuring lasting equity and prosperity.

Below, we discuss the impact of widening inequalities for each category:

— **SOCIO-CULTURAL:**

Social and cultural inequality disrupts social cohesion and causes community division. It often sparks political dissatisfaction and protests. Rising inequalities affect perceptions of fairness and social unity. "Black Lives Matter" and climate justice movements aim to increase awareness and provide opposition. They show that fighting systemic inequalities is essential for societal harmony and advancement.

— **TECHNOLOGICAL:**

Technological advancements can worsen or lessen inequalities based on their use and regulation. Automation and digitisation may cause job losses, potentially widening the gap between skilled and unskilled workers and income disparities. Technologies and business models targeting social and environmental issues demonstrate a need for inclusive solutions. Yet, without careful actions to guarantee fair access and benefits, technology risks enlarging disparities by excluding some groups.

— **ECONOMIC:**

Limiting access to resources for marginalised groups stifles growth and innovation, exacerbating economic and social inequalities. This impacts economic stability and hinders mobility, perpetuating social stratification. Policymakers realise the importance of tackling economic inequality by looking into wealth taxes and progressive policies.

— **ENVIRONMENTAL:**

Environmental degradation exacerbates inequalities, hitting low-income and marginalised communities hardest due to their lack of adaptation resources. These communities often suffer most from environmental impacts, highlighting the need to tackle environmental injustices to reduce disparities. This involves ensuring access to clean air, water and resources for vulnerable groups and promoting sustainable business and renewable energy solutions for inclusive environmental progress.

— **(GEO)POLITICAL, REGULATORY:**

Regulatory frameworks and geopolitical dynamics influence resource sharing, often disadvantaging marginalised and vulnerable groups. The political conversation is increasingly focused on tackling inequality through means such as wealth taxes and universal basic income, pointing to evolving regulations. However, geopolitical tensions and varied regulatory methods hinder collective efforts to address global inequalities, highlighting the importance of global cooperation and policy harmonisation.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

How will societal attitudes towards inequality evolve? Will there be an increase in polarisation or a collective push towards greater equity? How do cultural norms and values shape perceptions of fairness and justice, and to what extent do they influence policy decisions regarding inequality?

— **TECHNOLOGICAL:**

How does the rapid pace of technological change contribute to concerns regarding skills mismatches and job displacements, particularly in marginalised communities?

— **ECONOMIC:**

What impact will global economic shifts and crises have on inequality trends? How will changing labour markets, including the rise of the gig economy and remote work, affect income distribution? Can economic policies effectively address structural barriers to wealth accumulation and promote inclusive growth?

— **ENVIRONMENTAL:**

How do climate change and natural disasters disproportionately affect vulnerable populations, exacerbating inequalities in access to resources and resilience?

— **(GEO)POLITICAL, REGULATORY:**

How do geopolitical tensions and regulatory frameworks impact efforts to address inequality, particularly in terms of their alignment with social justice and equity goals?

WEAK SIGNALS:

Several manifestations serve as early indicators of the potential trajectory of widening inequalities. A clear sign is the mismatch of income and wealth, as exemplified by large jumps in living expenses that are not mirrored by similar growth in income. Moreover, there are more protests and social movements. For example, the "Black Lives Matter" movement and climate justice campaigns show that people are more aware and are acting against systemic inequalities.

Additionally, new technologies and business models are emerging that focus on solving social and environmental challenges. Examples include renewable energy innovations and sustainable business practices. Political discourse and policy priorities are changing to focus on reducing inequality. Proposals such as wealth taxes, universal basic income and progressive economic policies are becoming popular in some countries. These signals highlight the urgent need to address growing inequalities.

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3.8 EXPANDING INFLUENCE OF EAST AND SOUTH

DESCRIPTION:

The economic landscape of the world is undergoing a significant transformation, marked by the rise of non-Western economies. This megatrend involves the movement of global economic power. It is shifting from traditional Western countries to emerging markets and developing economies. In recent years, seven countries—China, India, Indonesia, Brazil, Russia, Mexico, and Turkey, together referred to as the E7—have seen impressive economic growth. They are challenging the powerful Group of Seven (G7) nations. Rapid industrialisation, technological advancement, demographic trends and strategic economic policies are driving this shift in economic power.

In the near term (multiple years to a decade), the economic power of non-Western countries is expected to continue its upward trajectory, with the E7 economies potentially doubling in size compared to the G7. China is projected to surpass the United States as the world's largest economy, reflecting its sustained high rate of economic growth and technological innovation. Meanwhile, emerging markets and developing economies are expected to continue to enjoy strong growth. They are predicted to grow faster than advanced economies.

In the long term, the economic influence of non-Western economies is expected to grow stronger. Asia may become more powerful than North America and Europe combined. By 2050, Asia will contribute over 50% of the global economic output, mainly led by China and India. Indonesia and Brazil are poised to benefit from the recalibration of economic influence. Additionally, Africa is becoming a key player in the global economy. This is because of its new free trade area. It is also working to diversify its economy, with a focus on inclusive and sustainable growth. This is part of Agenda 2063. Overall, BRICS countries (Brazil, Russia, India, China and South Africa) will become more influential. Their trading union will serve as a counter-design to the Western trading union.

Below, we discuss the relevance and impact of the expanding influence of East and South for each category:

— **SOCIO-CULTURAL:**

The rising power of emerging countries is reshaping their societal influence and perception. Cultural spill-over influences new trend developments. The growing influence of the East and South is changing global cultural dynamics, with cultures from Asia and Africa impacting global art, cuisine and entertainment. However, cultural tensions can emerge from differing values and norms, requiring dialogue and negotiation for mutual respect and cooperation.

— **TECHNOLOGICAL:**

Emerging economies are boosting global technological progression and digital transformation through increased investment in technology and innovation. They're rapidly embracing digital technologies and establishing innovation hubs, reshaping global markets and intensifying competition. The surge of non-Western economies, notably in AI, renewable energy and digital infrastructure, is challenging Western tech dominance. As technological rivalry grows, issues such as data privacy, cybersecurity and intellectual property rights require regulatory frameworks.

— **ECONOMIC:**

Sustainable consumption and recycling/upcycling foster innovation and entrepreneurship, creating new markets for eco-friendly products. The percentage of middle-class people in America and the EU has significantly decreased. Because of this, products and services aimed at the lower class may become more popular.

— **ENVIRONMENTAL:**

The expanding influence of the East and South has environmental implications, as rapid industrialisation and urbanisation in these regions contribute to global environmental challenges such as climate change and resource depletion. They need to grow in a way that sustains the environment. Collaboration between the East and South and Western countries is essential for addressing shared environmental concerns and the transition towards a more sustainable global economy.

— **(GEO)POLITICAL, REGULATORY:**

The rise of non-Western economies is shifting geopolitical dynamics, leading to new alliances and multipolar governance. Regulatory frameworks need to evolve to reflect the changing landscape of international trade and investment, balancing regional interests while ensuring fair competition and compliance with global standards.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

How might cultural clashes manifest as traditional values intersect with modernisation and globalisation?

— **TECHNOLOGICAL:**

How can the regulation of intellectual property be assured across borders? Can divides in the use and development of emerging technologies in different countries be overcome?

— **ECONOMIC:**

How might economic imbalances between developed and developing economies exacerbate global instability? What are the uncertainties surrounding the interconnectedness of supply chains and the effects of protectionist policies?

— **ENVIRONMENTAL:**

How could uncertainties regarding environmental sustainability impact decision-making processes across borders? In what ways might international cooperation be influenced by the urgency of addressing environmental challenges?

— **(GEO)POLITICAL, REGULATORY:**

How might competition for influence and resources between countries contribute to geopolitical tensions? What potential instabilities and conflicts could arise from the fragmentation of globalisation into regional trade blocks? How do populist nationalism and changing political dynamics challenge traditional modes of international cooperation and trade?

WEAK SIGNALS:

Early signs show that the East and South are becoming more influential. Asia's economies are growing steadily, China has become a major global economic force and Africa is focusing on growth that is inclusive and sustainable, as outlined in its Agenda 2063 as well as regional integration projects such as the African Continental Free Trade Area. This project allows goods, intellectual property and capital to move freely among African countries and will prove beneficial to a population of 1.46 billion people. BRICS, a trade union, is trying to establish trade ties with non-Western countries as a counter-draft to the US and Western-led trade blocks. Furthermore, China is expanding its Belt and Road Initiative, which includes multi-billion-dollar projects in Asia, Africa and Europe.
These signals show how the dynamics are changing. They are shaping the future of economic power and global collaboration. However, they also illustrate a shift towards a world with few powerful countries. Global trade is still key, but it now operates within a framework that emphasises regional cooperation.

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3.9 GROWING CONSUMPTION

FROM MIDDLE-CLASS BOOMS
TO SUSTAINABLE CONSUMPTION

DESCRIPTION:

The global consumer class is booming, with billions entering the market with increased purchasing power. By 2035, the global middle class is expected to grow to 5.5 billion people. Asia will contribute significantly to this growth. The middle class is growing, especially in emerging economies. Business models aimed at lower-income people are also emerging. These changes are altering what people buy and how goods are produced worldwide. They are also influencing societal values and the way economies are structured. Consumers are becoming more aware of their shopping choices. They look for sustainability and personal well-being. They also want personalised and engaging shopping experiences. Technology is helping to enhance these experiences. This megatrend is driven by several factors, including economic growth and urbanisation. Demographic shifts also play a role. Additionally, rising incomes and the desire for better lifestyles fuel it.

In the near term (multiple years to a decade), the surge in consumer markets, particularly in emerging economies, will continue. As people earn more disposable income, they are likely to spend more on goods and services. This increase in consumer spending will result in significant opportunities for businesses in different sectors. Technology improvements and online shopping platforms will simplify how people access goods and services. This will increase buying patterns around the world. Virtual and augmented reality will transform shopping and personalise experiences with product customisation and virtual exploration. Sustainable consumption is becoming more popular. People increasingly want products and services that match their values and concerns about society. This change will make industries, supply chains and business models more focused on sustainability and will lead to more innovation and investment in renewable resources. It will also boost circular economy practices.

In the long term, the trend of increased consumerism is expected to continue. However, there may be changes in what people buy and new consumption trends. In developing countries, the middle class could grow more powerful, which may shape global consumer culture. This can affect market trends in areas such as fashion and technology.

Below, we discuss the impact of growing consumption for each category:

— **SOCIO-CULTURAL:**

Growing consumption reflects evolving societal values and aspirations, driving individuals to seek improved lifestyles and consumption experiences. Consumers, particularly in emerging economies, are becoming more conscious of their purchasing choices, driving demand for ethically produced goods and services. Users expect brands to entertain and offer value beyond the product, for example via social media. This shift is reshaping consumer culture globally, impacting everything from supply chains to marketing strategies.

— **TECHNOLOGICAL:**

Renewable technologies and digital platforms are evolving, enabling consumers to make informed, sustainable choices. With rapid advancements in e-commerce and personalised marketing driven by data analytics and algorithms, shopping experiences are becoming more personalised and automated. Virtual reality and augmented reality offer immersive shopping without a physical presence. This technological progress is not only expanding consumer markets, but is also altering consumption habits by enhancing accessibility, customisation and immersion. Furthermore, digital payment systems are simplifying transactions and facilitating greater consumption.

— **ECONOMIC:**

Sustainable consumption and recycling/upcycling foster innovation and entrepreneurship, creating new markets for eco-friendly products. The percentage of middle-class people in America and the EU has significantly decreased. Because of this, products and services aimed at the lower class may become more popular.

— **ENVIRONMENTAL:**

Sustainable consumption reduces the environmental impact of using resources and lessens the strain on natural resources and ecosystems. This takes place via recycling, using renewable energy and practising sustainable farming. Nevertheless, the extent to which the general growth of consumption nullifies these positive effects is questionable.

— **(GEO)POLITICAL, REGULATORY:**

For sustainable consumption to become common, issues need to be tackled. These include making it affordable and easy to access. Digital products track user behaviour and shopping data. This activity needs clear rules, which should explain how to collect, store and use private data. Additionally, geopolitical tensions and trade agreements impact global supply chains, affecting the availability and affordability of consumer goods on a large scale.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

Will consumer preferences continue to prioritise sustainability and ethical practices, or will convenience and affordability dominate decision-making? How will cultural shifts and societal values influence consumption patterns in different regions? Are there potential cultural barriers to the widespread adoption of sustainable consumption practices?

— **TECHNOLOGICAL:**

What role will emerging technologies play in shaping the future of consumption? Will advancements in automation and artificial intelligence lead to further disparities in access to goods and services? How will concerns about data privacy and security affect consumer trust in digital commerce platforms?

— **ECONOMIC:**

How will economic fluctuations and global market dynamics affect consumer confidence and spending patterns? Will widening income inequality hinder the growth of the middle class and limit consumption opportunities? What impact will economic shocks, such as recessions and trade disputes, have on consumer behaviour and purchasing power?

— **ENVIRONMENTAL:**

What are the consequences of resource depletion and pollution resulting from an increased demand for goods? Can industries transition to sustainable production methods and circular economy practices quickly enough to mitigate environmental degradation caused by growing consumption? How will climate change and extreme weather events disrupt supply chains and impact consumer access to essential products?

— **(GEO)POLITICAL, REGULATORY:**

How will changes in trade agreements, tariffs and international regulations affect the availability and affordability of consumer goods? Will governments implement policies to incentivise sustainable consumption and penalise environmentally harmful practices?

WEAK SIGNALS:

Weak signals of growing consumption are evident, as consumers increasingly seek sustainable products and ethical practices, particularly in wealthy regions. Circular economy initiatives strengthen this change. They, along with digital payment systems, make things more convenient and also allow businesses to customise their offerings. Additionally, conscious consumerism trends prioritise brands aligned with societal values, driving significant shifts in consumption patterns towards sustainability. In the "Attention Economy", brands are shifting towards purpose-driven marketing, but risks such as greenwashing persist. Consumerism 2.0 is shaped by technology and involves using digital services a lot and paying attention to well-being. Older and active consumers want experiences made just for them. The notion of an "experience culture" underscores the demand for immersive experiences, shaping the future of digital consumerism.

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3.10 INCREASING DEMOGRAPHIC IMBALANCES

THE DEMOGRAPHIC DIVIDE:
BALANCING GROWTH AND DECLINE

DESCRIPTION:

This megatrend emphasises changes in the age of the population. It indicates an increase in elderly people. It also highlights changes in the numbers of people in different age groups. This impacts job markets significantly, which in turn has effects on the economy, possible income disparities, voting behaviours and public finances.

The world's population is rapidly increasing and is expected to reach 9.7 billion by 2050. Much of this growth is happening in Sub-Saharan Africa. At the same time, many developed countries are experiencing very low growth or no growth at all. Some are even seeing their populations decrease.

Population dynamics are changing due to several reasons. These include fertility rates, mortality rates, immigration and ageing demographics. These trends are creating noticeable imbalances in demographics globally as stages of transition differ.

In the near term (multiple years to a decade), demographic imbalances will become increasingly evident. High-income countries may see their populations stop growing or even decrease, which could lead to problems. One issue is an older population and an ageing workforce. Another is stress on healthcare and pension systems. Whereas Sub-Saharan Africa will likely see a fast increase in population these demographic shifts will pose challenges to economies, social structures and resource management strategies worldwide.

In the long term, population imbalances are expected to continue and may even get worse. This will affect economic growth, social unity and global politics. High-income countries with stagnating or shrinking populations might change their immigration policies and labour market dynamics. Meanwhile, regions with rapidly growing youth populations could experience unique socio-economic challenges. These include dissatisfaction, poverty and high unemployment among the youth. To address these issues, significant investments in education and skills training are necessary.

Below, we discuss the impact of Increasing demographic imbalances for each category:

— **SOCIO-CULTURAL:**

Ageing populations in developed countries are facing increasing intergenerational inequality, as younger generations face limited job opportunities and potential economic strain supporting elderly relatives. Meanwhile, regions with growing youth populations may face socio-economic challenges such as dissatisfaction and high unemployment among the youth, impacting social cohesion and stability.

— **TECHNOLOGICAL:**

Advances in assistive technologies and telemedicine are enhancing the quality of life of elderly populations and are supporting independent living. They are helping to tackle issues caused by ageing populations and shifts in workforce demographics.

— **ECONOMIC:**

The economic effects of population imbalances can be felt in many areas. They are impacting job markets, how people spend money and government budget policies. Developed countries have fewer working-age people, putting pressure on social welfare systems. Meanwhile, the number of young people in developing areas is growing. This creates chances for economic growth and innovation, but also provides challenges in terms of resource management and infrastructure development to support growing populations.

— **ENVIRONMENTAL:**

Demographic shifts influence patterns of urbanisation, resource consumption and environmental sustainability. Rapid urbanisation in areas with growing populations is generating an increase in the demands placed on infrastructure, boosting energy consumption and making waste management more challenging. This negatively affects efforts to mitigate climate change.

— **(GEO)POLITICAL, REGULATORY:**

Demographic imbalances are shaping political agendas, migration policies and international relations. Many countries are experiencing an increase in the number of older people, sparking debates on several topics. These topics include reforming pension systems, funding healthcare and employing immigrants to address workforce shortages. Meanwhile, countries with many young people are trying to focus on better education, more jobs and giving the youth a voice in politics.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

How will changing cultural norms and values affect fertility rates and family structures in different regions? What impact will an increase in life expectancy and delayed retirement have on intergenerational relationships and societal expectations regarding work and retirement?

— **TECHNOLOGICAL:**

What role will technological advancements, such as automation and artificial intelligence, play in mitigating labour shortages in ageing populations or addressing challenges related to youth unemployment? How will technology shape healthcare delivery and elder care services to meet the needs of ageing populations?

— **ECONOMIC:**

How will demographic shifts impact consumer behaviour, market demand and economic growth in different sectors? What strategies will governments and businesses implement to address labour shortages and skill gaps resulting from demographic imbalances? How will economic disparities between regions with ageing populations and those experiencing rapid population growth impact global trade and investment flows?

— **ENVIRONMENTAL:**

What are the potential environmental consequences of rapid population growth, such as an increase in demand for natural resources and infrastructure development? How will demographic imbalances influence efforts to mitigate climate change and promote sustainable development?

— **(GEO)POLITICAL, REGULATORY:**

How will demographic trends shape immigration policies and labour mobility agreements between countries? What geopolitical tensions may arise from competition over resources and migration flows resulting from demographic imbalances?

WEAK SIGNALS:

The global population soared during the period from 1926 to 2020, reaching 7.8 billion, and was mainly driven by growth in Asia and Africa. Despite reduced fertility rates, the average life expectancy reached 73 years in 2020. Societies are getting older. The number of people over 65 is expected to double by 2050. Meanwhile, Africa is seeing an increase in young people. International migration counters population decline in Europe. Intergenerational inequality arises, notably as ageing populations place strain on the fiscal and healthcare systems. People are living longer and retiring later. This limits job opportunities for younger people and also affects family relationships. There are worries about the rights of future generations. The labour force landscape is shifting, with some regions rapidly ageing while others are seeing youth expansion. China is experiencing a demographic shift that is affecting the world. As older people leave the workforce, there are worries about pension funds lasting and the impact on demographic dividends. Ageing populations wield electoral influence, prompting debates over political decisions favouring seniors.

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3.11 INCREASING INFLUENCE OF NEW GOVERNING SYSTEMS

FROM TOP-DOWN TO GRASSROOTS: EMPOWERING VOICES

DESCRIPTION:

New governing systems are gaining influence for several reasons, which are briefly discussed here. They prioritise principles of inclusivity, transparency and responsiveness, leveraging digital technologies and participatory mechanisms to engage citizens in governance. Essentially, new governing systems represent a departure from traditional top-down approaches to governance. They aim to foster collaboration, adaptability and effectiveness in addressing complex societal issues. These elements are changing old ways of governing, forming a multi-layered governing system.

In these new governing systems, non-state actors are becoming more prominent, for example, grassroots organisations. Decision-making processes are becoming more international, as there is a growing global awareness. Social media has a big impact on the formation of political bubbles and the perception of truth. Although there are increasingly innovative practices in governing, democracy is on the decline globally. This presents a risk to democratic systems and institutions, which must be addressed and mitigated.

In the near term (multiple years to a decade), these new governing systems are expected to grow. More non-state actors will be involved in making decisions. There will be a greater use of participatory governance. Additionally, digital media platforms will further change the way people inform themselves about news and how they connect with people of the same beliefs. As a result, personal beliefs are holding more weight than factual truth. This puts pressure on the media to combat fake news and misinformation, and maintain its role as a reliable source of information.

In the long term, the changes in government systems will likely be influenced by several factors, including advances in technology, the values of society and the state of geopolitical dynamics. While automated decision-making with the help of technology could make advances, ethical considerations about algorithmic inconsistencies regarding fairness, accountability, transparency and ethical biases could occur. The division between democratic and autocratic countries will intensify, which could lead to geopolitical and economic tensions.

Below, we discuss the impact of Diversification of the increasing influence of new governing systems for each category:

— SOCIO-CULTURAL:

New governing systems signify shifts towards inclusiveness and participatory decision-making, enabling a wide range of voices to influence governance and policies. These systems embody values of inclusivity and transparency, with grassroots organisations enhancing citizen engagement and community ownership. However, social media-driven political bubbles are challenging shared truths and worsening polarisation, thus negatively impacting social cohesion and trust in institutions.

— TECHNOLOGICAL:

Digital platforms and technologies crucially support citizen engagement and transparency in governance, offering real-time communication and collaboration. They allow public data to be used in self-correcting algorithms, simulating policy outcomes for automated decision-making. However, they also present challenges such as the spread of misinformation and the manipulation of public opinion through algorithms.

— ECONOMIC:

The potential loss of corporate lobbying power can alter industry dynamics, investment patterns and innovation. New governance systems change economic interactions by shifting decision-making roles between state and non-state players. Economic stability may also suffer due to reduced trust in traditional institutions and the growth of populism.

— ENVIRONMENTAL:

Participatory policymaking can tackle environmental issues through sustainable policies and practices. It utilises new governing systems, grassroots initiatives and participatory mechanisms to support community-driven conservation and sustainable development. However, solving complex environmental challenges demands multi-level governance coordination and faces obstacles from political polarisation and short-term interests.

— (GEO)POLITICAL, REGULATORY:

Futures literacy could enable policymakers to identify uncertainties and complexities, fostering anticipatory thinking and a sense of preparedness. Participatory, bottom-up approaches to policymaking consider the collective intelligence of citizens. While participatory governance enhances legitimacy and accountability, it also challenges established power structures and may lead to tensions between democratic and autocratic regimes.

Main uncertainties and challenges:

— SOCIO-CULTURAL:

How will diverse cultural norms and values influence the adoption and effectiveness of new governing systems? Will the increasing polarisation of societies hinder the inclusivity and consensus-building efforts of grassroots initiatives? How will the erosion of trust in traditional institutions impact citizen engagement and participation in governance processes?

— TECHNOLOGICAL:

How can governments ensure the security and integrity of digital platforms used for participatory governance, especially in the face of cybersecurity threats and data privacy concerns? Will digital divides exacerbate inequalities in terms of the access to information and opportunities for civic engagement, undermining the inclusivity of new governing systems?

— ECONOMIC:

How will the transition to new governing systems affect economic growth and stability, particularly in industries reliant on traditional power structures? What are the long-term financial implications of investing in digital infrastructure and capacity building for participatory governance? Can new governing systems effectively address economic inequalities and ensure the equitable distribution of resources and opportunities?

— ENVIRONMENTAL:

What role will new governing systems play in addressing pressing environmental challenges, such as climate change and biodiversity loss? Will competing economic interests and short-term priorities undermine efforts to prioritise environmental sustainability within new governing systems?

— (GEO)POLITICAL, REGULATORY:

How will regulatory frameworks adapt to govern the increasingly complex interactions between state and non-state actors in new governing systems? What are the geopolitical implications of the rise of participatory governance and the potential erosion of state sovereignty?

WEAK SIGNALS:

Weak signals indicate the subtle yet emerging manifestations of the collective intelligence trend. These include grassroots initiatives leveraging collective wisdom for community development projects, such as urban planning and environmental conservation efforts. Additionally, governments and organisations are increasingly utilising digital platforms and online forums to solicit input from citizens on policy decisions and public projects, reflecting a growing commitment to participatory governance. The proliferation of online collaborative tools and platforms facilitates knowledge-sharing and problem-solving among various groups, further enhancing collective intelligence capabilities. Moreover, governmental bodies and public institutions are integrating citizen feedback and crowdsourced data into decision-making processes, signalling a shift towards more inclusive and transparent governance practices. Lastly, there is a growing sense of recognition and support for participatory democracy initiatives, such as citizens' assemblies and deliberative polling, as legitimate channels for citizen engagement in shaping the future of society. These weak signals collectively indicate the gradual but significant adoption of collective intelligence principles in various spheres of public life.

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3.12

INCREASING SIGNIFICANCE OF MIGRATION

A WORLD ON THE MOVE: FROM DISPLACEMENT TO INTEGRATION

DESCRIPTION:

The increasing significance of migration is a prominent feature of our modern world. Every day, countless individuals embark on journeys across borders, driven by aspirations for better lives, security and prosperity. This megatrend covers different types of migration. It includes people who choose to move for jobs and those who are forced to leave their places of residence due to wars, persecution or natural disasters. This global phenomenon transcends geographical boundaries, impacting societies, economies and governance systems worldwide. Migration is influenced by many factors, including economic conditions, political instability and environmental changes. These factors will create a complex pattern of human movement in the 21st century. Migration is shaping how populations grow and how cultures change. Understanding its antecedents, its impacts and its consequences is vital.

In the near term (multiple years to a decade), migration is expected to continue to grow in significance. There will be more diverse migration patterns and reasons for migrating. Economic disparities, political instability and climate change will remain the primary factors fuelling migration. The way in which the world reacts to current crises, such as the conflicts in Ukraine and Syria, will influence migration patterns. This will keep the focus on border security and managing those borders.

In the long term, migration dynamics may further evolve in response to emerging challenges and opportunities. Technological advancements could facilitate both migration processes and border control measures. However, geopolitical shifts and environmental changes may intensify migration pressures, potentially making the management of migration more complex, both nationally and internationally.

Below, we discuss the impact of Increasing significance of migration for each category:

— **SOCIO-CULTURAL:**

Migration reshapes cultural landscapes, enhancing diversity and multiculturalism but also posing challenges for social integration and identity conflicts.

— **TECHNOLOGICAL:**

Technology facilitates movement and enhances communication, travel and border security, but raises privacy and surveillance concerns. Technologies such as blockchain and biometrics improve identity verification, reducing fraud but face ethical and regulatory challenges related to data protection and human rights.

— **ECONOMIC:**

Migration boosts the labour market by diversifying the workforce and facilitating skill mobility, but it also leads to wage gaps and job competition. Challenges include brain drain and wage suppression, while global economic disparities encourage individuals to seek better opportunities abroad, resulting in remittances that support communities back home.

— **ENVIRONMENTAL:**

Climate change leads to displacement by affecting migration dynamics. It causes people to move due to sea-level rise, extreme weather and environmental degradation, posing challenges for host communities that need resilience and adaptation strategies for climate refugees. Environmental migration intertwined with socio-economic issues deepens inequalities, especially in resource-scarce areas. To address this, the root causes need to be tackled and aid needs to be offered to those affected. Legal systems should evolve to include climate migration issues in asylum and refugee policies, underlining the need for international collaboration to find sustainable solutions for at-risk communities.

— **(GEO)POLITICAL, REGULATORY:**

Migration is sparking political debate, influencing policies, elections and international relations, while also fuelling xenophobia and populism. Governance challenges arise from diverging interests and geopolitical tensions, complicating management and human rights efforts. States' security measures often exacerbate humanitarian issues, highlighting the difficulty of balancing security and humanitarian duties. The political exploitation of migration, such as outsourcing asylum processing or using migration in diplomatic deals, illustrates migration's complex role in geopolitics, emphasising the importance of ethical migration governance.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

How will host communities adapt to increasing cultural diversity resulting from migration and what implications will this have for social cohesion and identity formation? What are the long-term effects of cultural integration on social norms, values and traditions within host societies and how will they influence attitudes towards migration?

— **TECHNOLOGICAL:**

How will emerging technologies such as AI, blockchain and biometrics impact migration processes and what are the potential ethical implications and risks associated with their use? How can technological advancements be leveraged to enhance migrant integration, access to services and the protection of migrant rights while mitigating digital divides and privacy concerns? What challenges and opportunities will arise from the use of social media and digital platforms in shaping migration narratives, fostering community support networks and combating misinformation and exploitation?

— **ECONOMIC:**

How will automation and AI-driven disruptions in job markets affect labour migration patterns and employment opportunities for both migrants and native populations? What are the economic consequences of brain drain in the countries from which people are emigrating and its impact on development trajectories?

— **ENVIRONMENTAL:**

What are the anticipated migration patterns and displacement trends resulting from ongoing environmental changes such as climate change, resource depletion and natural disasters? How will host communities and governments address the environmental impacts of migration, including the pressures exerted on infrastructure, resources and ecosystems?

— **(GEO)POLITICAL, REGULATORY:**

What challenges will arise from the fragmentation of migration governance and diverging national interests, and how can multilateral approaches and diplomacy address these complexities to ensure equitable and humane responses to migration challenges? How will border security measures and migration governance evolve in response to changing migration patterns, security threats and humanitarian crises?

WEAK SIGNALS:

Various weak signals indicate the evolving landscape of migration trends globally. Border militarisation is implemented by using military technologies and personnel to control borders. This approach points to increasing migration pressures and security worries. Additionally, some countries use migrants for their own political benefit. They make deals with other countries to handle asylum seekers outside their own borders. It also highlights the challenges in managing migration flows efficiently. Predictions about climate-induced migration focus on extreme weather and the lack of resources, demonstrating a pressing need for policies that adapt to these changes.

New data sources such as surveys and social media are being used. This suggests that efforts are being made to improve how we monitor and respond to changing migration patterns. Additionally, the ongoing dependence on networks of people living outside their home countries and economic differences are driving global migration pathways and employment patterns.

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3.13

SHIFTING HEALTH CHALLENGES

FROM VIRAL TO VITAL: ADAPTING TO THE NEW NORMS OF HEALTH CHALLENGES

DESCRIPTION:

Science has greatly lowered the rate of infectious diseases. However, today's health problems often involve non-communicable diseases (NCDs). Examples are heart disease, stroke, cancer, diabetes and chronic lung disease. These NCDs can result from unhealthy lifestyles and pollution.

Advances in healthcare have made people live longer. However, problems such as obesity, malnutrition, antimicrobial resistance, mental health issues and diseases from animals continue to exist. The COVID-19 pandemic has shown how vulnerable global health systems are and emphasised the need for urgent action to tackle new health threats. In addition, the acknowledgement of the multifaceted nature of health underlines the interplay of genetics, lifestyle choices and environmental factors.

In the near term (multiple years to a decade), the number of NCDs is expected to rise worldwide. This increase will be especially noticeable in developed countries and will pose huge challenges to healthcare systems. Electronic health technologies and data-driven healthcare are improving. They help prevent, diagnose, and treat diseases better.
In the long term, there will be ongoing efforts to use technology and data to improve healthcare. This could change how healthcare is provided. Individualised therapies in the form of personalised or precision medicine can provide better chances of finding a cure than "one size fits all" therapies. CRISPR-Cas9 gene editing could make traditional approaches to treating incurable diseases obsolete or prevent diseases altogether through the genetic enhancement of humans. Nanomedicine on the other hand can be used as a biosensor for the preventive detection of diseases or as medication. It autonomously realises disease-relieving effects in the affected area without impacting the whole body.

Below, we discuss the impact of Diversification of shifting health challenges for each category:

— SOCIO-CULTURAL:

Social issues such as NCDs and mental health highlight the need for holistic healthcare. Personalised medicine brings up concerns about privacy, data ownership and fair healthcare access. Changing lifestyles and urbanisation are reshaping societal norms in relation to health behaviours and disease prevention.

— TECHNOLOGICAL:

Technological advances such as CRISPR-Cas9 gene editing, mRNA vaccines and nanomedicines support personalised medicine, allowing for precise diagnostics and treatments. The growth of telemedicine and wearable health devices signifies a move towards digital healthcare, providing personalised solutions and enabling individual health management.

— ECONOMIC:

Work absence costs due to burnout and mental issues are increasing. Personalised medicine could lower healthcare costs by improving treatment targeting and avoiding unnecessary interventions. However, healthcare systems are facing pressure to manage escalating costs and the need for personalised treatments.

— ENVIRONMENTAL:

Environmental degradation, driven by pollution and climate change, significantly affects health, increasing non-communicable diseases such as respiratory illnesses and cancers. Sustainable policies and awareness campaigns are crucial to reducing these health risks by tackling environmental issues.

— (GEO)POLITICAL, REGULATORY:

The divide in health care between developing and developed nations is widening. Regulatory systems need to be adjusted to keep up with advances in gene editing, personalised medicine and nanotechnology, prioritising patient safety and ethics. The COVID-19 pandemic has exposed the weaknesses of the global health system, emphasising the need for international collaboration against health threats.

Main uncertainties and challenges:

— SOCIO-CULTURAL:

How will societal attitudes towards health behaviours and lifestyle choices evolve in response to shifting health challenges? What role will cultural norms and beliefs play in shaping access to and the acceptance of emerging healthcare technologies and treatments? How will disparities in healthcare access impact efforts to address NCDs and mental health issues? How does society deal with the increase in the transparency of sensitive data, such as previous illnesses, and possible discrimination against ill people?

— TECHNOLOGICAL:

What ethical implications will arise from the widespread adoption of precision medicine and gene editing technologies? How will technological advances impact healthcare privacy and security?

— ECONOMIC:

How will healthcare systems manage the financial burden of addressing rising rates of NCDs while maintaining the quality of the care? What economic implications will arise from the transition towards personalised medicine and innovative healthcare technologies? How will disparities in income and access to health care impact the adoption of emerging treatments and therapies? How can the long times (up to decades) for the development of new therapies be financed? Is the incorporated patent system enough of an incentive to invest in research and development, especially in treatments of less commonly spread diseases?

— ENVIRONMENTAL:

How will efforts to address environmental health factors, such as pollution and climate change, intersect with strategies for preventing and treating NCDs? What challenges will arise in balancing economic development with environmental sustainability to promote long-term health outcomes?

— (GEO)POLITICAL, REGULATORY:

What regulatory frameworks are needed to ensure the safe and ethical use of emerging technologies such as CRISPR-Cas9 gene editing and nanomedicine? How will geopolitical tensions and international cooperation influence the sharing of healthcare data and resources in response to global health threats? How can research and the development of therapies for diseases that do not offer sufficient return on investment be mitigated?

WEAK SIGNALS:

The rise of precision medicine is evident through various manifestations in the healthcare landscape, e.g. genetic testing in cancer treatment. Governments, healthcare institutions and pharmaceutical companies are now investing more in precision medicine. This means they are moving towards personalised healthcare.

Genetic testing kits and health apps are now more common. They allow people to manage their own health and offer personalised health advice. There is an increase in the use of telemedicine and wearable health technologies, which shows a growing dependence on digital resources for providing health care.

Startups and research projects focusing on creating new, personalised healthcare solutions are emerging. These include custom medical devices, targeted therapies and gene therapies, all pointing to potential breakthroughs in disease prevention and treatment. The first applications of gene therapy are used to cure blood disorders that have up until now been uncurable.

Public awareness campaigns are focusing on the stigma of mental health and environmental health. This shows that people are recognising the link between human health and broader societal and environmental factors.

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3.14 DIVERSITY-AWARE SOCIETY

A NEW ERA OF SOCIAL AWARENESS

DESCRIPTION:

In many Western societies, there is a growing awareness of social injustices. Consumers are becoming actively involved, demanding transparency and change. In the post-demographic world, new standards and challenges are emerging for both politics and businesses. The idea that there is a standard definition for all consumers is slowly disappearing. This change comes as people recognise and address the diversity and differences among individuals. Simultaneously, there is an increasing awareness of discrimination and a lack of equal opportunities. Previously marginalised groups are publicly and visibly advocating for equal opportunities. Products, services and infrastructures are expected to be inclusive and designed to accommodate everyone from the outset. Women are advocating for autonomy and fighting against the gender pay gap and sexual violence. Social media serves as a platform for activism, but also highlights the polarisation of society. Consumers are exerting increasing pressure on companies, demanding political stances and transparency. Similarly, politics is undergoing profound changes and facing numerous challenges. New democratic approaches are being tested, while the increasing power of global tech giants and the spread of misinformation threaten democracies worldwide.

In the near term (multiple years to a decade), the trend of diversity-aware culture and growing individualism are expected to continue shaping societal norms and behaviours. Consumers will increasingly seek transparency and accountability from both businesses and governments. This will lead to changes in corporate practices and political strategies. Companies will adopt inclusive design principles as a standard practice. They will integrate these principles into their products and services. This approach aims to meet the diverse needs of their customers. Social media will remain a prominent platform for activism and expression, influencing public discourse and holding institutions accountable.

In the long term, the trajectory of a diversity-aware culture and growing individualism will likely depend on how effectively societal institutions adapt to these changes. Advances in technology, especially in artificial intelligence and blockchain, could enhance transparency and inclusivity. However, the persistence of societal divisions and the evolving nature of activism could also present challenges to sustaining progress in these areas.

Below, we discuss the impact of a diversity-aware culture for each category:

— **SOCIO-CULTURAL:**

A diversity-aware culture deeply influences society's norms and values. It leads to a heightened awareness of social injustices and discrimination. This heightened awareness fosters a more inclusive environment in which previously marginalised groups advocate for equal opportunities. Grassroots movements and social media activism serve as catalysts for change. They amplify voices and demand accountability from both corporations and governments.

— **TECHNOLOGICAL:**

Social media platforms play a pivotal role in facilitating activism and mobilisation, serving as a tool for advocacy and spreading awareness of social issues.

— **ECONOMIC:**

Diversity-aware culture affects how consumers behave. People are more likely to support companies that match their values. These values include transparency and social responsibility. Consumer pressure motivates companies to embrace inclusive practices and transparent policies. This is essential for maintaining credibility and meeting changing societal expectations. Furthermore, companies that fail to address social injustices risk facing boycotts and reputational damage, impacting their bottom line.

— **ENVIRONMENTAL:**

A diversity-aware culture is not directly related to environmental issues. However, it connects with environmental activism within the larger social justice and equity movement. Activists for environmental causes highlight the uneven effects of climate change on marginalised communities and show how social and environmental issues are closely linked.

— **(GEO)POLITICAL, REGULATORY:**

A diversity-aware culture influences political discourse and policymaking, with an increasing focus on enacting laws and policies that promote diversity, inclusivity and equality. Diversity and its acknowledgement vary significantly across nations and governmental systems.

Main uncertainties and challenges:

— **SOCIO-CULTURAL:**

How will societal attitudes towards a diversity-aware culture evolve over time? Will there be pushback against a perceived "cancel culture" or a greater embrace of social justice movements? What impact will generational differences have on the trajectory of a diversity-aware culture? Will younger generations continue to drive change or will there be resistance from older demographics? How will cultural globalisation intersect with diversity-aware culture movements?

— **TECHNOLOGICAL:**

How will advancements in technology shape the future of social activism and advocacy? Will emerging technologies facilitate greater inclusivity and participation or will they exacerbate existing digital divides? Will algorithms amplify echo chambers or foster meaningful dialogue across various perspectives?

— **ECONOMIC:**

What will be the long-term economic implications of companies adopting diverse or “woke” branding and marketing strategies? Will these efforts lead to genuine change or be perceived as superficial attempts to capitalise on social movements?

— **ENVIRONMENTAL:**

How will a diversity-aware culture intersect with environmental activism, and what impact will this have on the prioritisation of environmental issues? Will there be synergies between social justice and environmental movements or will competing interests emerge?

— **(GEO)POLITICAL, REGULATORY:**

What role will international institutions play in promoting a diversity-aware culture and advocating for human rights on a global scale? How will regulatory frameworks change to meet the challenges of a diversity-aware culture? These challenges will arise in areas such as free speech, privacy rights and civil liberties. Will there be a balance struck between protecting individual rights and addressing systemic injustices?

WEAK SIGNALS:

There has been a notable surge in the demand for products that are ethically produced and transparently sourced. People are becoming more aware of social injustices and want companies to be more responsible. This includes how companies make products, manage supply chains and affect society. Consequently, there is an emerging expectation for businesses to demonstrate social responsibility. This is particularly amplified by social media activism and the empowerment of marginalised groups. Failure to address these concerns may lead to significant public backlash and reputational harm for companies.
Moreover, there is a growing recognition of the importance of diversity and inclusion, particularly in design practices across various industries. This involves designing products, services and digital interfaces that cater to a wide range of abilities, cultures, genders and ages. Moreover, intersectional feminism has started to emerge in brand activism, with companies aligning themselves with movements addressing discrimination. These are not only based on gender but also race, ethnicity, sexuality, disability and other intersecting identities. This trend signifies a shift towards more nuanced and inclusive approaches in corporate social advocacy.

Advances in technology are paving the way for innovative solutions aimed at promoting social change and political participation. This involves creating digital tools and platforms to fight misinformation and encourage people to participate in civic activities online. Furthermore, they help increase the visibility of voices that are often ignored.
These signals collectively indicate the potential for a diversity-aware culture to shape various aspects of society. The signals spread from consumer preferences, corporate ethics, design standards and feminist movements to technological developments. Businesses, policymakers and activists need to watch for signs of change in society to ensure that they can anticipate and adjust to new societal expectations and values.

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4 Cross-impact analysis

The term "cross-impact analysis" refers to a foresight tool that attempts to illustrate and analyse correlations between various elements being analysed and to take their mutual effects into account. Most events and developments are in some way related to other events and developments ("correlation"). First-level analysis does not tackle these complex interactions and the links between individual elements and events are not taken into account. Cross-impact analysis aims to fill this gap.

In the context of this project, cross-impact analysis is presented as a tool to illustrate the level of interconnection and interaction of the technological trends with the megatrends.

To perform the cross-impact analysis, the technology trends are listed on the left-most side of a table (along the y-axis) and the technology trends or megatrends are listed on the top-most row of the same table (along the x-axis). In each cell of the table, the interconnectedness and level of interaction between the corresponding trends are assessed. This is performed by expert judgement with the help of the research performed on technological trends and megatrends in sections 2 and 3, respectively. The entries on the preliminary assessment of interactions between trends can be particularly useful. A number is then assigned to each cell, ranging from 0 to 3 and denoting low to high interconnectedness. For each trend, the sums of their interconnected scores are given as a proxy for the overall level of importance that this trend possesses. Some indicative preliminary results as produced are provided as an example in Table 1.

	AGGRAVATING RESOURCE SCARCITY	CHANGING NATURE OF WORK	CHANGING SECURITY PARADIGM	CLIMATE CHANGE AND ENVIRONMENTAL DEGRADATION	CONTINUING URBANISATION	DIVERSIFICATION OF EDUCATION AND LEARNING	WIDENING INEQUALITIES	EXPANDING INFLUENCE OF EAST AND SOUTH	GROWING CONSUMPTION	INCREASING DEMOGRAPHIC IMBALANCES	INCREASING INFLUENCE OF NEW GOVERNING SYSTEMS	INCREASING SIGNIFICANCE OF MIGRATION	SHIFTING HEALTH CHALLENGES	DIVERSITY-AWARE SOCIETY	SUMS
DATA SCIENCE AND AI	1	3	3	1	1	3	3	1	2	1	1	1	2	1	24
IMMERSIVE TECHNOLOGIES	0	2	2	0	1	3	1	0	2	1	1	0	2	2	17
QUANTUM TECHNOLOGIES	2	0	3	2	0	0	0	1	1	0	0	0	1	1	11
SENSOR TECHNOLOGIES	2	2	3	3	2	1	1	1	2	1	0	1	2	1	22
NEW MATERIALS AND DIGITAL PRODUCTION	1	1	2	3	2	1	0	1	0	0	0	1	1	0	13
RENEWABLE ENERGY AND RESILIENCE	2	2	2	2	1	1	1	1	3	0	0	0	1	0	16
HUMAN ENHANCEMENT TECHNOLOGIES	3	1	2	3	2	0	1	1	3	2	0	2	1	0	21
CYBER TECHNOLOGIES	1	3	3	0	0	2	3	1	2	2	1	0	3	2	23
DIGITAL COMMUNICATION	1	2	3	1	2	1	0	2	0	0	3	1	1	1	18
LOW-POWER WIDE-AREA	0	2	2	0	2	2	0	0	2	0	0	0	1	1	12
ROBOTIC AND AUTONOMOUS SYSTEMS	2	3	3	2	2	1	2	1	1	0	1	0	2	0	20
SUMS	15	21	28	17	15	15	12	10	18	7	7	6	16	9	

Table 1: Indicative preliminary results given as an example of a cross-impact analysis for technological trends and megatrends. The scale of interconnectedness is as follows: 0 – Close to none, 1 – Low, 2 – Medium, and 3 – High.

5 Scenario Game

5.1 MOTIVATION

Foresight work is often challenged with not engaging with the members of an organization or decision makers to a sufficient extent. While analytical work on trends is the fundamental basis in developing foresight, it is paramount to think about alternative pictures of the future as well as about different scenarios and this is best done in group discussions and interactive setting.

Not only do group discussions allow for the inclusion of multiple perspectives, but such settings also foster active engagement with trends, scenarios and multiple futures. Following the paradigm of "understating vs. consuming", we have created an engaging workshop format, addressing leaders, foresight experts and any other potential stakeholder or expert interested in disruptive technologies and their future implications.

This workshop concept is named the "Scenario Game". The overarching goal of the Scenario Game is to jointly develop images of the future based on the information on technological trends and megatrends compiled in the previous step of this project. Further, the aim of the Scenario Game is to enable participants to engage with multiple futures and challenge their assumption about the future.

The Scenario Game aims to provide a less time-consuming approach that can be practiced more frequently. The tight format enables faster and more focused work in producing scenarios. The interactive aspect further enhances participant engagement and thus their performance and learning experience. The collaborative aspect improves "buy-in" of the resulting scenarios from participating members of an organisation, as well as team building.

Of course, this cannot replace the analytical rigour of a full scenario-planning process or the effects of several organisational interventions, but we believe that we have created a format that serves either as a starting point to engage with foresight or that allows us to take discussions regarding the future one step further.

5.2 PRINCIPLES

Figure 5: The "four archetype scenarios".

The Scenario Game is based on two principles.

1. The future cannot be predicted, but can be based on current trends. Potential scenarios can be described and this is illustrated in the future cone.

2. Scenarios exercises tend to describe four archetypes of possible scenarios, which is fundamental for the Scenario Game.

The future cone (Figure 4) is a representation of the various types of scenarios you can encounter in dealing with the future. These types are:

- Projected scenario: Default extrapolation from today and the "most probable" scenario to come to pass.
- Probable scenario: Current trends show that such a scenario is "likely to happen" in the future.
- Plausible scenario: Current knowledge indicates that such a scenario "could happen".
- Possible scenario: Current knowledge indicates that such a scenario "might possibly happen".
- Preferable scenario: This represents a desired future that is "wanted to happen".

Research has suggested that scenario exercises typically produce scenario sets that evolve around the same tonality, labelled as the four archetypes [Dator, 2009] (Figure 5). The four archetypes is a classification of future scenarios that presents four different types of scenarios that are typically very useful in thinking about the future. The four archetype scenarios are defined as follows [Dator, 2009]:

- **Continued growth** is a future in which the current trajectory and also the current problems persist and are enhanced, i.e. it is an expansion of the present. This future is very similar to business as usual, but not exactly the same. Business as usual is the continuation of the present, not a continuation of its trajectory.
- **Collapse** is a future in which the system reaches its limit and collapses.
- **Discipline** is a future of equilibrium. A steady-state civilisation focused on sustainability.
- **Transformation** is a future of radical departure from the present due to a transformative event or phenomenon, either spiritual or technological, where the very concept of being human is redefined.

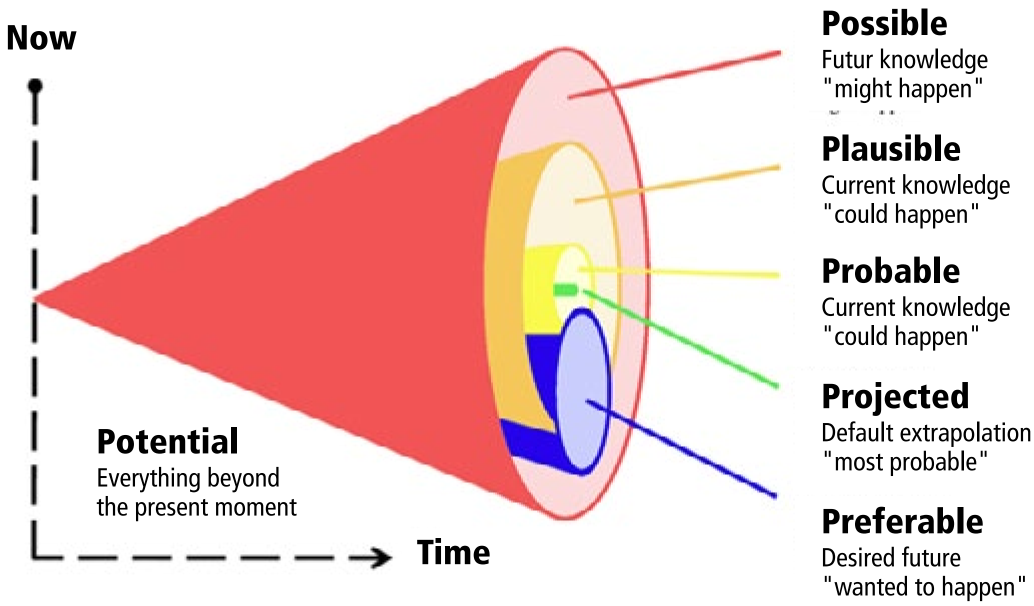

Figure 4: The future cone [van Dorsser et al., 2018]

5.3

DESCRIPTION AND MANUAL FOR THE GAME

While we provide suggestions on how the Scenario Game concept can be used, we also want to emphasize that the approach can be implemented in many ways, for different purposes and in various settings.
Our suggestions here are based on several Scenario Game workshops we have run, reflecting different contexts, participant constellations and timeframes.
Why have we called this approach the Scenario Game? It is not about winning; one cannot win the future. Instead, it is more about collaboration and playfully exploring different futures by using different trends in a structured way.

We provide the following resources for the Scenario Game:

- Trend cards
- Two scenario canvases
- User guide
- Video tutorial

The Scenario Game can either be played online of offline. All material is ready-to-print and can be found on *https://anticipatech.com*

The Scenario Game comprises two steps: a first more explorative step and a second more structured step. In the first, explorative step, the participants are assigned to teams and are provided with the first canvas (Figure 6) and the trend cards. The teams have the following tasks, also listed on the canvas:

1. Define the industry or particular area on which they would like to focus.
2. Define the time horizon on which they would like to focus, ranging from up to five, up to ten, and up to 30 years, or even beyond this timeframe depending on the industry or area of interest.
3. Choose two or three technological trends and megatrends that are most relevant to the chosen focus and time horizon.
4. Develop a scenario, combining the selected trends to provide a consistent picture of the future. Find a compelling title that describes this future world (scenario) and describe it with a few bullets.
Optionally, the cross-impact analysis can be used to detail the scenarios and also to assess the connections between the trends.
5. Consider the implications of the selected industry or focus, e.g. on products, services, operations, strategy or risk management.

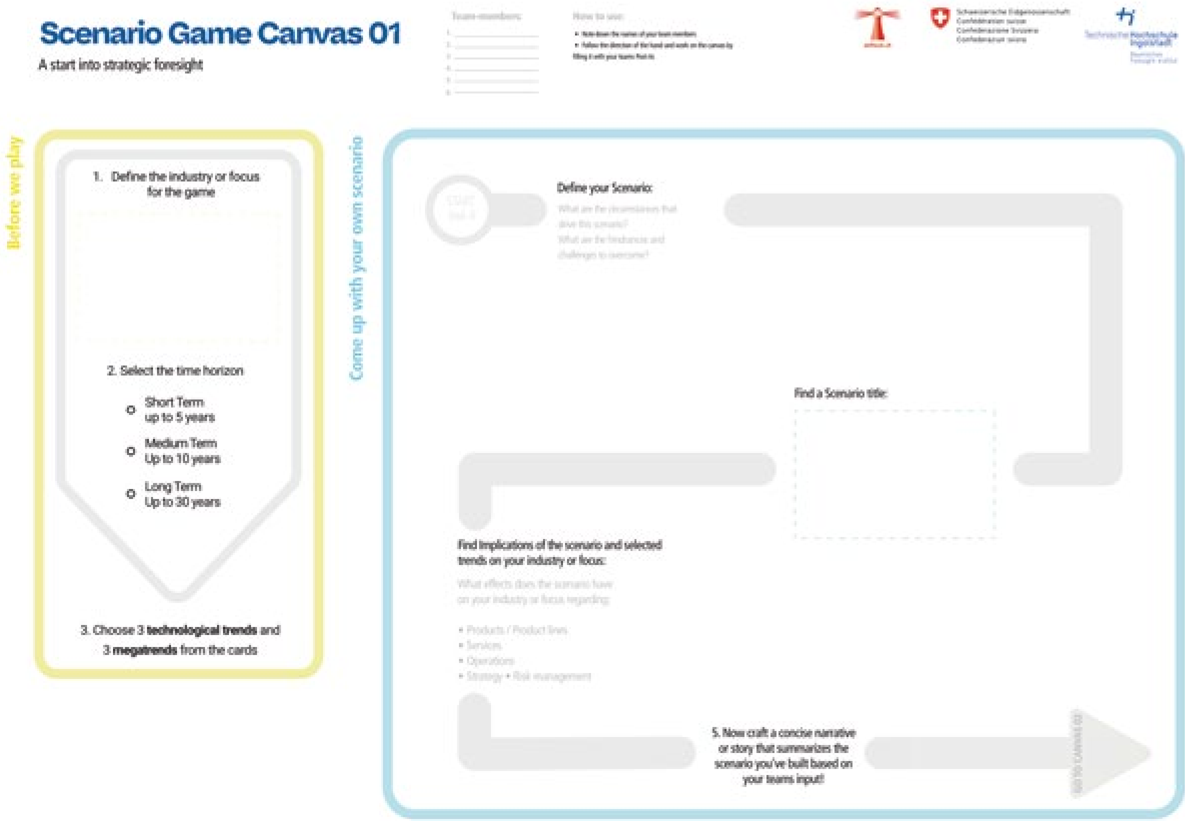

Figure 6: The canvas for the first step of the Scenario Game.

For the second, structured step, participants are introduced to two key principles of the Scenario Game: the future cone and the four archetypes. It is important that you emphasise that the future cannot be predicted, but alternative pictures of the future/scenario can be developed based on current trends. Participants must carry out the following task using the second canvas (Figure 7):

1. Allocate the scenario developed on the first canvas to one of the four archetype scenarios
2. Assess how the first scenario developed would play out in the other archetypes
3. Consider the implications for the four different scenarios
4. The cross-impact analysis can optionally be applied to provide further details about the scenarios

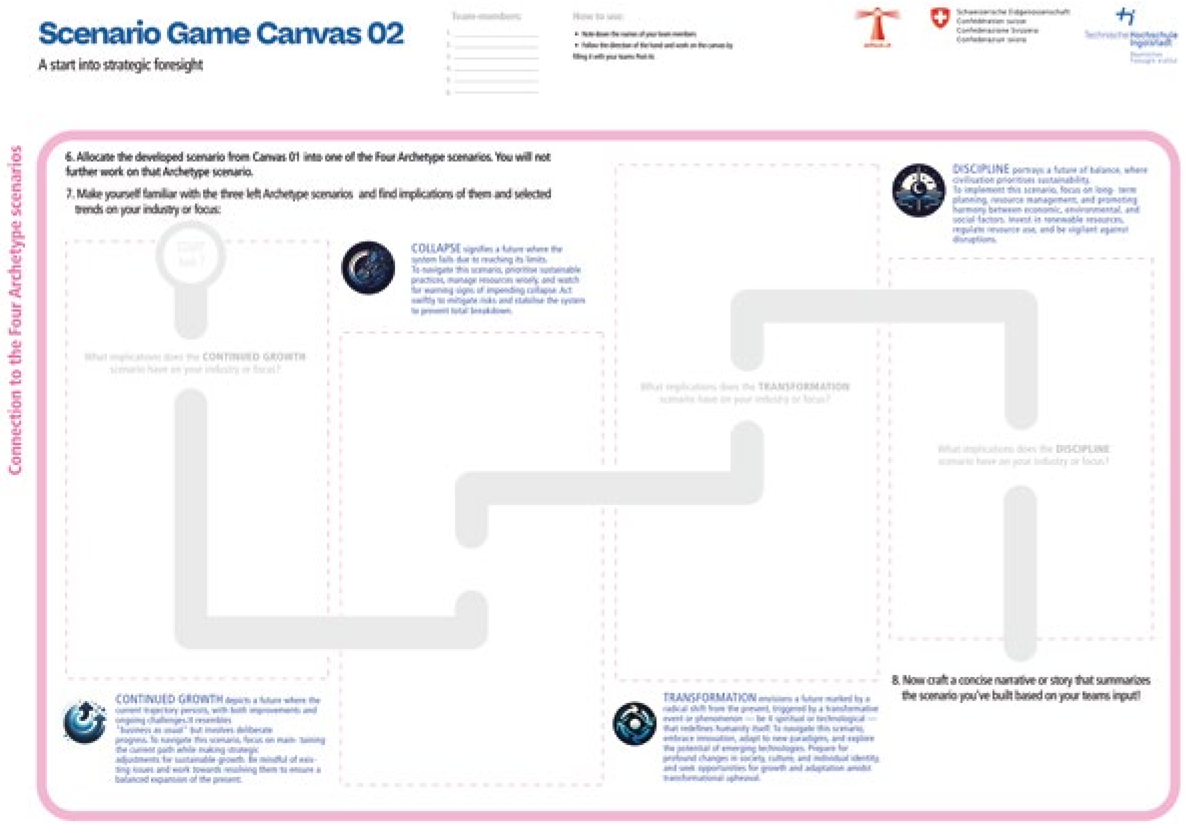

Figure 7: The canvas for the first step of the Scenario Game.

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Conclusion and next steps

As we conclude this report, you now possess a comprehensive understanding of the eleven pivotal technology trends tracked by armasuisse Science and Technology's foresight program. Recognising that technological advances do not occur in isolation, we have also explored 14 additional megatrends. These megatrends will inevitably shape the myriad use cases that leverage these various technologies, either individually or in synergy.

This knowledge allows you to fully engage with the "Scenario Game," the project's core deliverable. Whether you have 90 minutes, half a day or a full day, the tailored processes will enable you to develop a variety of scenarios. These scenarios will enhance your understanding of potential future outcomes and their implications.

Moreover, this project integrates seamlessly with other initiatives within the deftech program. By combining various content and processes, you can amplify your creative potential and envision groundbreaking possibilities. However, do remember that real impact is achieved in the present. All the insights and efforts culminate in the actions you take today.

Let’s work together and harness these trends, leverage our collective imagination and shape a future that is both innovative and actionable. The future is not just something that happens to us, it is something we create. Let's make it extraordinary!

About section

ABOUT THE PARTICIPATING ORGANISATIONS

The Bavarian Foresight Institute – Technische Hochschule Ingolstadt

The Bavarian Foresight Institute focuses on technology-oriented foresight research and the associated economic and social interdependencies.

Research is carried out in an application-oriented context. Research results are incorporated into consulting projects, published in academic journals and transferred to industry and society in various formats. The institute advances young academics by supervising doctoral theses Due to the close collaboration with various partners, the research institute focuses on third-party-financed public projects as well as industry projects.

https://www.thi.de/en/research/bavarian-foresight-institute/

Armasuisse Science and Technology

Armasuisse Science and Technology is the technology competence centre of the Federal Department of Defence, Civil Protection and Sport (DDPS). With its expertise in the areas of testing, research and innovation, it develops science-based foundations for its partners.

Known as deftech—defence future technologies—the technology foresight research program of armasuisse S+T inspires, informs and instructs the armed forces and its various stakeholders about the opportunities and threats posed by the use of technology.

Through its products and activities, it contributes to a collaborative and participative process that strengthens Switzerland's defensive capabilities.

https://www.ar.admin.ch/en/armasuisse-science-and-technology

ABOUT THIS PUBLICATION

A study conducted by the Bavarian Foresight Institute at the Technische Hochschule Ingolstadt for the technology foresight programme of armasuisse Science and Technology.

Study commissioned by: Dr Quentin Ladetto.

Study conducted by: Dr.-Ing. Konstantinos Konstantinidis, Prof. Dr. Jan Oliver Schwarz, Dr. Quentin Ladetto, Theresa Schropp and Philipp Schweiger.

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Theresa Schropp is PhD candidate at the University of the Bundeswehr Munich and of the Technische Hochschule Ingolstadt, Germany. Her research focuses on the topic of uncertainty in the context of decision-making and the associated relevance of strategic foresight.

In a world of rapid and chaotic change where technology plays an important role, we felt the need to create a foresight ecosystem from which we could structure and organise debates and exchanges between our different stakeholders.
In this joint project between armasuisse Science and Technology and the Bavarian Foresight Institute, we do not only provide a collection of relevant technology and megatrends, wealso provide an engagement format, the "Scenario Game", that allows us to work with these trends and explore the future, eventually developing foresight.

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