Office for Product Safety & Standards

Office for Product Safety and Standards Horizon Scan 1.0

Future and emerging technologically driven changes and horizon scanning methodology

November 2024

Executive Summary

The Office for Product Safety and Standards (OPSS) is the UK's product regulator. Our primary purpose is to protect people and places from product-related harm, ensuring consumers and businesses can buy and sell products with confidence. Good regulation delivers consumer protection and supports confidence, productivity, and growth for responsible businesses. The products, policies, and standards regulated by OPSS are shaped by continual innovation and social, environmental and technologically driven change. In order to be a proactive, forward-looking regulator OPSS works to anticipate future technology trends and emerging developments over time.

This project represents OPSS's first horizon scan, a systematic method for assessing future risks and opportunities arising from technologically driven change, to ensure that OPSS can optimise effective regulation for UK businesses, consumers, and stakeholders in future.

This work comprises of an initial assessment of seventy-one specific technologies of interest, using a blueprint methodology to support future horizon scans to be conducted by OPSS. This has been carried out in collaboration with Arup Foresight.

This document describes the methodology itself, the quality assurance and validation processes, and an overview of the outcomes of this first horizon scan. We have included in the report the taxonomy in full, comprising all seventy-one technologies. We also present those technologies identified as being the most relevant for OPSS (twenty in total).

This Horizon Scan 1.0 was designed to include several collaborative sessions, with extensive knowledge sharing throughout, to ensure that OPSS can continue to build its horizon scanning capability as it focuses on different elements of the changing regulatory and policy landscape.

In addition to this report, Arup has provided OPSS with all individual Rapid Evidence Reviews of the technologies assessed, a Playbook describing the tools and methodology (including lessons learned from this initial scan), a Capability Development Plan reflecting on skills and knowledge gaps as well as OPSS' future aspirations. A final deliverable is a database containing all evidence and scoring, with the option for OPSS to introduce weightings depending on focal priorities and needs.

1 Introduction

The Office for Product Safety and Standards (OPSS) was created in January 2018 to deliver consumer protection and to support business confidence, productivity, and growth. OPSS's primary purpose is to protect people and places from product-related harm, ensuring consumers and businesses can buy and sell products with confidence.

OPSS is the UK's product regulator.

- We are responsible for the regulation of most consumer goods (except for vehicles, medicines, and food) and we are the national regulator for construction products.
- We hold policy responsibility for product safety, legal metrology (weights and measures), standards and accreditation, hallmarking, and Primary Authority.
- We enforce regulations across the product lifecycle from design, manufacture and assessment through to supply, end use and safe disposal.

OPSS also holds enforcement authority for a range of goods-based and environmental regulations, for more detail please see our most recent Delivery Report (OPSS 2023a).

1.1 Research at OPSS

The science and engineering teams within OPSS provide evidence and advice for the development of policy, as well as the delivery and enforcement of product safety regulations. Their core functions include:

- Commissioning and undertaking research.
- Providing up-to-date scientific evidence and advice.
- Assessing product safety.
- Managing access to external experts and scientific databases.

OPSS wishes to become a more proactive and future facing regulator. To this end, OPSS are developing a new horizon scanning function to help systematically assess future technologically-driven changes (TDCs) up to 10-15 years ahead. This 'Horizon Scan 1.0' was run in collaboration with Arup Foresight, as a learning and upskilling exercise so the new function can independently run horizon scanning in years to come.

1.2 Foresight at Arup

Arup Foresight sits within a company of over 17,000 engineers, planners, architects, designers, and specialists. Arup Foresight helps organisations understand trends, explore new ideas, and create resilience in the face of uncertainty. Originally established to support Arup's own engineers and designers by exploring the future context for major infrastructure projects and the needs and expectations of its future users, Arup Foresight now operates both as an internal think-tank and a consultant to public and private sector organisations from a broad range of sectors.

Arup Foresight's insights and ability comes from experience in applying a wide range of foresight methodologies, including horizon scanning, combined with Arup's global engineering and consulting domain expertise. Over the last 20 years, Arup have also developed our own suite of innovative assets, tools, and platforms to support Foresight services. This includes Arup Drivers of Change cards and the Arup Inspire technologically-driven change platform.

1.3 Project objectives

Public sector organisations aim to deliver positive, statutory outcomes for society, communities, and the environment in which they operate. OPSS are part of the Department for Business and Trade, who are responsible for (amongst other things) ensuring the UK remains at the leading edge of international trade and product availability and safety. Accelerating technological innovation, manufacturing and commerce evolutions, net zero transition, and changing supply chains are just some of the many factors causing rapid change for the consumer products and instruments that fall under OPSS' regulatory remit. As a trusted product regulator, OPSS needs to be able to anticipate future changes in products to protect consumers and communities, and to support business confidence and productivity in the UK economy. Horizon scanning is a tool that enables OPSS to systematically identify emerging and future innovations and trends, assess the related opportunities and challenges across scales, and prioritise the emerging changes which have the greatest impact to OPSS (Hines, P. et al. 2019).

This project consisted of an initial horizon scan of technologies across a range of technology readiness levels and assessment of their relevance for OPSS through assigned metrics and expert moderation. The main purpose of this horizon scan was to build capacity within OPSS for foresight and futures thinking, ensuring that OPSS can conduct future horizon scans efficiently and effectively. The outcome of horizon scanning conducted within OPSS, including both this first horizon scan and future horizon scans, will be used as evidence to highlight and inform policy to any potential regulatory changes that may be required.

This initial horizon scan was designed to achieve the following objectives, with further information detailing the process of achieving each of these objectives provided in Section 2 (Methodology).

Develop and sort a long list of technologies into a taxonomy.

This long list was structured to cast a wide net regarding innovation across all areas of responsibility apart from construction products. A draft list of technologies and an initial literature review was provided at the start of the project by OPSS' Horizon Scanning team. The long list was developed in collaboration with a global network of experts, known as Skills Networks within Arup, Arup's established library services, external partners, and OPSS' horizon scanning team drawing on additional relevant literature.

Develop metrics for assessing technologies based on OPSS' activities and responsibilities.

Given the need to prioritise the technologies, the metrics and assessment framework, further detailed in Section 2 (Methodology), sets out areas of critical consideration for each technology. This was evaluated by experts and refined before any assessments or scoring took place. A draft of these metrics, based on workshop discussions across OPSS, was provided at the start of the project by OPSS

Gather evidence, in the form of rapid evidence reviews on each technology, to support reviews and scoring.

Evidence was drawn from a wide range of resources, including Arup library and knowledge management services, OPSS, and other subject matter experts within Arup. This combination of multiple sources ensured a comprehensive view across future technologies.

Score and prioritise each technology by applying metrics to the evidence gathered.

The project team scored and assessed each technology following clear instruction on the scoring system to ensure consistency.

Facilitate a process of review and validation.

Holistic reviews of the technology definitions and scoring were done collaboratively by panels of OPSS product experts, foresight and innovation experts, and specific technology specialists drawn from both OPSS and Arup. The review process also included sense checking key stages and ensuring the rapid evidence reviews properly captured OPSS' roles and responsibilities.

Share knowledge of what worked and what did not, to create a plan for how to best embed and develop horizon scanning capability in OPSS.

Across the project, a small core team made up of colleagues from both OPSS and Arup have worked collaboratively to share knowledge. This report, a working database of the horizon scan outputs, and the seventy-one Rapid Evidence Reviews are the primary outputs of the project, as well as assisting OPSS in developing capabilities, tools and techniques for ongoing horizon scanning to enable the monitoring of technologies over time. We also developed together: a foresight 'playbook' to guide further applications of foresight methodologies, a 3-year capability development plan, reflecting on the skills and knowledge gaps identified over the course of the project, with reference to OPSS priorities.

2 Methodology

Like OPSS, Arup and Arup's Foresight team are continuously assessing new and emerging technologies that impact the built environment and society more broadly. This section summarises the methodological approach taken for this first horizon scan and makes suggestions for changes and adaptions to improve future horizon scans. Scan 1.0 encompassed five stages, as shown in Figure 1:

Figure 1: Five stages of methodology

The following sections describe the five stages of the methodology.

2.1 Stage 1: Technology long-listing

This stage reviewed and expanded upon an initial technology list from OPSS to create a comprehensive long-list of technologies. The long-list of technologies was developed based on the following principles:

- Technologies should be application-agnostic.
- Technologies should be 'emerging', or have significant emerging aspects, rather than being fully commercialised.
- Technologies should be excluded if they concern workplace products, vehicles, medicine, or food, as those products are outside OPSS' regulatory responsibility.

Based on these principles, some technologies in the initial list were excluded. For example, cryptocurrencies and volatile organic compounds (VOCs) were considered outside of OPSS' remit, Silica is an emerging development captured under 'ultralight technologies', and 'automation' was excluded as this is more of a contextual driver shaping innovation rather than a specific technology.

Macro-scale contextual factors were removed, as these are not technologies but drivers shaping the development of technology (for instance, 'circular economy', 'water scarcity' and 'future of internet'). These have been detailed separately in Section 3 (Horizon Scan Outputs) of this report.

This stage resulted in seventy-one technologies being long listed.

2.2 Stage 2: Taxonomy Development

Arup and OPSS worked collaboratively to review the long list of technologies and define a taxonomy. The objective of the taxonomy was to develop mutually exclusive, application-agnostic categories that could facilitate the rest of the horizon scan and prioritisation process.

To develop the taxonomy, a variety of existing emergent technology taxonomies and classification systems were reviewed (BEIS 2020). This included Arup's own emerging technology material and the 2020 NASA Technology Taxonomy (NASA 2019). Arup also reviewed a draft taxonomy developed by OPSS before the outset of this project.

After reviewing the existing taxonomies, several different ways to form the taxonomy were considered. Considerations for primary fields and sub-fields included innovation fields, technology areas, applications, contextual factors, and OPSS' roles and responsibilities. The OPSS horizon scanning team and Arup Foresight identified some benefits and drawbacks of the existing taxonomies to inform the construction of this taxonomy. For example, benefits included taxonomies that mapped well onto remits and responsibilities, allowed for complex interactions between enabling technologies, and provided clear definitions; drawbacks included taxonomies that were too specific, could not accommodate enabling and cross-cutting technologies, or were too systems-focused. Considering these as well as OPSS workshops, stakeholder needs, and previous rapid literature reviews, three main requirements for the taxonomy were established:

- All items in each level of the taxonomy need to be of the same type or kind.
- Each level needs to be clearly defined.
- The longlist must be a longlist of technologies, not applications or contextual trends and drivers.

Technologies were assessed for inclusion based on the responsibilities, interests, and objectives of OPSS. The technologies were then grouped into overarching clusters or themes. This stage also considered the grouping of technologies against the amount of information/time required for the subsequent evidence reviews, to ensure that these were consistent as possible in size and scope for research and scoring purposes. The final Rapid Evidence Reviews varied in scope depending on the reviewer and the quality and availability of current literature. To mitigate this we spent a significant amount of time moderating the research work and scoring. The quality and availability of literature is further described in Section 3.2 (Prioritisation of technologies).

The final taxonomy developed consisted of a three-tier hierarchy, comprised of five 'Primary fields', each containing three 'Subfields' and a variable number of 'Technologies'. The taxonomy structure is illustrated in Figure 2. The full taxonomy, including all the technologies, is presented in Section 3.1 (Taxonomy).

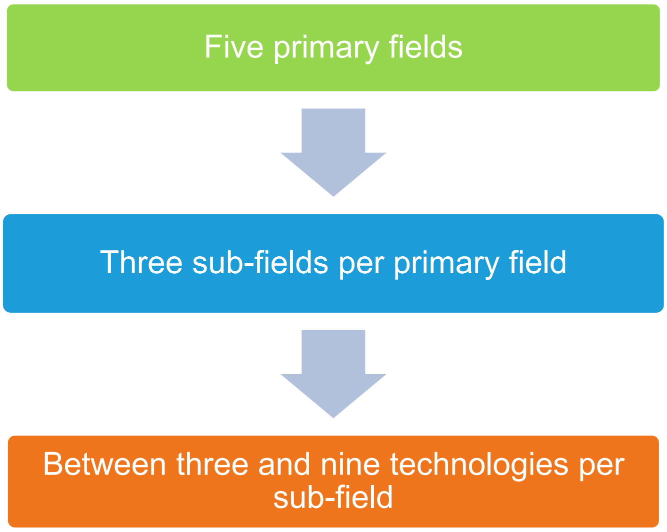

Figure 2: Overview of taxonomy

Once the taxonomy was agreed on, specific applications of technologies were removed, to keep it application-agnostic (for example, 'blockchain for logistics' was removed as it is an application of blockchain technology). Additionally, only on completion of the rapid evidence reviews were some further issues found. The evidence reviews themselves illustrated how some technologies had more overlap than anticipated, while other technologies would benefit from being further subdivided than initially realised and therefore should have been considered as a potential subfield. This is something that future horizon scans could respond to.

2.3 Stage 3: Metrics and assessment framework

Arup and OPSS worked collaboratively to identify a Multi Criteria Analysis (MCA) framework by which to assess each technology. MCA is a prioritisation and decision support technique especially developed to assess complex environments (Dean, M. 2022). The framework identifies key factors and a range of metrics to determine the effect of a particular intervention (in this case, technologies).

OPSS identified four key factors against which the technologies would be scored. This list was expanded to 5 metrics, following a stakeholder workshop, to separate the harms, hazards and risks associated with a given technology from its wider-scale societal impact. Following this, specific and measurable values were identified against each key factor. The metric assessment framework is shown in Figure 3:

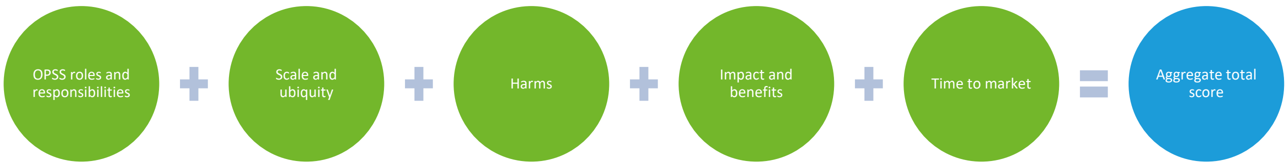

Figure 3: Metrics and assessment framework

OPSS roles and responsibilities metric

This metric is a measure of how relevant a particular technology is to OPSS. To develop the metric, OPSS provided a list of policy and enforcement duties, roles and responsibilities within the organisation, and a list of cross-cutting activities and duties. In each review, the relevant roles and responsibilities that could be impacted by each technology were identified. The combined number of roles and responsibilities and cross-cutting activities were used to determine the OPSS remits score. The OPSS remits score ranges from a score of 1 (less than four relevant roles and cross-cutting activities) to a score of 5 (greater than twenty-one relevant roles and responsibilities).

Scale and ubiquity metric

This metric is a measure of how significant and widespread the technology is likely to be. The metric was calculated from three sub measures:

1. **Market size:** The current estimated size of the global market for the technology. The market size score ranged from a score of 1 (estimated market size of <$1 billion USD) to a score of 5 (estimated market size of >$300 billion).
2. **Compound annual growth rate:** The projected compound annual growth rate (CAGR) for the technology market. The CAGR score ranged from a score of 1 (CAGR of less than 9%) to a score of 5 (CAGR of greater than 42%).
3. **Enabled technologies:** The number of other emerging technologies (from the taxonomy) that the technology could enable or contribute to the development of. This metric is intended to identify technologies that are particularly central to innovation and technological change. The enabled technologies score ranged from 1 (no enabled technologies) to 5 (greater than thirty-five enabled technologies).

Harms and hazards metric

This metric considers the new Product Safety Risk Assessment Methodology (PRISM), used by market surveillance authorities and enforcing authorities in Great Britain with responsibility for consumer product safety (OPSS 2023c). PRISM provides authorities with an updated risk assessment methodology that addresses some of the limitations of the EU Safety Gate Rapid Exchange of Information System (RAPEX) and allows for a more comprehensive, robust, and informed assessment and consideration of risk. PRISM was developed by OPSS following a review of the existing arrangements with extensive input from local authorities and national regulators. Two relevant measures were taken directly from the framework:

1. **Number of hazard types:** Hazard types that the technology could lead to, chosen from the PRISM list of common product safety hazards. The hazard score ranged between a score of 1 (no hazard types identified) to a score of 5 (7 or more hazard types identified).

Hazard category	Hazard examples
Mechanical	Sharp edges, trapping hazards, crushing hazards, impact hazards
Size and shape	Small parts with the potential to be inhaled or ingested Suffocation or strangulation hazards such as blind cords and clothing with sashes or drawstrings
Electrical	Live 240v conductors; arcing; overload; short circuit

Fire and explosion	Ignition sources and fuel sources, e.g. naked flames, hot surfaces, poorly designed machinery, flammable furniture and furnishings
Thermal	Hot or cold surfaces of equipment
Ergonomic	Poorly designed chairs and I.T equipment
Noise and vibration	Noisy and vibrating machinery
Microbiological	Bacteria, viruses, e.g. bacterial contamination of cosmetics
Chemical	Substances that are carcinogenic, toxic, corrosive etc. e.g. cadmium in jewellery, cadmium and other heavy metals (lead, nickel, mercury & arsenic) in care products29, phthalates in toys, asbestos in building materials or as a contaminant in consumer products
Lack of protection	Smoke alarms that fail to activate; infant car seats and PPE that do not provide the specified level of protection

Table 1: PRISM table of common product safety hazards (OPSS 2023c)

2. **Degree of harm:** The possible degree of harm caused by a technology, chosen from the PRISM harm severity levels. The degree of harm score ranged between a score of 0 (no harm) to a score of 4 (possible risk of death). This score range was later changed from 0-4 to 1-5 for consistency with other metrics, a change which is further described in Section 3.3 (Stage 5: Scoring, weighting, and validation).

Level	Nature of harm	Potential for multiple casualties?
1	Injury or ill health that after basic treatment (first aid, normally not by a doctor) does not substantially hamper functioning or cause excessive pain; usually the consequences are completely reversible. *Examples: minor cuts, bruising, pinching, sprains and strains, piercing, 1-degree burns or 2-degree burns*	Yes / No
2	Injury or ill health for which a visit to A&E may be necessary, but in general, hospitalisation is not required. Functioning may be affected for a limited period, not more than about 6 months, and recovery is more or less complete. *Examples: cuts >10 cm on body and >5 cm on face, requiring stitches; major bruising (> 50 cm2 on body and >25 cm2 on face); concussion involving a short period of unconsciousness; dislocations or fractures of finger, toe, hand, foot, jaw; fractures of wrist, arm, rib, nose, jaw; piercing deeper than the skin; 2 degree burns 6-15% of body surface; electric shock causing temporary cramp or muscle paralysis; temporary loss of sight or hearing; poisoning causing reversible damage to internal organs; allergic reactions and widespread allergic contact dermatitis; reversible damage from microbiological infection.*	Yes / No

3	Injury or ill health that normally requires hospitalisation and will affect functioning for more than 6 months or lead to a permanent loss of function. *Examples: cuts / laceration or bruising to trachea or internal organs; concussion causing prolonged unconsciousness; sprains and strains causing muscle, ligament or tendon rupture/tear; dislocation of ankle, wrist, shoulder, hip, knee or spine; fracture of ankle, leg, hip, skull, spine (minor compression fracture), jaw (severe), more than 1 rib; crushing of extremities, arm, leg, trachea, pelvis; amputation of finger/s, toe/s, hand, foot, arm, leg, eye; piercing of eye, internal organs, chest wall; ingestion causing internal organ injury; internal airway obstruction or suffocation / strangulation without permanent consequences; 2 degree burns 16-35% of body surface and 3 degree burns up to 35% of body surface; epileptic seizure; permanent loss of sight (one eye) or hearing (one ear); poisoning causing irreversible damage to internal organs; strong sensitisation provoking allergies to multiple substances; irreversible effects from microbiological infection.*	Yes / No
4	Injury or ill health that is, or could be, fatal, including brain death; consequences that affect reproduction or unborn children; severe loss of limbs and/or function, leading to more than approximately 10% of disability. *Examples: cuts / laceration of spinal cord, brain, oesophagus, deep laceration of internal organs; bruising of brain stem or spinal cord causing paralysis; concussion resulting in coma; dislocation or fracture of spinal column; fracture of neck; crushing of spinal cord, chest (severe), brain stem; amputation of both arms or both legs; piercing of aorta, heart, bronchial tube or causing deep injuries in organs; ingestion causing permanent damage to internal organ; internal airway obstruction with permanent consequences; 2 or 3 degree burns >35% of body surface; electrocution; permanent loss of sight (both eyes) or hearing (both ears); poisoning causing irreversible damage to nerve system; anaphylactic reactions; prolonged hospitalisation from microbiological infection.*	Yes / No

Table 2: PRISM table of harm severity level (OPSS 2023c)

Reviewers were also asked to qualitatively outline any other aspects of harm, including:

- Harms a technology may present in relation to non-physical aspects such as psychological, financial, reputation, privacy, data loss, and wider cyber-security issues such as distributed denial-of-service (DDoS) attacks.
- Harms a technology may present in relation to end-to-end product lifecycle, for example during manufacture, retail or recycling and disposal.
- Harms a technology may present at a macro-scale, across STEEP fields, for example the environmental or social impact.

Impact and benefits metric

This metric is a subjective assessment of the wider-scale impact of the technology and the potential benefit it could provide to individual users. Two measures were used to evaluate this:

1. **Macro-scale impact:** An assessment of the degree of potential impact a technology could have across Social, Technological, Economic, Environmental, Political (STEEP) categories. The macro-scale impact score ranges from a score of 1 (little to no macro-scale impact) to a score of 5 (significant impact against multiple fields).
2. **Benefits to consumers:** An assessment of the potential benefits a technology could have for consumers. The benefits score ranged from a score of 1 (no benefit) to a score of 5 (great, potentially life-saving, benefit).

Reviewers were also asked to qualitatively outline any other aspects of benefit, as with harms, including:

- Benefits a technology may present in relation to non-physical aspects such as psychological, financial, reputation, privacy, data loss, and wider cyber-security issues such as distributed denial-of-service (DDoS) attacks.
- Benefits a technology may present in relation to end-to-end product lifecycle, for example during manufacture, retail or recycling, and disposal.
- Benefits a technology may present at a macro-scale, across STEEP fields, such as the environmental or social impact.

Time to market metric

This metric relates to the Technology Readiness Level (TRL) of a technology, which describes the stage of development and commercialisation it has reached (NASA 2021). The scale followed included the standard 1-9 scale typically used to describe TRL, as well as an additional score of 9+, which was intended to capture where a technology was widely available on the market. The TRL scale was as follows:

1 - Basic principles observed.

2 - Technology concept formulated.

3 - Experiment proof of concept.

4 - Technology validated in lab.

5 - Technology validated in relevant environment.

6 - Technology demonstrated in relevant environment.

7 - System prototype demonstrated in operation environment.

8 - System complete and qualified.

9 - Actual system proven in operational environment.

9+ - System widely available in market

The score assigned to the TRL metrics ranged from a 1 (TRL of 1-3) to 5 (TRL of 9+)

2.4 Stage 4: Rapid evidence reviews

Rapid evidence reviews were conducted by members of both the Arup and OPSS project team on the seventy-one technologies long listed in Stage 1.

Arup Library, a dedicated team who assisted with research and information-gathering, provided access to the latest research from leading publications and disseminated high-quality literature. The Arup Library has access to a wide variety of information sources including Sage and ScienceDirect, and access to specialist research databases including the Materials Science and Engineering database and Bloomberg NEF (New Energy Finance) database. Arup Library also has access to Statista, Factiva, and Profound for data analytics on trends across industries, case studies, and contextual information.

A temporal guide of developments two to fifteen years ahead was given. The literature search was guided by the use of certain keywords or phrases in relation to the technologies. These included:

- Future of…
- Innovation in…
- Evolution of…
- Potential applications of…
- Developments in…
- Opportunities for…
- Changes in…
- Uncertainties in…
- Risks for…
- Challenges for…

A form-based system was used to ensure the all the information ascertained enabled reliable, consistent scoring of each technology using agreed metrics. The questions were structured as follows:

Table 3: Submission form questions

Question	Response type
Describe what the technology is.	Written response
Give a high-level overview of how this technology is developing and the key considerations, applications, and risks.	Written response
Outline how this technology may relate to or impact on OPSS's roles and responsibilities.	Written response
Select all the OPSS roles that are likely to be impacted by this technology.	Multiple choice
Select all the OPSS cross-cutting activities that are likely to be impacted by this technology.	Multiple choice
Describe the current and projected future scale and ubiquity of this technology.	Written response
Select any technologies from the list which may be enabled by this technology.	Multiple choice
Estimated current market size.	Currency amount

Estimated compound annual growth rate.	Percentage
Outline the key potential harms and benefits this technology may present to the user or consumer.	Written response
Outline any potential harms and benefits this technology may present in relation to non-physical aspects such as psychological, financial, reputation, privacy, data loss, and wider cyber-security issues such as DDOS attacks.	Written response
Outline any potential harms and benefits this technology may present in relation to end-to-end product lifecycle, for example during manufacture, retail or recycling and disposal.	Written response
Outline any potential harms and benefits this technology may present at a macro-scale, across STEEP fields, for example the environmental or social impact.	Written response
With consideration of Social, Technological, Economic, Environmental and Political (STEEP) fields, what scale of impact might the technology and its application have?	1-5 scale
Select all the relevant macro-drivers of interest to OPSS listed below which this technology may have impact on.	Multiple choice
Select all the hazard types which may be presented by this technology.	Multiple choice (PRISM list of common product safety hazards)
Enter the most relevant consumer harm severity level for the technology.	0-4 scale (PRISM harm severity rating), later mapped onto a 1-5 scale for consistency with other metrics
Simplistically, how might applications of this technology benefit consumers?	1-5 scale
Give an overview of the technology readiness level (TRL) for this technology.	Written response
Select the defined TRL for this technology.	1-9+ TRL scale
Given the literature provided by the library and your own research, how much information is available on the technology?	1-5 scale
With respect to the literature reviewed, how confident in the range of sources are you?	1-5 scale

2.5 Stage 5: Scoring, weighting, and validation

Each of the technologies were assessed and scored based on the metrics and information collected and developed as part of the rapid evidence reviews. An OPSS remits score was assigned based on the number of relevant roles and cross-cutting activities identified by the reviewers' for each technology. The harm score was mapped onto a 1-5 scale from a

0-4 scale, adding 1 to each harm level from the PRISM framework to keep a consistent 1-5 frame across metrics. Some of the scores were also rebalanced to ensure that the scores were distributed evenly across the scale of responses, avoiding all the technologies scoring the same for a metric. For example, the CAGR score originally ranged from a score of 1 (less than 10%) to a score of 5 (greater than 100%). The rebalanced scores included the market size, CAGR, enabled technologies, hazard, and harm (as previously described). The following table provides an overview of the final definitions and scales used to score each technology:

Metric	Sub-metric	Explanation	Score and associated value
OPSS roles and responsibilities metric	OPSS remits score	Combined number of relevant roles and cross-cutting activities, selected from a list provided by OPSS.	1=<4 2=4-7 3=8-11 4=12-21 5=>21
Scale and ubiquity metric	Market size score	Current global market size for the technology, in United States dollars (USD).	1=<$1 billion 2=$1-5 billion 3=$5-50 billion 4=$50-300 billion 5=>$300 billion
Scale and ubiquity metric	CAGR score	Projected CAGR within any period over the next 2-15 years (best data available).	1=<9% 2=9-15% 3=<15-25% 4=<25-42% 5=>42%
Scale and ubiquity metric	Enabled technologies score	The number of additional technologies from the longlist that are enabled by this technology.	1=0 2=1-5 3=6-15 4=16-35 5=>35
Harms and hazards metric	Hazard score	Number of hazards selected from the PRISM common product safety hazards.	1=0 (No hazard) 2=1 3=2-3 4=4-7 5=>7
Harms and hazards metric	Degree of harm score	The relevant nature of harm selected from the PRISM harm severity levels.	1=0 2=1 3=2 4=3 5=4
Impacts and benefits metric	Consumer benefit score	Simplistically, how applications of this technology might benefit consumers.	1=No benefit 2=Minor benefit (e.g. greater ease of use) 3=Benefit (e.g. cost or efficiency savings) 4=Significant benefit (e.g. significant improvement to quality of life) 5=Great benefit (e.g. life-saving)

Impacts and benefits metric	Macro-scale drivers score	With consideration of Social, Technological, Economic, Environmental and Political (STEEP) fields, the scale of impact the technology and its application might have.	1=Little to no macro-scale impact 2=Minor impact against a single field 3=Minor impacts against multiple fields 4=Significant impact against a single field (perhaps including minor impacts against others) 5=Significant impact against multiple fields
Time to market metric	Technology Readiness Level (TRL) score	Based on the Technology Readiness Levels described in Section 3.3 (Stage 3: Metrics and Assessment Framework).	1=1-3 (research) 2=4-6 (development) 3=7-8 (prototyping, demonstration) 4=9 (market readiness) 5=>9 (already widely available in market)
Information availability and quality (not included as part of the overall score, further described in Section 3.2: Prioritisation of technologies)	Information availability score	How much information is available on the technology based on the literature provided and the reviewer's individual research.	1=No or very little information 2=Limited information, insufficient information to support the MCA 3=Information available, but some items in the review not adequately covered 4=Information available to cover and respond to all metrics 5=A large amount of highly relevant information
Information availability and quality (not included as part of the overall score, further described in Section 3.2: Prioritisation of technologies)	Information quality score	The reviewer's confidence in the range of sources reviewed.	1=None/irrelevant sources 2=Google search / other journalistic outlets / sponsored information 3=Other grey literature 4=Established technology sources 5=Peer-reviewed sources

Table 4: Final metrics, definitions, and scales

Reviewed simplistically, the ranking of the technologies based on these scores revealed a prioritisation of the technologies which most closely align with OPSS' regulatory and policy remit. Following the reviews and scoring, Arup and OPSS engaged a review panel to sense-check and validate each description and score, ensuring fair and even scoring across all technologies covered. The panel was comprised of OPSS staff and Arup technical experts, who also provided feedback to ensure that each review appropriately reflected the available literature. OPSS staff completed an additional review of the scoring to validate that the full range of OPSS remit was properly considered in each review.

As described in Section 2.2 (Stage 2: Taxonomy Development), the validation process revealed the challenges of the broad scope of the technologies reviewed. For example, a Rapid Evidence Review was completed for Human Augmentation, but it was not included as part of the final taxonomy of seventy-one technologies. The validation process of the Rapid Evidence Review and scoring revealed that Human Augmentation was an amalgamation of many technologies, resulting in artificially high scores that were incomparable to the other technologies in the taxonomy.

Weighting

An initial review was taken of the unweighted scores for each technology against the relevant metrics. Following this, a trial weighting approach was taken with consideration of the wider context for OPSS, the organisation's priorities, and the degree of urgency associated with each metric. The weighting of each metric was turned into a multiplier for the score of that metric, using the equation below:

$$\frac{number\ of\ metrics\ x\ (weight\ of\ individual\ metric)}{\sum(weight\ of\ all\ metrics)}$$

The number of total metrics refers to either the number of main metrics (five) or the number of sub-metrics within a metric (two to three, depending on the metric). Not all metrics have sub-metrics, and this is further described in Section 2.3 (Stage 3: Metric and assessment framework). It was collectively determined that the most significant metric is the potential harm or hazard a technology could cause. In addition, the TRL was deemed significant as a key indicator. Scores were processed in a database in such a way that weightings could be added and experimented with. The trial weightings included:

- Weighting towards potential risk of harm by changing the weight for the harms metric ('weighted harms score') from 1 to 2, keeping all else at 1. OPSS identified that the weighting towards potential risk of harm should be used for the use of the output of this horizon scan, reflecting OPSS' priority to reduce harm to consumers and businesses.
- Weighting towards potential risk and TRL by changing the weight for the harms metric ('weighted harms score') and TRL metric ('weighted TRL score') from 1 to 2, keeping all else at 1.
- Weighting towards impact, ubiquity, and benefit by changing the weight for the impact and benefit metric ('weighted impact and benefit score') and weight for the scale/ubiquity metric ('weighted scale/ubiquity score') from 1 to 2, keeping all else at 1.
- Weighting towards the harm severity sub-metric, overall harms and hazards, and TRL by changing the harm sub-metric ('degree of harm score'), the harm metric ('weighted harm score') and TRL metric ('weighted TRL score') from 1 to 2, keeping all else at 1.

Sensitivity analysis

Sensitivity analysis addressed how the uncertainty in the output of a mathematical model or system can be divided and allocated to different sources of uncertainty in inputs. Recalculating outcomes to determine the impact of a variable under sensitivity analysis was important to ensure findings were credible, understandable, and relevant for the purposes of OPSS.

Sensitivity analysis was done to measure the impact on the overall ranking of the technologies subject to a 10% increase in the weighting for each measure (changing the weight of a metric from a weight of 1 to a weight of 1.1). This helps to identify which measures have the greatest impact on the overall prioritisation.

The findings are presented as an average positional change across the full ranked list of technologies following a 10% increase in the weighting of each measure and each overall metric from a baseline level where each metric is equally weighted. The calculation to establish this figure was:

$$\frac{\sum\left|(Baseline\ ranking\ of\ each\ technology) - (10\%\ weighted\ ranking\ of\ each\ technology)\right|}{Total\ number\ of\ technologies}$$

Results of the sensitivity analysis done are as follows:

Metric	Sensitivity
Remit metric	0.493 (Ranking least sensitive to changes in this metric weighting)
TRL metric	0.493
Harms metric	0.535
Impact metric	0.606
Scale/ubiquity metric	0.606 (Ranking most sensitive to changes in this metric weighting)

Table 5: Results of sensitivity analysis

The sensitivity analysis indicates that, of the various metrics, weighting of the remit and TRL metrics has slightly less impact on the prioritisation than weighting of the Scale/ubiquity and impact metrics. This could be because there is relatively greater correlation between the TRL and remit metric and the other scoring.

The different sensitivity of the metrics does not indicate a problem in the scoring itself but should be considered when developing a weighting approach for the prioritisation exercise, as the outcomes will be more sensitive to some metric weightings than others. For example, if there is a desire to weight towards both harms and scale/ubiquity, a greater weighting on the harms metric than on the scale/ubiquity metric could be advised to avoid the scale/ubiquity metric having an outsized impact on the results. Further sensitivity analysis could be conducted in future horizon scanning activities.

2.6 Expansion opportunities

Future horizon scans looking at emerging technologically driven changes can take this methodology, repeat it, and/or edit some of the MCA approached to nuance the study. Readiness to regulate was initially proposed to be included as a metric within Horizon Scan 1.0, however further discussion with the project team resulted in the decision to move this discussion and assessment to a future discussion within OPSS.

The question of ‘readiness to regulate’ a technology is complex as it requires consideration of readiness across the whole regulatory process – from the degree of understanding of a technology and its risks, through to methods of regulations (RHC 2021). Measures to assess ‘readiness to regulate’ amongst other things, may include:

1. Political: the political will to regulate the technology.
2. Institutional: the institutional capacity to regulate a technology, for example, whether there is an appropriate piece of legislation in place or if new legislation is needed.
3. Organisational: the knowledge required to regulate the technology, for example understanding of the potential risks and identifying the entities who would be subject to regulation, and whether OPSS has a duty to regulate.
4. Commercial: the costs and business salience of regulation.
5. Infrastructure: The presence of appropriate and accessible infrastructure to support regulation, for example, the availability of facilities to test products.

3 Horizon Scan Outputs

3.1 Taxonomy

This initial horizon scan identified seventy-one technologies from a broad field of TDCs, following the long-listing process described in Section 2.1 (Stage 1: Long-listing). These were organised into a taxonomy of 5 primary fields, each with 3 subfields. This taxonomy was intended to be a set of categories with multiple dimensions with mutually exclusive and collectively exhaustive characteristics, such that each technology under consideration had a defined categorisation. The process of developing the taxonomy is described in Section 2.2 (Stage 2: Taxonomy Development). Technologies evidently relate to each other within and across categories, such as being enabled by, and enabling other technologies. The process of evidence review itself highlighted these relationships and this was captured as part of the Rapid Evidence Reviews. The full taxonomy is presented in Figure 4.

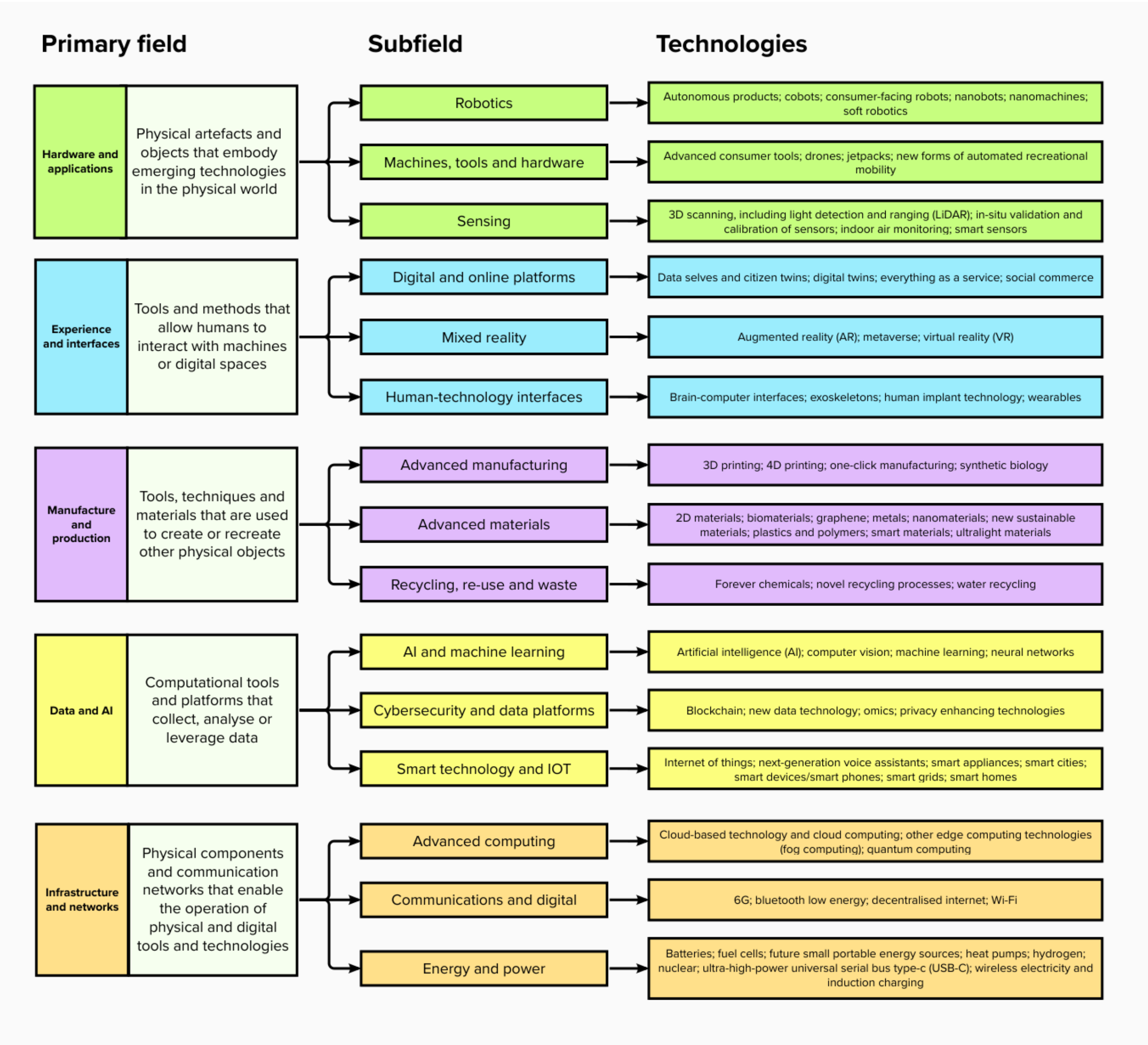

Figure 4: Full Taxonomy

Hardware and applications

Physical artefacts and objects that embody emerging technologies in the physical world, including the subfields of Robotics, Machines, tools and hardware, and Sensing.

Robotics: Machines which are designed to perform specific tasks that were traditionally done or controlled by humans, with a variable degree of self-sufficiency and decision-making capabilities. Includes:

- Autonomous products.
- Cobots.
- Consumer-facing robots.
- Nanobots.
- Nanomachines.
- Soft robotics.

Machines, tools, and hardware: Physical instruments, objects, and equipment which are purpose oriented. Includes:

- Advanced consumer tools.
- Drones.
- Jetpacks.
- New forms of automated recreational mobility.

Sensing: Technologies connecting the physical and the computing world. They detect and react to data collected from the physical environment and transmitted them as electronic signal to be processed. Includes:

- 3D scanning, including light detection and ranging (LiDAR).
- In-situ validation and calibration of sensors.
- Indoor air monitoring.
- Smart sensors.

Experience and interfaces

Tools and methods that allow humans to interact with machines or digital spaces, including the subfields of digital and online platforms, human/technology interfaces, and mixed reality.

Digital and online platforms: A product that enables other products, services, and business. Include:

- Data selves and citizen twins.
- Digital twins.
- Everything as a service.
- Social commerce.

Human/technology interfaces: These technologies enable the transfer of information between computing devices and people. They can be physical internal and external parts of computers and technology devices. They enable humans to operate and interact with both physical and non-physical space. Includes:

- Brain-computer interfaces.
- Exoskeletons.
  Human implant technology.
- Wearables.

Mixed reality: Mixed reality is the integration of digital information into a real-world environment, allowing live interaction and feedback between both realms. Mixed reality applications can transform how people access information and share experiences and virtual spaces. Includes:

- Augmented Reality (AR).
- Metaverse.
- Virtual Reality (VR).

Manufacture and production

Techniques and materials that are used to create or recreate other physical objects, including the subfields of advanced manufacturing, advanced materials, and recycling, re-use, and waste.

Advanced manufacturing: Group of technologies working at the junction of manufacturing, information and communication technologies. They are commonly composed of four groups: design and engineering technologies, planning and control technologies, information management technologies, fabrication and assembly technologies. Includes:

- 3D printing.
- 4D printing.
- One-click manufacturing.
- Synthetic biology.

Advanced materials: Advanced materials are materials produced for specific applications with targeted requirements. Their advanced characteristics can include their structure, their properties, their fabrication processes and their performance. Includes:

- 2D materials.
- Biomaterials.
- Graphene.
- Metals.
- Nanomaterials.
- New sustainable materials.
- Plastics and polymers.
- Smart materials.
- Ultralight materials.

Recycling, re-use, and waste: Technologies, products, and waste materials related to recycling and circular economy processes, right-to-repair, and handling of highly persistent waste products. Includes:

- Forever chemicals.
- Novel recycling processes.
- Water recycling.

Data and AI

Computational tools and platforms that collect, analyse or leverage data, including the subfields of artificial intelligence (AI) and machine learning, cybersecurity and data platforms, and smart technology and internet of things (IoT).

AI and machine learning: Advanced analysis and algorithmic technologies that can interpret existing information and automate or support decision-making and action. Includes:

- Artificial intelligence (AI).
- Computer vision.
- Machine learning.
- Neural networks.

Cybersecurity and data platforms: The combination of data, policies, processes, and technologies employed to secure information, protect organisations, and protect individuals' cyber assets. Including specific biological research through omics, and financial activities through blockchain. Includes:

- Blockchain.
- New data technology.
- Omics.
- Privacy enhancing technologies.

Smart technology and IoT: Networks of objects that are connected to the internet offering real-time insights into how people and organisations are using space and interacting. Allows asset owners and operators to monitor the operational effectiveness of objects and places across their lifecycle. Includes:

- Internet of things.
- Next-generation voice assistants.
- Smart appliances.
- Smart cities.
- Smart devices/smart phones.
- Smart grids.
- Smart homes.

Infrastructure and networks

Physical components and communication networks that enable the operation of physical and digital tools and technologies, including the subfields of advanced computing, communications and digital, and energy and power.

Advanced computing: Group of technologies that enable innovative computing capabilities that conventional computer can't perform or that significantly improve traditional capabilities. Includes:

- Cloud-based technology and cloud computing.
- Other edge computing technologies (fog computing).
- Quantum computing.

Communications and digital: Technologies that facilitate data flow between devices. Includes:

- 6G.
- Bluetooth low energy.
- Decentralised internet.
- Wi-Fi.

Energy and power: Technologies that generate or store energy and equipment that distributes power to devices and infrastructure. Includes:

- Batteries.
- Fuel cells.
- Future small portable energy sources.

- Heat pumps.
- Hydrogen.
- Nuclear.
- Ultra-high-power universal serial bus type-c (USB-C).
- Wireless electricity and induction charging.

3.2 Prioritisation of technologies

The technology prioritisation in this section reflects the unweighted scoring, meaning that each component of the overall score was not weighted towards one aspect (for example, weighted towards harm or towards TRL). The results of the prioritisation are summarised below. Some items should be considered when reviewing the prioritisation:

As discussed in Section 2.5 (Stage 5: Scoring, weighting, and validation), the moderation workshops aimed to address the areas where information was limited or not included in the Rapid Evidence Reviews. However, there is greater uncertainty in some reviews where information was limited or there was a lack of quality information available. To address this, the prioritisation ranking should be viewed in conjunction with the 'information quality' and 'information availability' scores, which were decided by each reviewer and give an indication of the level of information available for the review.

Using a scale of 1 (low) to 5 (high), a high score indicates that plenty of high-quality information was found, and a low score indicates that there were gaps in information or that the sources found were of a low quality. Note that the prioritisation is impacted by the weighting, and the information quality and availability scores - while important - do not feed into the total score but are separate measures.

The table below summarises the twenty most highly ranked technologies across the reviews.

Rank	Technology	Total score (/25)	Information availability (/5)	Information quality (/5)
1	Internet of things	22.0	5	5
2	Digital twins	21.5	4	5
3	In-situ validation and calibration of sensors	21.0	4	4
4	Batteries	20.7	4	4
5	Machine learning	20.5	5	5
6	3D printing	20.3	5	4
7	AI[1]	20.3	5	4
8	Smart sensors	20.3	4	4
9	Smart materials	19.7	4	5

[1] See discussion on page 30 for more on our new approach to AI since this work was done

10	Social commerce	19.7	4	3
11	Synthetic biology	19.5	5	4
12	Computer vision	19.3	3	4
13	Plastics and polymers	19.3	5	4
14	Wearables	18.8	5	4
15	Drones	18.5	5	5
16	Fuel cells	18.5	4	5
17	Neural networks	18.5	5	5
18	Biomaterials	18.3	5	5
19	Heat pumps	18.3	5	4
20	Wireless electricity / wireless power transmission	18.3	4	3

Table 6: 20 most highly-ranked technologies

3.3 High-harm technologies

The following two technologies were identified and given the highest possible score for harm (10), a combination of the number of possible common product safety hazards (scored on a scale of 1-5) and the degree of harm with reference to the PRISM Risk Assessment framework (scored on a scale of 1-5).

- Jetpacks
- Human implant technology

Twelve more technologies scored just one mark short (9) of the highest possible score.

- Internet of things
- Digital twins
- Batteries
- Fuel cells
- Exoskeletons
- One-click manufacturing
- Smart appliances
- VR
- Nanobots
- Advanced consumer tools
- Indoor air monitoring
- Nanomachines
- Nuclear
- New forms of automated recreational mobility

The high-harm technologies included, for example:

One-click manufacturing

One-click manufacturing, as a software process, does not present direct physical risks to users. However, there is significant potential risk associated with manufacturing processes that allow users to produce their own products, without oversight. The sale of designs of products that may present physical risk is also a possibility, with one high-profile example being the sale and distribution of designs for 3D-printed guns. The further associated risks could range from faulty products (e.g., faulty remote-manufactured circuit boards) through to the production of products that could cause physical harm.

Human implant technology

Human implant technology is invasive, raising significant concern for human health. Uncontrolled movement of implants within bodies, possible allergic and immune reactions to implant materials, infection from poor cleaning, and unknown effects on human nervous systems are all possible physical risks. Consumer products utilising human implant technology could require the use of lithium-ion batteries, known to present electrical, thermal, fire and explosion, and chemical hazards. There is also high potential for non-physical risk related to combining digital systems and human bodies, and concern surrounding the ethics and lack of regulation of these technologies.

Batteries

There are a number of safety and environmental challenges with batteries. The extraction and processing of the metals required is both expensive and harmful to the environment. Lithium-ion (Li-ion) batteries, already ubiquitous in many consumer products, present a fire risk under certain conditions. Mechanical, electrical, and thermal stress, as well as manufacturing defects can result in a process called thermal runaway. In this state, the battery produces excessive heat, pressure build up, toxic gas release and can lead to fire and/or explosions. Additionally, End of First Life (EoFL) batteries are becoming a growing waste-stream as large-scale application, such as electric mobility (e-mobility), becomes prevalent. This presents environmental and safety waste hazards. New risks to public health could emerge from the location of waste management sites, and generally in terms of the nature and behaviours of Li-ion batteries utilised at scale.

3.4 High-benefit technologies

The following nine technologies were given the highest possible score for benefit (5) as part of the benefit to consumers assessment.

- AI
- Machine learning
- Wireless electricity / wireless power transmission
- Computer vision
- Graphene
- Neural networks
- Plastics and polymers
- Nanobots
- Water recycling

This score indicates how applications of the technology might benefit consumers, with a score of 1 indicating no benefit and a score of 5 indicating great benefit (lifesaving). The high-benefit technologies included, for example:

Graphene

Graphene is finding a myriad of applications such as for nanogenerators, sensors, bulletproof surfaces, as a structural support for other chemicals/nanomaterials, flexible smart materials, leading it to be hailed as a “miracle material” by some. The potential and appetite for graphene to revolutionise many areas of material science and products is huge. The main thing holding it back is the cost of producing graphene in a sufficient amount and quality

Nanobots

Nanobots can serve as multifunctional and specialised robots. They can be controlled with various mechanisms such as magnetic chemical, optical, acoustic, electrostatic, thermal, enzymatic. The combination of these novel control modes and their size means nano bots can complete tasks at a cellular or molecular level for manipulation or targeted drug delivery, with significant benefits for biomedicine and healthcare outcomes.

3.5 High-impact technologies

The following twenty-three technologies received the highest possible score (5) for macro-scale drivers, which is based on the number of pre-identified contextual factors that the technology may impact on.

- Internet of things
- Digital twins
- AI
- Batteries
- In-situ validation and calibration of sensors
- Machine learning
- 3D printing
- Smart materials
- Smart sensors
- Synthetic biology
- Wireless electricity / wireless power transmission
- Computer vision
- Graphene
- Neural Networks
- Plastics and polymers
- Smart devices / smart phones
- 4D printing
- 6G
- Future small portable energy sources
- Metaverse
- New data technology
- Data selves and citizen twins
- Quantum computing

The contextual factors considered included circular economy, new retail / consumer models, future of online marketplaces, future of the internet, resource scarcity, re-use, re-task, and right to repair; personal data, future of mobility, future of supply chains, industry 4.0 / 5.0, future of regulation, and safety and standards. The highest-scoring technologies have significant impact against multiple social, technological, economic, environmental, political, legal, and ethical (STEEP) fields. The high-impact technologies included, for example:

AI and machine learning

As AI carries out processes that mimic and go beyond human capabilities, AI has the potential to impact every industry and field of consumer products. There are challenges with enforcing non-compliance for machines acting as a human decision-making system, bringing complexity to the future of regulation and safety and standards. Machine learning is a facilitator for automation in many industries and an enabler for research, innovation, and new technologies, impacting consumers across products, supply chains, retail/consumer models, circular economy, and resource use. A new phase of industrialisation is driving industry 5.0, an industrial revolution shaped by AI and advanced technology. AI and machine learning are changing the digital landscape, reshaping the way devices connect and how personal data is used and stored. Environmental impacts include high levels of energy consumption but also possible advances in sustainability and efficiency of the production or operation of consumer products, influencing change to supply chains and mobility.

It is recognised by the authors of this paper that in the time since the research behind Scan 1.0 being undertaken (Jan-Feb 2023) the focus on AI in the public sector has increased significantly. This increase began with the AI White Paper published in March 2023 (DSIT 2023) and latterly saw the UK host the Summit for AI in November 2023. There has also been significant progress in the past 12 months in the capability of consumer-available AI systems. These developments have led OPSS to create an AI-specific workstream utilising our new Innovation Hub to join up with efforts across our department, government, industry and academia. For regulators such as OPSS, the approach to the regulation of the use of AI in the domains for which they are the regulators responsible, and the use of AI as a regulatory tool, are the key considerations being developed.

Smart sensors, in-situ validation and calibration of sensors, and the Internet of things

Smart sensors can collect at scale the data used in smart homes and cities to allow for household environment automation and remote control, informing mobility and consumer models while introducing ethical considerations around personal data. In-situ validation and calibration can reduce costs and improve both operational efficiency and productivity by using real time data across a multitude of different sectors. The rapidly growing importance of smaller and more diversely functional smart sensors across applications such as healthcare, prevention and safety, and smart appliance platforms has boosted the growth of the global smart devices market. The Internet of Things (IoT) is an enabling framework across the field of smart technology, from smart cities and transport systems to advanced manufacturing. This is driving complexity for regulators, businesses, and consumers by connecting physical and digital products and blurring the lines between devices, systems, and objects.

3D printing, 4D printing and smart materials

As the cost of 3D printing technology declines, production may become extremely local and customised, having profound economic effects through improved consumer choice. 4D self-repairing products and self-healing products could drive change in manufacturers business models because they may change sale patterns and revenue streams by negating the need for new purchases. These durable products can embed low energy or passive actuation into buildings or into products, generally reducing overall energy usage. The environmental impacts of creating products layer-by-layer include using only the material needed, potentially using less energy and producing less waste associated with raw materials. Smart and metamaterials have enormous potential impact across multiple fields, enabling technological innovation and precision engineering of new products and technologies to maximise desired material qualities such as efficiency, conductivity or insulation. However, they also have possible legal and ethical impacts, as harm caused by products printed from open-source files can be difficult to regulate or standardise.

3.6 STEEP(LE) trends

Looking across all seventy-one Rapid Evidence Reviews, trends and themes of impact emerged. These were categorised by Social, Technological, Economic, Environmental, and Political (STEEP) impacts. The standard STEEP framework was extended to STEEPLE, to include legal and ethical categories. This framework supports a holistic and integrated exploration of the future across topics, trends, and technology interactions.

Social

Trends seen across the technologies that relate to society and its organisation and norms include the following:

Personal data bias

In technologies such as AI and machine learning, algorithms are being used to make decisions about individuals that can result in discrimination or bias if the training data is biased or if the algorithms are not designed to be fair. In combination with personal data being collected by smart home devices, wearables, and other 'smart' personal technologies, these data dynamics are at risk of becoming invasive. Even objects like vacuum robots, or home assistants, which respectively use computer vision or audio, can document sensitive consumer information, the value and risk of which may not be immediately obvious to the consumer. This is addition to concerns around privacy.

New retail and consumer dynamics

Provisions of everything as a service can see the digitisation and decentralisation of retail functions delivered over the internet rather than being provided for locally and physically. Instead of a company or consumer having an exchange that at some point is physical, there may never be a clear tangible product, leading to a lack of clarity on expectations, jurisdiction, and responsibility.

Wellbeing and e-health

IoT, wearables, and implant technology could have large-scale social impact on the management of health and wellbeing through the rise of e-health and health monitoring opportunities. Humans have more access than ever to personal health data, yet are at greater risk of that health data being compromised by cyber threats or shared without consent. Equally, there could be a reduction of individual agency over personal time used to improve wellbeing due to advanced human-computer interfaces becoming overbearing. Smart phones have provided new, ubiquitous ways to connect with each other but also are known to lead to technology overuse and dependency, which leads to anxiety, impaired or lost sleep, and reduced mental health in some users. The scale of impact this is having on how modern society operates and communicates is becoming more evident as more generations are using these technologies for the majority of their lifespans.

Technological

Trends seen across the technologies that relate to application of scientific knowledge for practical purposes, especially in industry, digital, engineering, or applied sciences include the following:

Automation efficiency

Advanced manufacturing and material sciences, 3D and 4D printing all offer potential efficiencies in materials and production, if allied appropriately. Other technologies can also contribute to this, such as computer vision used in manufacturing to check the quality of components along with smart sensors and in-situ sensors for calibration. Increased efficiency and reliance on technology and automation to manage safety and quality testing can also be seen.

Future of the internet

Ubiquitous connectedness with fully intelligent and distributed networks will continue to evolve the way we use the internet. 6G is expected to realise the ambition of an everywhere and anytime connected Internet of Everything (IoE) society. Web3 is being developed through a combination of decentralised technologies such as blockchain, peer-to-peer networking, and cryptographic protocols. These technologies allow for the creation of Decentralised Applications (dApps) and platforms that are not controlled by any single entity, but rather operate on a decentralised network of computers. The Metaverse is one potential framing of the future internet with multiple applications, such as the consumer metaverse (e.g., retail, consumer goods, entertainment, travel, financial, healthcare), the enterprise metaverse (e.g., meetings, training and commerce), and the industrial metaverse (e.g., manufacturing, travel and transport, healthcare, energy and utilities, aerospace and defence and financial and education). There are clear economic and social benefits from improved connectivity and future evolutions of the internet. However, there are also a number predominantly non-physical harms, including privacy and security harms related to moving more of our lives online and increasing the amount of data collected and shared.

Cybersecurity

Increased automation and prevalence on connected technology with IoT has created cybersecurity vulnerabilities beyond traditional web systems, as it arises from isolated hardware that could be compromised in unforeseen ways. For example, a smart appliance disclosing personal information beyond the simple usage of the product. Because of the relatively limited computing power of most IoT devices, this currently limits the complexity and effectiveness of cybersecurity that can be implemented, and because the devices are connected not just to a central server but to each other, increasing the number of interactions that could be vulnerable to attack. Social commerce also increases and normalises the transfer of money online, which are also significant avenues for cybersecurity scams, particularly for seniors, children, and other vulnerable people. Blockchain can potentially offer some solutions to these challenges.

Economic

Trends seen across the technologies that relate to the economy, trade, industry, the creation of wealth and efficient use of resources include the following:

New supply chains

Distributed manufacturing, with advanced manufacturing and material sciences, 3D and 4D printing, all offer potential disruption to supply chains. Meanwhile IoT and other smart applications of technology, such as appliances and sensors, can support end-to-end product tracking in novel ways, improving accountability and resource monitoring. Blockchain may potentially enable end-to-end product life cycle management by keeping track of all processes, product changes and developments from conceptualisation through to recycling and reuse. This diversification and proliferation of at home manufacture could have profound effects on the future of supply chains, shopping, and routes to market. Disruption of traditional manufacturing, distribution, and sale systems could present significant challenges to how OPSS regulates products and ensures their safety.

Future of online marketplaces

Growth in peer-to-peer sales and distributed supply chains may also be harder to monitor. In particular, the rise of social commerce may make it more difficult to track and verify the quality and safety of products and product vendors, posing challenges to market bsurveillance. Recent examples have included the sale of untested home cosmetics via short video sharing social media sites. Online marketplaces are a critical meeting of a combination of trends around the future of the use of the internet along with the cybersecurity risks mentioned prior, requiring consumer protection against scams.

Job market disruption

As has been the case in previous industrial revolutions, innovations in technologies lead to significant disruptions in job markets and a disparity of impacts across skill sets and geographies. A reduction of worker autonomy and agency can be seen as a result of automation, as one example. The scale of change that AI, machine learning, and novel manufacturing processes offer could lead to job displacement and automation of traditionally labour-intensive processes. This may have a significant impact on employment in certain sectors that can't be foreseen at the current time.

Environmental

Trends seen across the technologies that relate to the natural world and the impact of human activity on its condition include the following:

Circular economy

Opportunities to enable the transition to a circular economy can be found in 3D printing, 4D printing, smart materials, and biomaterials. Re-use, re-task, and right to repair can be enabled by novel applications of technology, such as materials that can repair themselves. However, there are also challenges related to liability of repaired functionality, especially for products with higher potential for harm should the repaired product fail. The growth of home fabrication and distributed manufacturing is also a key potential enabler to reduce waste and better use resources. Products which are made locally can reduce the waste involved in transport and enable a more direct route to keep materials within the product lifecycle.

Environmental waste management

For those new products that cannot be re-used or recycled, absorption and clean-up of environmental toxins and spills becomes important. This is particularly important in the context of advanced new materials and forever chemicals, which may be based on novel chemistries. The mass adoption and production of products integrating new technologies that require portable power also increases the number of lithium-ion batteries entering the market. If the recovery and recycling of batteries is not prioritised, there will be an increase in the amount of hazardous waste with potentially severe negative impacts to environmental and human health. Technologies such as AI can find applications in waste analytics to identify solutions to enable waste management solutions. Nanobots may play a role in environment by the detoxification and removal of substances like heavy metal or cyanide at a molecular level.

Future of energy

Many of the technologies disrupt the use of energy. Whilst some offer efficiencies, many in their proliferation also lead to high energy consumption, due to the use of the internet and remote data processing. The training and optimising of a machine learning model may lead to hundreds of tonnes CO_2. New clean energy sources and storage may mitigate this as well as off-grid and small-scale localised energy production. Fuel cells and future small portable energy sources are particularly suited for providing off-grid decarbonised power.

Political, Legal, and Ethical

Trends seen across the technologies that relate to the governing, policy or public affairs of the UK include the following:

Security of supply

There is a global trend toward a reduction of reliance upon energy imports. This is increasingly relating to resource scarcity and dependence on limited resources such as rare earth metals that many emerging technologies depend on. This can be seen in the global supply chains and political concerns around lithium-ion batteries, in the context of increasing adoption of electrification in mobility. For example, most lithium-ion battery manufacturing capacity is concentrated in China, which raises security concerns as more of these batteries are embedded in automobiles and critical infrastructure.

Ethics of technology

AI and machine learning present a range of ethics concerns through their applications, primarily in the way their application can continue or entrench societal biases. Various complex applications have resulted in a rise in ethical, legal, and societal demands for these systems to provide human-understandable model-level explanations and interpretations for their processes, so undesirable outcomes can be avoided. Technology enabled misinformation through online bots and deepfakes are also widely seen as significant risks to political discourse and community harmony.

Future of regulation

The widespread deployment of AI and machine learning, and other emergent online technologies has informed calls for regulation requiring explanations and interpretations of the decisions made by algorithms. The European Union is set to create the world's first broad standards for regulating or banning certain uses of artificial intelligence in 2023. Smart technologies challenge some of the concepts in existing regulations, including definitions of product and services and the notion of being on the market, which does not consider that software updates could fundamentally change the operation of the product. These challenges are not just non-physical, as the control of intellectual property, the risk of counterfeiting goods, the potential for production of hazardous products, and the enforcement of products made by software that could be biased or flawed are all potential risk associated with 3D printing, 4D printing, and one-click manufacturing. These considerations all present new challenges and opportunities for regulation.

4 Conclusion

The output of this horizon scan demonstrated the breadth of new, emerging, and future technologies that relate to the operations and responsibilities of OPSS. Applications of these technologies have a range of implications for product testing and legal metrology, from the regulation of consumer products which utilise machine learning in the manufacturing process, to the increase in portable batteries entering the waste stream.

This first horizon scan also revealed opportunities where OPSS can leverage these technologies to improve consumer safety and support businesses. Blockchain could be used to classify products, or AI could help to identify potential safety issues through analysis of product information and product reviews, for example. OPSS itself, or product manufacturers, could potentially use computer vision to assess and quality-check product safety.

A combination of these emergent technologies could be used for automatic fault detection in products. In the non-physical realm, as online product platforms gain traction, OPSS will have to consider its role in making both these services and any physical products that people subscribe to socially and psychologically safe. OPSS will also need to consider its role in enforcing decisions regarding consumer products which have been made within software.

This horizon scan is Scan 1.0 for OPSS as part of OPSS' growing effort to engage with foresight and futures thinking. The collaborative process introduced horizon scanning methodology, challenges, and lessons learned. This project also resulted in a package of materials for OPSS to continue to draw from and iterate upon in future horizon scans, including the Rapid Evidence Reviews for each of the seventy-one technologies, the database of scoring, moderation changes, and interactive weighting tool, a playbook of the horizon scanning process with key considerations, and a capability development plan for OPSS to continue work in horizon scanning.

This work will enable OPSS' horizon scanning team to build OPSS' knowledge about future change, with an aim to better make regulation work to protect people and support businesses.

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Appendix 1: Lexiconography

This appendix explains the language we use in futures work in OPSS.

Foresight: A process by which one comes to a fuller understanding of the forces shaping the long-term future which should be taken into account in policy formulation, planning and decision making.

Horizon Scanning: The process of looking for early warning signs of change in the policy and strategy environment.

Futures: An approach or way of thinking about the possible, probable, and preferable futures and the underlying structures that could give rise to particular future characteristics, events, and behaviour.

Scan: *(noun)* An article, usually part of a Horizon Scanning process, that describes an external event or emerging trend that points towards change in the policy and strategy environment. (verb) To look for articles that describes an external event or emerging trend that points towards change in the policy and strategy environment.

Trend: A visible – or emerging – pattern of events that suggest change. In futures thinking, a 'trend' becomes a 'driver' when it acts on the policy or strategy area of interest

Horizon Scan 1.0: The initial horizon scan conducted by Arup Foresight and the OPSS Horizon Scanning Team.

Multi-criteria assessment (MCA): a prioritisation and decision support technique specially developed to assess complex environments and related key factors, in which a range of metrics are used to weigh up the effect of a particular intervention.

Rapid Evidence Review: A term used in Horizon Scan 1.0 to describe a quick, structured snapshot presenting the evidence found about each technology in the relevant literature.

Sensitivity analysis: Method of addressing how the uncertainty in the output of a mathematical model or system can be divided and allocated to different sources of uncertainty in inputs.

STEEP/STEEP(LE): A framework for holistic and integrated exploration of the future across topics, trends, and technology interactions. STEEP encompasses social, technological, economic, environmental, and political impacts. STEEP(LE) extends this to include legal and ethical categories.

Taxonomy: a set of dimensions with mutually exclusive and collectively exhaustive characteristics such that each object under consideration has one and only one characteristic for each dimension.

Technology-driven changes (TDCs): Emerging and future changes influenced by the development and adoption of technology.

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