Department for
Business, Energy
& Industrial Strategy

# The Prioritisation of Future Innovations

## A Consultancy Study for the Department of Business, Energy and Industrial Strategy (BEIS)

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Any enquiries regarding this publication should be sent to us at:
enquiries@beis.gov.uk

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# Executive Summary

Steer Economic Development (Steer-ED), an independent economic development consultancy, undertook a consultancy project for the Department for Business, Energy and Industrial Strategy (BEIS) between December 2019 and April 2020. The aim of the study was to generate an evidence-base to support the work of the Regulatory Horizons Council (RHC) by identifying priority areas for their consideration.

The Regulatory Horizons Council (RHC) is an independent expert committee that identifies the implications of technological innovation, and provides government with impartial, expert advice on the regulatory reform required to support its rapid and safe introduction. Priority areas for the RHC will be technological innovations and/or business models with high potential economic, social and environmental benefit, and where regulatory reform is needed to facilitate the rapid and safe introduction of these products, services and business models.

Prior to commencing the study, BEIS had conducted an internal horizon scan to capture a large selection of innovations (around 500) likely to come to market over the next ten years. This 'horizon scanning' exercise was the key input to Steer-ED's work. The objective of Steer-ED's work was to transform the spreadsheet of innovations into a taxonomized and prioritised list, enabling the RHC to identify potential areas where regulatory reform could help unlock the economic and social benefits (including health, welfare, environmental and other non-market benefits) of new and upcoming technological innovations.

Steer-ED developed a methodological approach which sought to assess the *attractiveness* and *feasibility* of innovations. Attractiveness focused on the potential benefits of the innovations, both economic and social. Feasibility focused on the regulatory dimension – the current regulatory situation, and the scope for added value through regulatory change. Steer-ED sought to develop an approach which is scalable (it can be 'ramped-up' as the evidence base expands), adaptable (the study is not a 'one-shot' effort, and can be reused as new questions/priorities arise) and forensic (there is a clearly documented process which leads to the prioritisation recommendations).

Steer-ED undertook five stages of work. These are described in detail in this report and the accompanying Technical Appendix. In brief, the five stages were:

- Stage 1: Taxonomy Creation – using a combination of data science methods and manual review, the innovations spreadsheet was sorted into a set of groups/clusters according to the application, or purpose, of the innovation, and the primary technology of the innovation. Every innovation from the original list was assigned to one application group and one technology group. The result was a list of 151 unique application/technology groupings.

- Stage 2: Developing a Metrics Framework – in discussion with BEIS, Steer-ED developed a set of 23 metrics which could be used to assess the attractiveness and feasibility of the 151 groupings. These metrics were assigned priorities – 12 higher priority, and 16 lower priority. Metrics included for example 'estimated size of the global market' (economic metric), 'estimated health & welfare benefits' (social metric), and 'potential to add value through regulatory change (regulatory metric).

- Stage 3: Evidence Base Creation – this involved collation of publicly available information sources into very short, rapidly generated literature reviews. One short literature summary was produced for each of the 151 groupings, focusing on potential impacts, current regulatory environment, and scope for regulatory reform.
- Stage 4: Scoring – based on the literature summaries and the consultant team's professional judgement, the 151 groupings were scored according to the 12 higher priority metrics. Scores were then aggregated to generate a list of the top 44 'most promising' combinations. These were taken forward into a second round of scoring – the remaining lower priority metrics were scored for these 44 groupings.
- Stage 5: Prioritisation – in order to generate a prioritised list of innovations, a spreadsheet front-end was built which allows weighted preferences (around for example risk appetite, time preference and so on) to be input, and then generates a rank ordering of the groupings as an output. In April 2020, a Weightings Workshop was held with representatives of the RHC, BEIS and other relevant government stakeholders. Workshop participants were presented with a 'neutral' (equally weighted) preference set as a starting point and participated in a discussion to determine the RHC's optimal preference set, as well as broader reflections on the approach.

The study's main report presents a set of outputs generated through the above process, applying the RHC's preferences as agreed at the Weightings Workshop and reflective of the Council's overall aim to prioritise areas with high potential benefit and where regulatory reform is most needed. The top 20 innovation groupings are reported, alongside an additional 11 which were generated by a subsequent sensitivity analysis (described below). Steer-ED observed that the groupings which seem to dominate are those which:

- Have major potential for impact on lives/well-being;
- Exhibit cross-cutting impacts (for example transport innovations have implications for decarbonisation, safety and the environment); and
- Provide flexibility as to the various different regulatory approaches which could add value.

Notably, health-themed innovations, which made up around one third of the underlying dataset, are remarkably absent from the prioritised list – featuring only twice in the top 31. This appears to be because they do not exhibit the second two characteristics from the list – having relatively focused, rather than cross-cutting, benefits, and given the rigid existing regulatory landscape.

A sensitivity analysis was undertaken to test how different RHC weightings preferences for the metrics could alter the list of top 20 groupings, in comparison with the equally weighted (neutral) scenario. It was found that for the most part, changes resulted in re-ordering of entries within the top 20, but minimal changes in the innovations appearing in the top 20. The most significant changes were generated by the RHC's preference not to penalise groupings with long time-horizon benefits and/or low-quality information; as well as the RHC's preference to prioritise novel and high-potential regulatory change. This set of changes resulted in the inclusion of more forward-looking, high potential and unknown/unproven technologies – such as for example hyperloop and hydrogen fuel cells.

The limitations of the study are set out in detail in this report. Major limitations were around: the size of the task within the resource constraints of the study, meaning it was necessary to take a 'light-touch' approach to literature reviews and scoring; the lack of reliable evidence, in particular because many of the innovations have not yet reached market; issues of consistency across the large number of judgements and decisions made as part of the scoring exercise; and finally, the fact that the outputs themselves can be combined in many different ways. This flexibility is a strength of the study however it also means that there is no single 'right answer' output.

This report finishes with lessons learnt, recommendations for further work and the next steps BEIS is taking with the outputs of this project. The study has shown that it is possible to analyse innovations through the lenses of attractiveness and feasibility, and that the albeit simplistic categorisation into application and technology groupings provides a useful structure for comparison. Despite the challenges of collecting and assessing data on innovations not yet commercialised, this study has demonstrated that in many cases there is nonetheless publicly available data to indicate potential economic, social and regulatory implications. To safeguard against the lack of information in some cases, BEIS took forwards a long list of innovations and conducted engagement with key stakeholders as a more detailed evidence-gathering exercise to generate the final short list.

In terms of follow-up work, Steer-ED recommends building on this study by: repeating or updating the six-week horizon scanning exercise (this could be as a repeat 'light touch' horizon scan); continuing to expand the evidence-base, adding to the light-touch literature reviews and amending scoring as more evidence comes to light; reviewing the suitability of the application/technology groupings (various recommendations are made for how these could be reviewed); and finally, continuing to work with the scoring spreadsheet, inputting alternative preferences and carrying out sensitivity analysis to reflect the RHC's developing priorities.

# Introduction

## Background and Drivers

The aim of this short-term consultancy project was to generate an evidence-base to support the work of the Regulatory Horizons Council (RHC). The RHC is an independent expert committee, supported by a team of civil servants, established by the Department for Business, Energy and Industrial Strategy (BEIS),[1] as a commitment from the White Paper on Regulation for the Fourth Industrial Revolution.[2]

It will provide the government with expert advice on priorities for regulatory reform to benefit the UK economy and society. Priority areas will be those with high potential benefit, where regulatory reform is needed to facilitate the rapid and safe introduction of these products, services and business models. The RHC will make recommendations to government in these areas on broad priorities for regulatory reform, based on the potential benefit for the UK economy and society while protecting citizens and the environment.

As a precursor to this project, BEIS conducted an internal horizon scan to capture a large selection of pan-economy innovations likely to come to market over the next ten years. Horizon scanning is used as an overall term for analysing the future: considering how emerging trends and developments might potentially affect current policy and practice. For the RHC's purposes, this exercise involved identifying emerging technologies where regulation may need reform in order to support their safe and rapid introduction.

The horizon scan took place over a time-limited six-week period. Innovations were collected from publicly available sources such as news bulletins, technology and business magazines and technology blogs. Innovations were defined as 'technologies with known applications' (for example, AI-enabled smart home devices, rather than AI per se), with a total of 542 innovations collected during this internal horizon scan.

Subsequently, Steer Economic Development (Steer-ED), an independent economic development consultancy, was commissioned to transform the spreadsheet of innovations into a taxonomized list to then be prioritised. The purpose of prioritisation was to identify areas where government intervention:

- Is most necessary (that is, where regulatory reform is required, or the current regulatory regime is insufficient); and

[1] See: https://www.gov.uk/government/groups/regulatory-horizons-council-rhc
[2] Department for Business, Energy & Industrial Strategy, *Regulation for the Fourth Industrial Revolution* (2019). https://www.gov.uk/government/publications/regulation-for-the-fourth-industrial-revolution

- Crucially, would be most likely to bring forward innovations that could deliver large-scale social and economic benefits.

The taxonomized and prioritised spreadsheet of innovations is the prime output from Steer-ED's work. This descriptive and narrative report accompanies that spreadsheet, detailing the methodology and outputs of Steer-ED's work and recommended next steps.

## Objectives for the Study

The prime objective of this study was to produce an output that enables the RHC to identify potential areas of focus for regulatory change. The RHC will take this work forward by stress-testing these priority suggestions with internal and external stakeholders, moving towards the final aim of making regulatory recommendations to government. The project achieved its objective by:

- Creating a suitable 'taxonomy' to sort the BEIS dataset of innovations. The taxonomy allows for meaningful comparisons and prioritisations to be made at the category level rather than at the individual innovation level, so that the output can be used to generate recommendations for areas of focus.
- Developing a suitable metrics framework. This framework sets out the key questions of interest that were used to score and prioritise the innovations.
- Collating a suitable stock of evidence to facilitate evidence-based scoring of innovations, in a clear, consistent and documented process.

Combining the scores using a structured method of weightings and multipliers that can be adjusted to reflect preferences (around for example risk appetite, time preference and regulatory objective). These preference weightings are used to produce the final output – a priority ordering of the innovation groupings.

## Structure of this Report

The remainder of this report is structured as follows:

- *Approach* details the conceptualisation of the methodology that Steer-ED used to approach the work;
- *Study Methodology* details how the study was undertaken, step-by-step, including some early outputs and sensitivity analysis;
- *Limitations of the Approach* highlights key concerns and caveats of the analysis;
- *Lessons from Testing the Conceptual Framework* reflects on the lessons learnt through the course of the study;

- *Recommended Further Work* contains recommendations for follow-up work, given the early outputs and stated limitations of the study;
- *BEIS Next Steps* describes the department's response to this work; and finally
- A separate *Technical Appendix* contains technical details and materials produced as part of this work.

# Approach

## Conceptualising the Innovation-Regulation Interface

Due to the novel nature of this work, the study required development of a bespoke methodology. The final methodology is described in detail later in this section (see *Study Methodology).* In approaching this work, Steer-ED sought to create a methodology that captures various characteristics or nuances of the regulation-innovation interface, addressing these in sufficient detail to be able to produce immediate outputs, whilst also recognising that this study is the start of a much longer-term and ambitious programme of work. As such, developing a methodology with suitable longevity was a key consideration. The final methodology needed to be:

- Scalable – such that it can be 'ramped-up' as the evidence-base expands;
- Adaptable – such that it can re-focus attention on issues of interest to the RHC as and when necessary, and;
- Forensic – such that it is possible to trace and diagnose factors pertinent to the relationships between innovation and regulation.

Figure 1 summarises the initial approach proposed by Steer-ED, which captures some of the most significant conceptual challenges of the innovation-regulation interface. As the study progressed, this framework evolved. For any specific innovation group from the underlying data (the Innovations Spreadsheet), [3] we can think of an 'attractiveness' dimension and a 'feasibility' dimension. These are described in more detail overleaf.

**Attractiveness**

The conceptualisation of attractiveness combines market and non-market components. The market component is, from a pragmatic perspective, the estimated UK share of overall global market potential.

The Innovations Spreadsheet takes a global view because it sets out to identify all types of innovation of potential future relevance to the UK. However, these innovation groups will naturally have differing economic relevance to the UK's future. The UK will be particularly well-positioned to exploit the potential of some innovations, but will be less well-positioned to exploit others. The non-market component is comprised of a range of public benefits that are not captured directly in market-delivered benefits (this is examined in greater detail below).

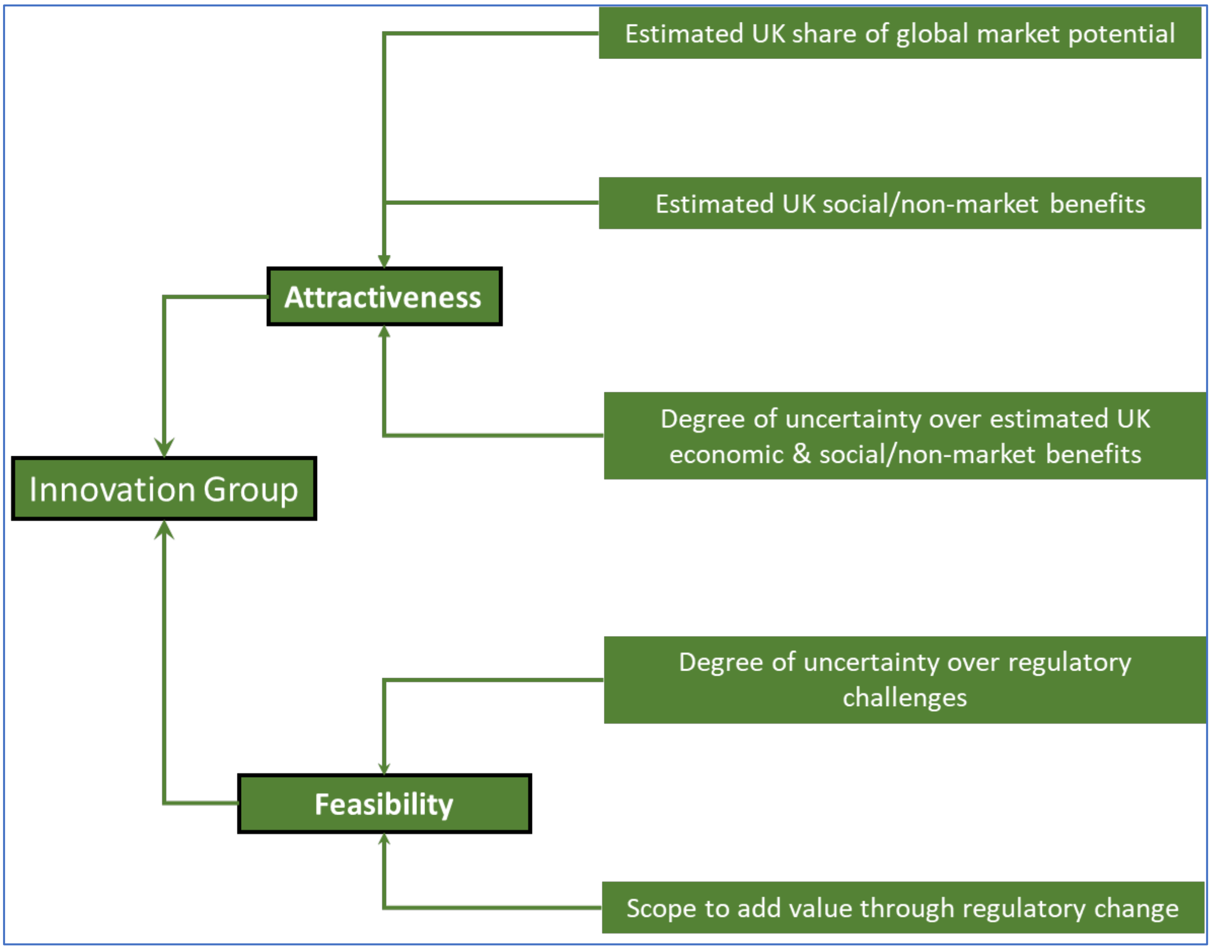
In addition, this conceptual framework explicitly recognises that, as with all such forward-looking exercises, substantive uncertainties exist that should be factored into the assessment rather than ignored.

[3] The characteristics of the underlying data are described on page 12, 'The Innovations Spreadsheet'.

## Feasibility

The feasibility dimension represents the extent to which *in principle* innovation groups are helped or hindered by the regulatory approach (both at present and in terms of the potential evolution of that regulatory approach). In this respect, the ‘feasibility’ dimension is specific to regulatory concerns and does not attempt to address other factors that also determine how feasible it is for the UK to exploit these global innovation opportunities.

**Figure 1: Initial conceptual framework: ‘attractiveness’ versus ‘feasibility’**




Source: Steer-ED, 2020

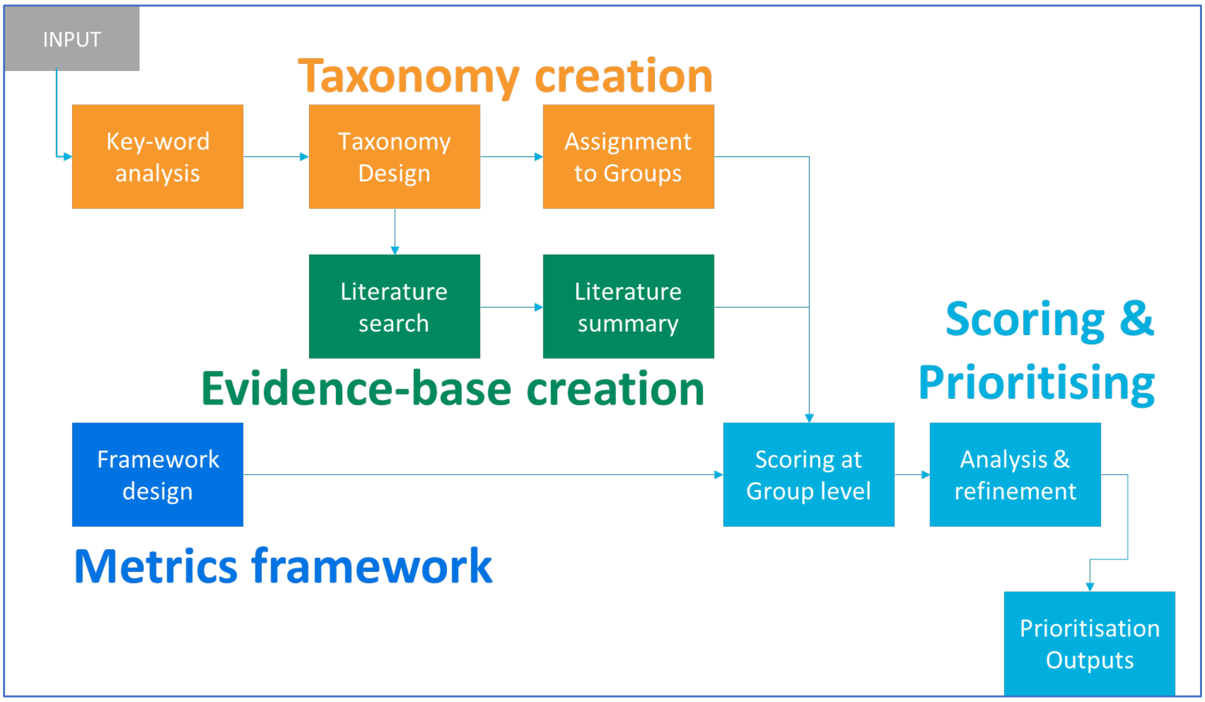
This feasibility dimension is broken down into two main elements: scope to add value through regulatory change and, as with the attractiveness dimension, the degree of uncertainty in understanding this regulatory dimension.

The explicit recognition of uncertainties for both attractiveness and feasibility is an important feature of this framework, because it is designed to avoid ‘spurious precision’. If there is a high degree of uncertainty, it is better to be frank about this than to gloss over the challenge. This aspect will be particularly important as the RHC starts to engage with this type of dataset, because it will form a basis for prioritising ‘watch and observe’ innovations and, potentially, the research activities that can reduce these uncertainties in the future.

# Study Methodology

Figure 2 shows the work undertaken for this study. The four stages of work (taxonomy creation; metrics framework development; evidence-base creation; and scoring & prioritising) are described in detail at the end of this chapter. Before getting to these, we offer some thoughts on the interface between innovation and regulation, a key crossover area on which the RHC will be focusing as it develops its agenda.

**Figure 2: Study Workflow**




Source: Steer-ED, 2020

## Input: The Innovations Spreadsheet

The input to Steer-ED's work was an innovations spreadsheet compiled by BEIS during a pre-cursor six-week horizon scanning exercise. Innovations were collected and manually inputted into a spreadsheet from a range of different publicly available sources such as Google News alerts, technology and business magazines, and tech blogs. Innovations were included in the scan so long as they:

- Were likely to come to market within the next ten years;
- Had a clear *application*, rather than being a technology alone.

The innovations spreadsheet consisted of 542 innovations, with various characteristics recorded for each innovation. Steer-ED conducted an initial data quality assessment before progressing to the next stage of work. The spreadsheet was found to contain almost no missing or erroneous entries, and so further 'data cleaning' was not deemed necessary. Further details of the innovations spreadsheet, included the sources consulted and fields collected, can found in the Appendix section *Details of the Innovations Spreadsheet.*

## Stage 1: Taxonomy Creation

The original intention of Steer-ED's work was to score each individual innovation from the horizon scanning spreadsheet. However, it became quickly apparent that this would not yield helpful results, for the following reasons:

- The innovations differ greatly in terms of scale and specificity (for example some reference whole sectors or industries in generic terms, while others describe very specific individual products or processes). This means that comparisons of potential and feasibility cannot be made fairly at the individual innovation level.
- It would be near impossible to robustly score the most specific innovations without significant expert input.
- The horizon scanning exercise was intended to provide a snapshot rather than a comprehensive review of innovations. The specific innovations in the list are, to some extent, arbitrary. Therefore, it is more reliable to use them as a signal of higher-level categories of emerging innovations, which is what the taxonomy focuses on.

Therefore, this first stage of work was to characterise the innovations in the spreadsheet so that recommendations could be made on the basis of clusters or *groupings* of innovations broadly consistent in scale and specificity. In order to achieve this, three stages of processing were undertaken: (1) text processing; (2) topic modelling; and (3) manual review. The open-source data science software 'R' was used to conduct this processing. A high level summary of these three sections is included here, and detailed accounts of the three stages can be found in the appendix section: *Taxonomy Creation: Detailed Methodology.*

- **Text Processing** involved making changes to the free-text inputs to optimise them for key-word analysis. This included: correcting spelling errors; removing words with little meaning (articles, conjunctions, prepositions and so on, and also generic technology words); and hyphenating commonly occurring contiguous pairs (such as 'autonomous vehicle' and 'deep fake') such that they would be modelled as single key word inputs.
- **Topic Modelling** used an algorithmic process to sort the innovations into small clusters or groups. After some experimentation, Steer-ED found that the most meaningful results were obtained by assigning each innovation to two clusters: one for the technology underlying the innovation, and one for the application, or purpose, of the innovation. Steer-ED experimented with various cluster sizes/levels in order to arrive at a set which could be used to categorise each innovation in the input spreadsheet. The method sought to strike a balance between over-generalisation (which would result in few categories with very broad feature sets) and over-specificity (which would

result in a large number of clusters, each highly specific to a small set of innovations).

- A **Manual Review** was undertaken to review and refine the topic modelling outputs. Topics were merged or separated as appropriate, ensuring that final categories were roughly equivalent in terms of scale and specificity. The review also included line by line consideration of the innovations spreadsheet, to check that every innovation had been appropriately allocated.

The final output was a categorisation of every line in the innovations spreadsheet into one of 37 technologies and 31 applications. When combined, there were 151 unique combinations of technology and application assignments - for example, ‘healthcare/pharmacology’ and ‘agriculture/drones’.[4] These combinations were a key output from the work, and were then taken forward to be scored according to the metrics framework and scoring process.

Figure 3 shows the full set of application/technology combinations identified by the work. Colour coding indicates the most densely populated categories, and red cells indicate empty combinations. Note the pervasiveness of the technology grouping ‘AI, big data and machine learning’, which is the primary technology for 109 (20%) of the 542 innovations in the spreadsheet.

**Figure 3: Application and technology categorisations for the 542 innovations**

| | AI, Big Data & Machine Learning | New Materials | Robotics | Genetic Engineering/genomics | Cameras, sensors and scanners | 3-D Printing | ADAS | Blockchain | Computing/Computer Processing | Platforms and UIs | Drones | Virtual Reality | Battery Technology | Internet of Things | Wearable technology | Stem Cell | Implant & neurotechnologies | Satellites, space travel, aerospace | Photovoltaics | Nanotechnology | Pharmacology | Business Model | Mechanical Engineering | V/STOL | Agritech | Electronics | Filtration | Molecular Chemistry | ITS | Electricity Generation | Hydrogen Fuel Cell | Nuclear Technology | Modular Construction | Laser | 5G/Wireless Technology | Prosthetics | Hyperloop |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Medical Treatment | 13 | 8 | 13 | 18 | 10 | 5 | | | 2 | | 6 | 1 | | | 5 | 10 | 8 | | | 3 | 5 | 3 | | | | 3 | | 3 | | | | | | | 1 | 2 | |
| Medical Diagnosis | 23 | 2 | 2 | 4 | 5 | 1 | | 1 | 6 | | | 3 | | 1 | 1 | | | | | | 1 | 1 | | | | | | | | | | | | 1 | | | |
| Food, water & agriculture | 5 | | 7 | 14 | 3 | 3 | | 2 | | | 2 | | | 1 | | | | | | | | | 1 | | 5 | | 1 | | | | | | | | | | |
| Vehicles and Components | 1 | | | | | 6 | 19 | | | | | | 11 | | | | | | | | | | | 4 | | | | | | | 2 | | | | | | |
| Waste/Recycling | 2 | 16 | 3 | | 1 | 2 | | | | | | | 1 | | | | | | | 1 | | | | | | | 2 | | | | | | | | | | |
| Biometrics/Personal Identification | 18 | 1 | 1 | | 1 | 1 | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | 2 | | | |
| Aerospace | 1 | | 4 | | 3 | 1 | | | | | 3 | | 1 | | | | | 6 | | | | | 4 | | | 1 | | | | | | | | | | | |
| Energy | | 5 | | | | | | | | | | | 1 | | | | | | 6 | 2 | | | | | | | | | | 3 | 1 | 3 | | | | | |
| Logistics | | | 1 | | | | 1 | 3 | | 2 | 3 | | | 8 | | | | | | | | | | | | | | | | | | | | | | | |
| Consumer goods | 5 | 6 | | | | | | | | | | | | 1 | 2 | | | | 1 | | | | | | | | | | | | | | | | | | |
| Data Security | 5 | 2 | | | | | | 4 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Disaster prediction/prevention | 6 | 1 | | | 5 | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | |
| Finance | 3 | | 2 | | | | | 7 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Construction | | 4 | 3 | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | | | | |
| E-commerce | | | | | | | | | | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Security | 2 | 1 | | | 2 | | | | | | 3 | | | | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Training/Education | 2 | | 2 | | | | | | 1 | | | 4 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Manufacturing | 1 | 3 | | | 1 | | | | | | | | | 1 | | | | | | 1 | | | | | | 1 | | | | | | | | | | | |
| Regulation/Administration | 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Currencies | 7 | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Entertainment | | | | | | 1 | | | | | | 6 | | | | | | | | | | | | | | | | | | | | | | | 1 | | |
| Computing | 3 | 2 | | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mobility | | | | | | | | 1 | | 3 | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | 1 |
| Physics | 1 | 2 | | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Carbon Capture/Storage | | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Environment | | 1 | | 1 | | | | | | | | | | | | | | 1 | | | | | | | | | 1 | | | | | | | | | | |
| Commerce | 1 | | | | 1 | | | | | 1 | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | |
| Traffic Management | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | | | | | | | | |
| Health & Safety | | | | | | | | | | | | | | | 3 | | | | | | | | | | | | | | | | | | | | | | |
| Insurance | | | | | 2 | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Journalism | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

[4] Note that while there are technically 1147 possible combinations (=37 x 31), many combinations were empty. For example there were no technologies in the category ‘agriculture/pharmacology’. Of the possible 1147 combination, 151 contained entries.

Source: Steer-ED, 2020

## Stage 2: Developing a Metrics Framework

A framework was developed to enable the scoring and prioritisation of application/technology groupings. In accordance with the aims of the project, it was necessary to create a scoring framework that captured the following broad considerations:

- The potential economic value of the innovation grouping, over a given period;
- The potential social value of the innovation grouping, over a given period;
- Various regulatory aspects, including the scope to add value through regulatory change, the extent to which the current regulatory regime is fit-for-purpose; and the potential for harm from regulatory inaction; and
- The level of uncertainty inherent in the information available, including the quality of source material and the Technology Readiness Level (TRL) of the innovation.

Through an iterative process, BEIS and Steer-ED developed jointly a set of 28 metrics and associated scoring guidelines to capture these four considerations. After trialling the metrics, this was reduced to 23, as limitations in the information available meant that five of the metrics could not be scored robustly.

Metrics were given a priority rating: 12 were considered higher priority, and the remaining 16 lower priority. The 12 higher priority metrics were scored for all 151 groupings. These were designed to provide enough information to ascertain which application/technology combinations would be most fruitful to take forward. The lower priority metrics were designed to provide additional context, and were scored only for a subset of ‘high potential’ innovations.

An overview of the metrics developed is summarised in Table 1 below, and the full set of 28 metrics is listed in the *Metrics Framework* section of the Appendix (Table 4), which provides details of how each metric was used in the final approach.

**Table 1: Outline of the Metrics Framework Developed**

| Priority | Economic | Social | Regulatory | Uncertainty |
|---|---|---|---|---|
| Higher | Size of global market<br><br>Percentage UK could plausibly gain | Health & Welfare<br><br>Environment<br><br>De-carbonisation | Potential for added value through change in incentives, constraints, and technical standards. | Degree of uncertainty over economic benefits<br><br>Technology Readiness Level |

| | | | | |
|---|---|---|---|---|
| | | Personal Safety & Resilience | | Quality of information available |
| Lower | *Contribution to economic goals such as productivity uplift and job creation | Degree of alignment with government grand challenges | Extent to which existing regulation is fit for purpose<br><br>Novelty of innovation relative to existing regulatory experience<br><br>Severity of regulatory inaction | |

Source: Steer-ED, 2020. *Categories marked with an asterisk were initially considered, but later discarded due to insufficient available data.

## Stage 3: Evidence base creation

The next stage of the process was to gather an evidence base to inform the robust scoring of groupings. The evidence base focused on three key areas: potential impacts, current regulatory environment, and scope for regulatory reform.

The evidence base was created through a series of rapid small-scale literature reviews. Three consultants were assigned to the task of scoring the innovations and collecting a suitable evidence base to score the groupings they had been assigned. The consultants' background knowledge and expertise were considered when assigning them to groupings, to enable them to use their professional experience when conducting the exercise.

Although scoring was carried out at the application/technology combination level, scorers were advised to be guided by the specific innovations in the spreadsheet when considering what technologies/applications each description pertained to. A rapid evidence review was conducted for each of the 151 groupings. This involved:

- Searching for relevant, publicly available sources such as policy papers, think pieces, consultancy studies and academic reviews.
- Recording briefly the most pertinent information according to the three themes (potential impacts, current regulatory environment, and scope for regulatory reform).

Literature reviews were recorded in tables separated by theme and supplied to BEIS alongside the final spreadsheet output for the study.

Due to the nature of the exercise, and the time available, it was essential to place a strict time limit on the literature review process. Where information was not found (in particular, the 'scope for regulatory reform' question was often difficult to answer), the literature reviews were left blank. As with many elements of this project, the literature reviews should be considered a starting point, which can be added to or adjusted as the evidence base expands and/or further interrogation of the themes takes place.

The scoring process (described below) was carried out using the information collected in these literature reviews as the starting point. Scorers used their own professional judgement, in combination with the information collected and presented in the literature reviews, to make scoring decisions.

## Stage 4: Scoring

A two-stage scoring process took place. First, the 151 application/technology combinations were scored using the 12 higher priority metrics alone. These scores were then aggregated to derive an initial priority ordering. From this, the 44 highest scoring combinations were then scored for the lower priority metrics.[5] This two-stage approach reduced the burden on the scoring exercise.

Scoring was undertaken using the information collected for the literature reviews (Stage 3), as well as scorers' own professional judgement. The metrics framework clearly defined the range of scores that could be chosen and was designed with simplicity in mind. For most categories, a score of High/Medium/Low/Zero was required. Various steps were taken to ensure that a team of scorers could confidently use their judgement to score the groupings on a similar basis to one another. Details of how this was achieved, and the specific scoring guidelines produced, can be found in the Appendix section *Scoring guidelines.*

## The method used for aggregating the 12 higher priority metrics to obtain the top 44 groupings is described in Appendix section *Methodology for calculating top 44 groupings.*Stage 5: Prioritisation

The 23 metrics were designed such that they can be combined and weighted in different ways to reflect the strategic priorities of the RHC. This flexibility is one of the strengths of the approach, allowing the dataset to be 'queried' in multiple different ways as the interests and priorities of the RHC develop. It is beyond the scope of this study to produce detailed analysis of the dataset. The study does not therefore offer a definitive 'final list' of innovations to take forward. Rather, the aim is to provide the underlying data, and a 'proof of concept' for combining scores, such that further work can be conducted by BEIS and the RHC to explore a range of different possible scenarios or preferences.

[5] 44 was chosen because of the tied nature of some of the scores. Below 44, the subsequent 25 innovations all scored an equal rank.

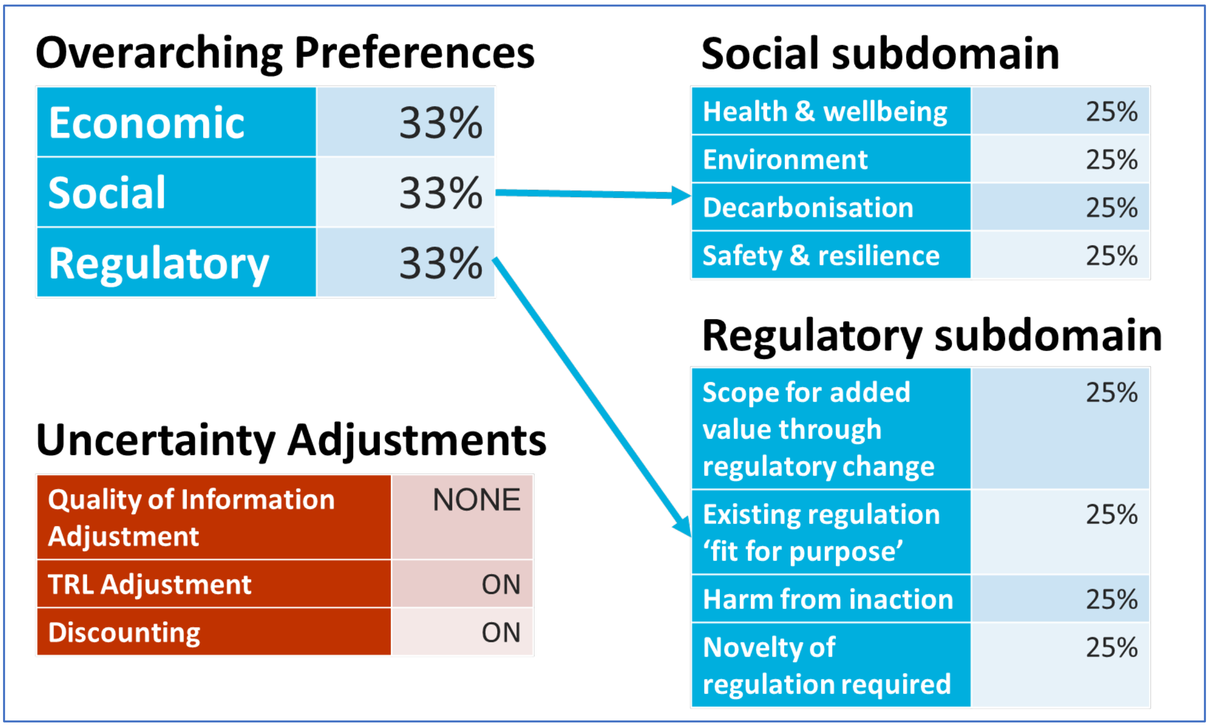
Choices around how to weight and combine scores are needed to produce prioritisation outputs. The inclusion (or exclusion) of various key variables, and the weighting of each variable, gives the opportunity to reflect a range of different strategic priorities, which could be around:

- Risk appetite – willingness to base decisions on uncertain information, experimental technologies and novel regulation types;
- Time preference – the extent to which future benefits are discounted;
- Preference for benefits in certain social domains, for example decarbonisation, over others, or balancing multiple social objectives in a single innovation grouping; and
- Preference for types of regulatory intervention, such as incentives rather than constraints.

One of the outputs of this study was a spreadsheet front-end, which was developed to accompany the scoring spreadsheet and allow the user to adjust the controls/weightings to produce prioritisation outputs. These are demonstrated in Figure 4, with initial 'neutral' weightings. The elements of this spreadsheet front-end are that:

- Overall score is based on a weighted average of the three overarching areas (economic, social and regulatory);
- The Social and Regulatory score each represent a weighted average of the scores in the relevant subdomain, according to the percentages set on the control sheet;
- Discounting of 3.5%, applied to the future projection of economic benefits, can be applied by switching the 'Discounting' option to 'ON'. When turned off, no discounting is applied; and
- Quality of information and TRL adjustments (that is, the de-prioritisation of innovations with poor quality source information and/or a low TRL) can be incorporated as additional categories in 'overarching preferences' if desired.

**Figure 4: Illustration of key choices around weighting presented at the RHC weightings workshop ('equal weighting' option)**




Source: Steer-ED, 2020

## RHC Weightings Workshop

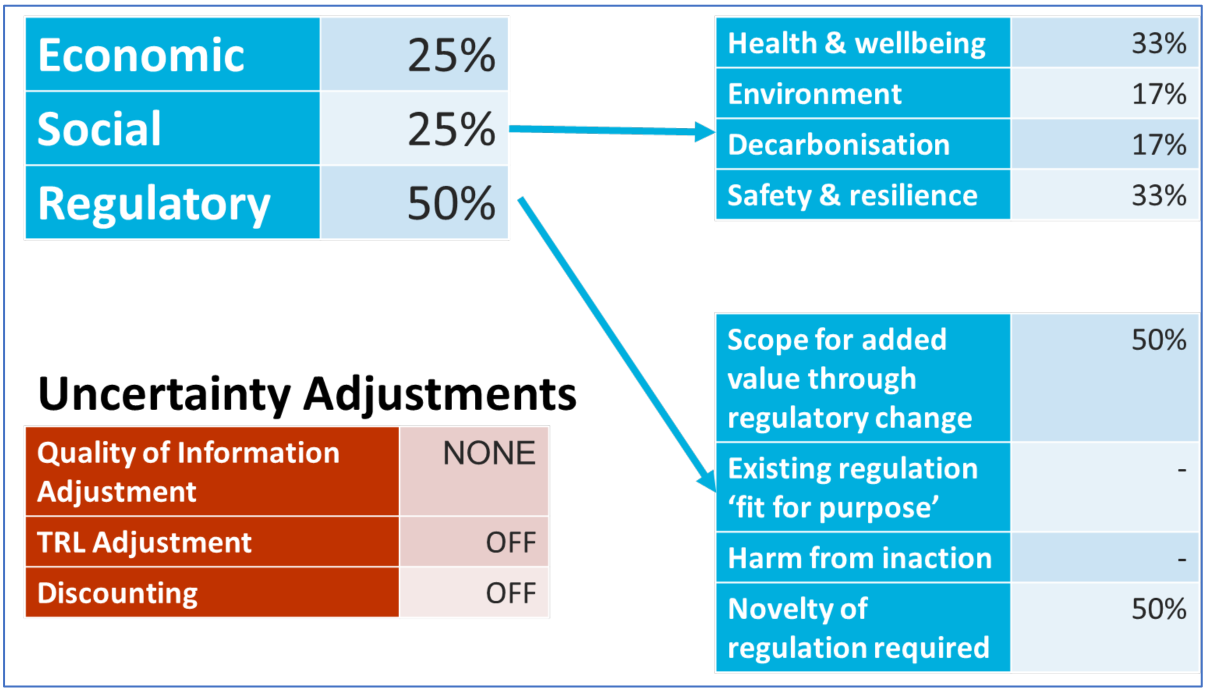
Following the initial work to categorise and score innovations, a requirement of this project was to hold a workshop with BEIS and representatives from the RHC to discuss the key weightings decisions, as set out in Figure 4, needed to produce prioritisation outputs.

The Weightings Workshop was held in April 2020, by teleconference. It included representatives from the RHC, BEIS, UK Research and Innovation (UKRI) and Government Office for Science (Go-Science). The study methodology and approach were described to the participants, followed by a discussion on the below key questions. The visualisation in Figure 4 was shown, with the neutral percentages/weightings used as a starting point. Participants were asked:

- Whether the overall 'balance' between economic, social and regulatory domains in the proposed weighting feels appropriate.
- Whether the weightings proposed for the subdomains feel appropriate;
- To what extent outputs should be adjusted for uncertainty and/or discounted; and
- Finally, participants were asked to share any broader reflections on the approach, and whether there should be any additional subdomains considered within each of the three domains

A detailed account of the points raised in the workshop is available in the Appendix section *Summary of the RHC weightings workshop*. Key decisions/discussion points were as follows. These are also illustrated in Figure 5.

**Figure 5: Weightings preferences agreed at the RHC weightings workshop**




Source: Steer-ED, 2020

- Participants agreed to move away from the proposed weightings in the 'equal weighting' setup: There was agreement that weighting should be equal between total benefits and RHC impact. Additional weight was placed on the regulatory dimension, such that it makes up 50% of the score, with the remaining 50% encompassing economic and social benefits.

- There was concern about potential overlap between environmental and de-carbonisation benefits. There was also significant discussion, and some differences in views, around whether including two separate environmental measures might detract from the welfare/safety domains if all were equally weighted. Participants therefore agreed to apply the social subdomain weightings in the following ratio: Health & wellbeing (2): Environment (1): Decarbonisation (1): Safety & resilience (2).

- Participants discussed the likelihood of overlap between the regulatory metrics, and therefore decided that it would be unnecessary to include all four. 'Scope for added value' and 'novelty of regulation required' were considered to be the most useful, given the RHC's role, to be applied with 50% weighting each.

- Participants recognised the inevitable uncertainty and data quality limitations inherent in an exercise such as this, and agreed that it would not be helpful for the RHC – a horizon focused body – to place too much emphasis on near-term benefits or groupings with most certainty around outcomes, as this could result in missing high potential opportunities. This resulted in the proposal that quality of information adjustments and discounting should be turned off.

- Finally, a range of additional metrics, information sources and considerations were raised, which should be investigated further in future work.

## Outputs

Based on the weightings agreed at the RHC prioritisation workshop (Figure 5), a priority ordering of the application/technology groupings can be produced. The top 20 ranked groupings are shown in Table 2. It is interesting to note the prevalence of groupings from the Transport & mobility sector – which represent 8 of the top 20, and four of the top five. The next two most important categories are Food, water & agriculture (four out of 20) and Space & scientific research (again, four out of 20). In general, what characterises the Top 20 seems to be:

- Major potential for impact on lives/well-being;
- Cross-cutting impacts (for example transport innovations have implications for decarbonisation, safety and the environment); and
- Regulatory flexibility. There is potential for regulatory change from multiple different routes – including through incentives, constraints and technical standards.

**Table 2: Top 20 Application/Technology groupings, based on the RHC proposed weightings**

| Rank | Sector | Application/Technology |
|---|---|---|
| 1 | Transport & mobility | Vehicles and Components/Advanced Driver Assistance Systems (ADAS) |
| 2 | Transport & mobility | Mobility/Vertical and/or Short Take-off and Landing (V/STOL) |
| 3 | Transport & mobility | Vehicles and components/Battery Technology |
| 4 | Transport & mobility | Vehicles and components/Vertical and/or Short Take-off and Landing (V/STOL) |
| 5 | Space & Scientific research | Aerospace/AI, Big Data & Machine Learning |

| Rank | Sector | Application/Technology |
|---|---|---|
| 6 | Transport & mobility | Logistics/Advanced Driver Assistance Systems (ADAS) |
| 7 | Food, water & Agriculture | Food, water & agriculture/Agritech |
| 8 | Food, water & Agriculture | Food, water & agriculture/AI, Big Data & Machine Learning |
| 9 | Health & medical | Medical Treatment/Pharmacology |
| 10 | Transport & mobility | Mobility/Hyperloop |
| 11 | Space & Scientific research | Aerospace/Robotics |
| 12 | Food, water & Agriculture | Food, water & agriculture/Internet of Things |
| 13 | Health & medical | Medical Diagnosis/Computing/Computer Processing |
| 14 | Space & Scientific research | Aerospace/Satellites, space travel, aerospace |
| 15 | Space & Scientific research | Aerospace/Mechanical Engineering |
| 16 | Transport & mobility | Mobility/Platforms and UIs |
| 17 | Entertainment, leisure, media | Entertainment/5G/Wireless Technology |
| 18 | Food, water & Agriculture | Food, water & agriculture/Robotics |
| 19 | Construction & Manufacturing | Manufacturing/Internet of Things |
| 20 | Transport & mobility | Vehicles and components/Hydrogen Fuel Cell |

Source: Analysis produced by Steer-ED and BEIS, 2020

## Sensitivity analysis

A sensitivity analysis was undertaken by BEIS to test how adjusting various weightings on key metrics affected the top 20 ranked groupings (Table 2). An additional 11 application/technology groupings were uncovered as being potential priority areas when testing alternative preference weightings, mainly arising from the numerous approaches to accounting for uncertainty through including uncertainty indicators. These 11 additional groupings are shown in Table 3.

The sensitivity analysis uncovered the following:

- Increasing the weighting on the regulatory dimension (and accordingly, reducing the weighting on the economic and social dimensions) had little effect on the groupings in the top 20, except for changing the positioning within the top 20 for some lines.
- Changing the ratio of social weightings (from equal weighting to 2:1:1:2) has almost no material impact on the top 20. The top 10 remain almost completely unchanged, and there are only minor positioning changes within the top 20.
- Changes to the regulatory sub-domain weightings have important impacts on the top 20 list. By excluding the fields ‘harm from regulatory inaction’, and ‘fit for purpose of existing regulation’, some groupings – such as those around drones and 3D printing – are removed from the top 20.
- Discounting and uncertainty adjustments also have substantive effects on the top 20. In general, by removing these adjustments, the top 20 includes more of the far from market, high potential and unknown/unproven technologies – such as for example hyperloop and hydrogen fuel cells.

**Table 3: Additional application/technology groupings introduced by the sensitivity analysis**

| Application | Technology |
|---|---|
| Space & Scientific research | Drones |
| Food, Water & Agriculture | Drones |
| Construction & Manufacturing | New Materials |
| Space & Scientific research | 3-D Printing |
| Banking, Finance, Commerce | AI, Big Data & Machine Learning |

| | |
|---|---|
| Transport & Mobility | Drones |
| Food, Water & Agriculture | Mechanical Engineering |
| Energy Generation & Storage | Electricity generation |
| Environment & Waste | Satellites, space travel, aerospace |
| Food, Water & Agriculture | Blockchain |
| Construction & Manufacturing | Robotics |

# Limitations of the Approach

This study should be considered a ‘proof of concept’ for the prioritisation of innovations. The type of work is in itself innovative, and the approach was designed specifically for the task at hand, rather than using an existing well-established methodology. It should be considered an exploratory, learning exercise. The approach had several limitations, as follows:

- The size of the task was a considerable limiting factor affecting the evidence gathering and scoring processes. Given the large number of innovation groupings, literature reviews had to be approached in a light-touch way and strictly time-limited. This resulted in considerable gaps in the evidence-base, particularly around the regulatory aspects. This is a significant concern given the priority placed on the regulatory metrics by the RHC prioritisation, and so BEIS has developed Next Steps as set out below to best move forwards;
- Even with significant additional time, it may be that some of the evidence being sought simply does not exist. Estimating the potential impact and regulatory possibilities for a novel technology that has not yet reached market is a speculative exercise, and therefore the quality of underlying information should be approached with due caution;
- A scoring exercise of this magnitude – in terms of both the number of innovations considered, and the range of different metrics – poses a significant risk around input quality. Allocation to different scorers, with expertise in different sectors/innovation areas, helps to ensure expert knowledge is used when making judgements. However, this also poses the potential for inconsistency between interpretations. Furthermore, the differing nature and development stage of the innovations under consideration meant that even a single scorer would face issues of inconsistency and non-

comparability. Efforts were taken to minimise these inconsistencies, as described, but this will always be a concern in this type of work;

- Allocation to categories of application and technology, although informed by data science, was an exercise of manual review and allocation. Although the exercise attempted to ensure consistency across categories in terms of scale, there is no straightforward science to conducting this task and no single answer to how this grouping should be undertaken. Further work should involve revisiting some of these categories to establish whether they are fit for purpose, with potential for higher level grouping or breaking down into further subdomains;

- The original horizon scan was not (nor could ever be) a fully comprehensive scan of innovations. It provides only a six-week snapshot (conducted during October to November 2019), with likely bias towards innovations most 'newsworthy'. However, to a certain extent this issue was mitigated by higher-level categories being taken forward to the scoring exercise – reducing the emphasis on specific innovations and their frequency of occurrence. It is also likely, due to the nature of the work, that the horizon scan will become out of date relatively quickly. A repeat 'light-touch' horizon scan is recommended to keep the evidence base up to date;

- Although numerical manipulation and data science methods were involved, this work was at its core an exercise in human judgement. Steer-ED recognises that as BEIS move forward with use of the scoring spreadsheet, they may wish to query or modify some of the judgements within. The methodology has therefore been designed for maximum transparency. In future, BEIS will be able to consult the literature summaries and scoring spreadsheet in order to query and/or modify scores;

- The effects of EU Exit trade negotiations, and possible COVID-19 implications, were not taken into consideration during preparation of this study; and

- Finally, the spreadsheet does not in its current form give clear answers in terms of which innovations should be prioritised. The method for combining scores (of which there are almost limitless variations) contributes as much to the final prioritisation as the underlying scores/judgements. For this reason, sensitivity analysis has been undertaken to demonstrate the impact of different scoring combinations on the prioritisation outputs, and this was used to aid discussion at the Weightings Workshop. This work will be continued by BEIS and the RHC as they move forward with prioritisation considerations.

# Lessons from Testing the Conceptual Framework

As stressed at the start of this report, this has been an experimental and exploratory study, and as such has tested a conceptual framework to determine whether this framework is 'fit for purpose' – and if not, how it needs to be modified.

In headline terms, this study has demonstrated that:

- It is possible to analyse the information in the BEIS innovations spreadsheet through the complementary 'lenses' of the *attractiveness* and the *feasibility* of different innovation groups from a regulatory perspective;
- It is possible to construct a flexible and adaptive analytical approach based on a set of discrete 'building blocks' that can be configured and combined 'on demand' to investigate queries posed by the RHC;
- The data-science-led sorting and categorising exercise provided a helpful characterisation of the innovations collected by the original horizon scan, allowing scoring to take place on a more consistent and comparable basis;
- Although simplistic, conceptualising innovations in terms of 'application' and 'technology' provides a useful structure and could be repeated in future studies. Further nuance could be added by including secondary categories of application and technology; and
- Despite the challenges of collecting and assessing data on innovations which have not yet come to market, this study has demonstrated that in many cases there is publicly available data to broadly indicate the potential economic, social and regulatory implications of innovations. That being said, there was a scarcity of information found in some domains and for some research questions – in particular for the question of scope for added value through regulatory change. This is a concern given that the RHC prioritisation workshop indicated that metrics in this category were of most use/interest for the RHC.

These methodological findings indicate that the current study has provided a useful basis for moving forward. The inevitable twin challenges of a need to rely on highly subjective judgments whilst coping with a high degree of uncertainty will require a structured and consistent 'evolutionary' approach. This, in turn, will need a suitable analytical framework able to reflect and react to changes in subjective judgements and changes in uncertainties over time. One advantage of the conceptual framework proposed, tested and modified via this study is that it possesses this adaptability in regard to changes in subjective judgements and uncertainties. As new information and insights become available this framework can be re-calibrated and used to produce updated estimates.

# Recommended Further Work

The work undertaken for this study was experimental, and at the outset unpredictable. It has produced first outputs and was used to hold a weightings workshop with the RHC and other representatives. In terms of follow-up or additional work, Steer-ED recommend the following possible options:

- The Horizon Scan exercise, which initially took place during a six-week period, could be repeated in a 'light-touch' manner, identifying the extent to which innovations uncovered are captured by this study, or fall outside the categories defined in this study. This will help to give a clearer understanding of the level of coverage provided by this methodology and mitigate the risks identified with relying only on the original six-week horizon scan.
- Additional consideration of the application and technology categories could be undertaken, considering whether some areas should be merged or divided. This would be complimented by an additional horizon scan (described in the first point, above), helping to ensure a more comprehensive coverage of innovation areas.
- The evidence base, which as noted was collected in a 'light-touch' manner and contains missing entries, can be added to over time. As the RHC considers groupings of interest and investigates the attractiveness and feasibility of these areas, additions to the evidence base can be made to reflect any new information uncovered. The assigned scores can also be updated/amended as new information comes to light, and this can be used to generated revised prioritisation outputs. In particular, the regulatory scores should be revisited and the evidence-base strengthened, given the RHC's focus on these areas.
- The red (empty) cells in the application/technology matrix shown in Figure 5 could provide a useful starting point for considering some of the innovations that may have been missed by the horizon scan.
- Suggestions for additional metrics were raised in discussion at the RHC Weightings Workshop. These could be further investigated, with a view to collecting evidence to support these metrics and scoring the innovations. The scoring spreadsheet developed for this study is sufficiently flexible to allow new metrics to be added 'post hoc'.
- As discussions within the RHC develop and new government priorities arise (the response to the COVID-19 pandemic being a case in point), new ideas around how to prioritise innovations will come to light. The flexible spreadsheet tool can be used to assess the implications of these discussions on the priority ordering of application/technology groupings. Sensitivity testing can also be performed to demonstrate how prioritisations change (or remain static) as preferences evolve.

During the process of querying the prioritisation outputs, we expect that BEIS will come across areas of the evidence base which could be modified, updated or built on. The outputs have been designed such that they can be built on in this way, with sufficient transparency of scoring and process to allow additions to the work to occur in the future.

# BEIS Next Steps

As set out above, there were some important limitations to the approach, due to the challenges of gathering information on a large number of pan-economy innovation groupings. Additionally, the focus on emerging innovations means that some of the evidence being sought simply does not exist. Estimating the potential impact and regulatory possibilities for a novel technology that has not yet reached market is a speculative exercise. Information was particularly scarce regarding the regulatory aspects, which is a significant concern given the priority placed on the regulatory metrics by the RHC prioritisation.

To mitigate these limitations, a long list of the Steer-ED outputs was taken forward as an indication of the potential priority areas that the RHC might make recommendations around. Generating this long list from an initial set of 542 innovations and 151 innovation groupings was therefore a key output of the Steer-ED work. BEIS took the top 31 innovation groupings as generated by the process set out in this paper and conducted in-depth evidence-gathering through engagement with key stakeholders. This was used to supplement the existing evidence base and scoring to decide upon a final set of priority areas.

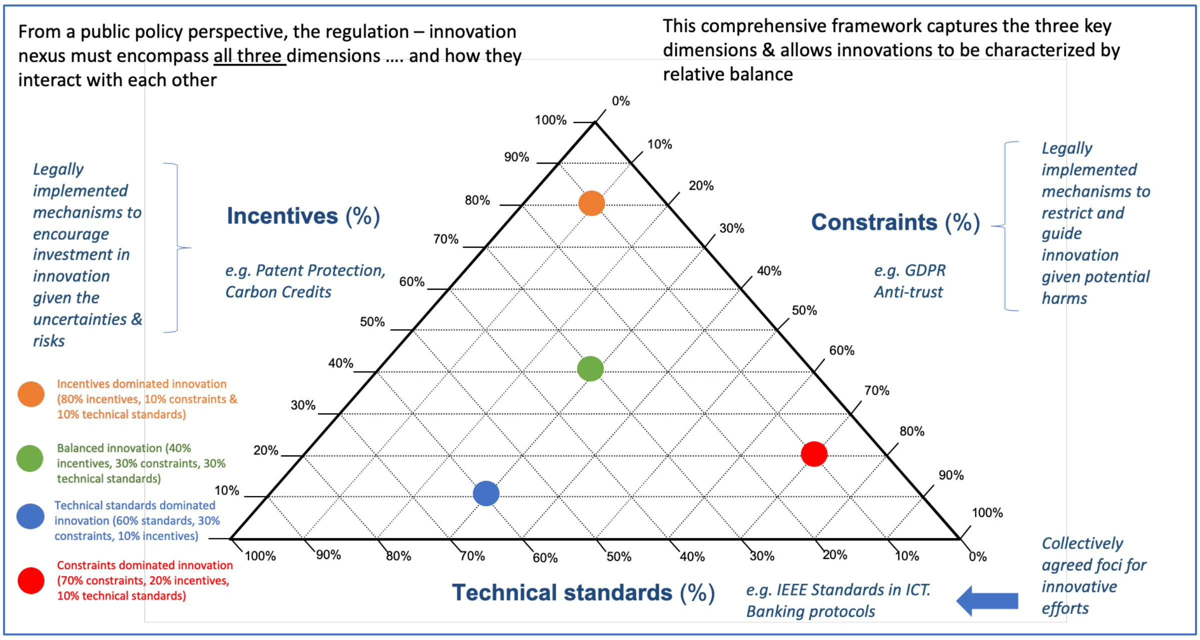
# Technical Appendix

## Regulatory Classification

Given the complexity of the ways in which regulatory stances can impact innovation, for this study Steer-ED considered a number of ways to characterise regulatory stance and its impact on innovation. Figure 5 demonstrates the classification system developed for this study. Innovations were assessed for their use of each of the three categories of regulatory approach – incentives, constraints and technical standards. This was scored both for the current (status quo) state, and for the potential future state – the scope to add value through change in each of the three.

This scoring was not used in the final weighting/prioritisation approach proposed during this study, since the RHC wished to remain 'neutral' to regulatory approach. However, it may be of use for the RHC to return to these scores at a future date.

**Figure 6: Simplified classification of regulatory approaches**




Source: Steer-ED, 2020

**Incentives** covers all aspects of regulation that encourage and facilitate. Examples are Research and Development (R&D) grants and subsidies (for example R&D tax credits), patent protection and schemes such as carbon emission mitigation credits.

**Constraints** (prohibitions) are anything in the regulatory stance that discourages and penalises, such as General Data Protection Regulation (GDPR) or anti-trust law.

**Technical Standards** are captured separately because they can play a key role in focusing R&D investment and innovation activities by guiding firms (and public sector R&D performing organisations) as to where the potential returns on investment are likely to be particularly high. Importantly, technical standards can be both domestic

(British Standards) and international in nature. International standards can be collectively agreed within the private sector at a global level, for example standards set by the Institute of Electrical and Electronics Engineers (IEEE) or via the technical standards covered by Free Trade Agreements (FTAs). They may also be more loosely defined, for example a technical framework that defines a common approach permitting (but not requiring) collaboration between different parties.

As Figure 5 shows, different types of innovation (and indeed entire industries) will tend to ‘map across’ to different regions of this triangular characterisation. Some innovations are dominated by the incentives side of regulation whilst others are dominated by constraints or technical standards. Some innovations may be more balanced in the sense that they are influenced by all three aspects in broad equivalence.

## Details of the Innovations Spreadsheet

This section provides further details of the Innovation Spreadsheet – which was produced by the BEIS horizon scanning exercise and was the input to Steer-ED’s work.

Innovations were collected during a time-limited six-week period. There was no geographical or sectoral boundary placed on the innovations collected. Innovations could be sourced from anywhere in the world, from any sector of the economy, and could encompass new products, processes and even new business models or services. A comprehensive list of the sources consulted is as follows:

- Google news alerts for: innovation(s), technology, technologies, emerging technology, emerging technologies, technological innovation(s)
- Technology/business magazines: WIRED, Scientific American, TechCrunch, New Scientist, The Economist, FT, MIT Technology, SciTechDaily, Springwise, Fast Company Compass, Sifted, Bloomberg, Nat Bullard
- Tech blogs/tech influencers

Multiple occurrences of the same or highly similar innovations from different sources were collected as separate lines in the spreadsheet.

The spreadsheet comprised the following information about each innovation, which was manually inputted:

**Descriptive:**

- A brief description of the innovation;
- A second, more detailed, description of the innovation;
- Details of the information source.

**Additional information (drawn from the information source where available, otherwise based on best estimate):**

- The primary technology and any underlying/enabling technologies;
- An indication of the likely sector(s) affected;
- The estimated Technology Readiness Level (TRL) of the technology, used as a proxy for estimated time to market and confidence rating; and
- A judgement about source reliability.

# Taxonomy Creation: Detailed Methodology

## Text Processing

Before topic-modelling could be undertaken, the free-text descriptions of the innovations and enabling technologies were processed to improve the quality of inputs for the following topic modelling exercise. This involved removing errors and removing or refining words to make the text more suitable for key-word detection. The processes were as follows:

- Removal of standard 'meaningless' words (such as conjunctions, prepositions and articles) using an R-library of common 'stop-words'.
- Removal of non alpha-numeric characters (such as punctuation marks) and possessive indicators ("'s").
- Replacement of words not found in the standard dictionary. These were predominantly typing mistakes which had occurred in the original free-text entries – for example 'delviery' was replaced with 'delivery'; 'helmut' was replaced with 'helmet', and so on.
- A more bespoke removal of words found to occur frequently in the text, but which did not provide useful key-word outputs, most often because they were generic technology-related words such as 'device', 'computer', 'system' or 'technique'[6].
- Finally, words which occurred frequently as contiguous pairs (such as 'deep fake', 'autonomous vehicle' and 'real time')[7] were joined, so that these terms would be considered as single key-word inputs by the topic modelling algorithm.

Having carried out these steps, the entries were then ready for a topic modelling approach to be applied.

[6] The full list of these terms is as follows: system; device; people; technology; company; technique; computer; compute.

[7] The full list of these terms is as follows: autonomous vehicle, driverless vehicle, deep fake, bulletproof vest, mobile phone, smart phone, virtual reality/VR, mixed reality, machine learning, real time, nuclear waste, battery power(ed), three dimensional, eye sight, 3D print-er/ed/ing

## Topic Modelling

A Latent Dirichlet allocation (LDA) method was used. LDA is one of the most common approaches used in text analysis for topic modelling. It is a mathematical modelling approach, which defines each input 'set' (in this case each set was an individual entry in the Innovations Spreadsheet) as a collection of topics represented in varying proportions; and each topic as a set of words, with varying probabilities of belonging to the topic.[8]

Topic modelling was initially carried out on the simplified description of each innovation (for example, one of the simplified descriptions in the spreadsheet is 'a drone that delivers food to homes'). However, the topic modelling returned an unhelpful mixture of terms related to purpose/application (in the example, these would be the words 'deliver', 'food', and 'homes') and terms related to the underlying technology (in this example, 'drone'). The decision was therefore taken to separate *technology* words from *application* words and conduct two separate analyses. This was achieved through the following process:

- Two separate inputs from the innovation spreadsheet were considered for each innovation: 'detailed name'; and 'primary enabling technology'. Both fields are free-text descriptions, but typically the latter is shorter and simply describes the key technology underpinning the innovation, while the former may contain several sentences or even paragraphs describing the innovation.

- Text processing, including the removal of stop words, generic technology words, joining of contiguous pairs and so on, as described above, was carried out for the two fields separately, to create two separate word-sets for each row – a technology word-set, and a 'detailed name' word-set.

- All the words in the technology word-set were then removed from the 'detailed name' word-set for each row. This meant that terms such as 'drone', 'machine-learning', or 'pharmacology' were removed from the description of the innovation, leaving behind a set of words which more clearly described the *purpose* of the innovation. This is hereafter known as the 'application word-set'.

- LDA topic modelling was then applied to the two separate word-sets. Each innovation was assigned to one *application* topic and one *technology* topic. The algorithm is programmed with a user-defined number of topics ('n'), which in this case could range from n = 1 (all innovations would be assigned to a single topic) to n = 542 (every innovation would be given its own topic). The analysis was run using n = 2, 20, 50, 100, 200 and 400 topics. As well as sorting innovations into topics ('topic allocation'), the analysis provides an additional output, which is a probabilistically generated set of terms that 'define' each topic – that is, terms which are most strongly associated with each topic. These are referred to as 'term lists'.

[8] For a comprehensive description of Latent Dirichlet Allocation, see Chapter 6 in Silge, Julia, and David Robinson. Text mining with R: A tidy approach. " O'Reilly Media, Inc.", 2017.

- Note that the lower the n, the more the algorithm is forced to group relatively dissimilar innovations together. Thus at n = 2, the term lists are meaningless, since large numbers of unrelated innovations must be grouped together.[9] Meanwhile, at the level of 200 or 400 topics, topic allocations are much more coherent, creating highly specific groupings, but result in many topics being assigned only a single innovation[10], thus not achieving the desired grouping/clustering of innovations (this is particularly the case at n = 400). For further illustration of term lists, Table 6 and Table 7 in the Appendix show term lists for application and technology word sets from the n = 20 topic modelling.

- In arriving at the final approach, Steer-ED experimented with different levels of n. Using term lists and topic allocations generated by n = 20 and n = 50, a broad characterisation of the contents of the spreadsheet was generated and was found to produce useful indications of some of the most important applications and technologies present in the spreadsheet. However, it failed to capture sufficient nuance to be fit-for-purpose.

- Using term lists and topic allocations generated by n = 50 and n = 200 was found to be most helpful, best mitigating the incoherence of shorter topic lists and the unhelpful specificity of longer topic lists[11]. The topic allocation and term lists for these two levels was used as the input for the next phase of work. It can be considered an algorithm-driven ‘suggestion’ as to how the original 542 innovations can be grouped meaningfully by theme. The following manual review then ensured definitions were consistent in terms of scale/specificity to allow for fair comparisons across groupings.

## Manual Review

A manual process was undertaken to refine the groupings generated by the LDA modelling. This involved the following:

- Examining the n = 50 term lists. Where feasible, one or two overarching description terms were given, which broadly described the topic to the human reader. For example, the set containing the terms ‘detect’, ‘healthcare’, ‘scan’, ‘live’, ‘access’ was assigned the overarching term ‘healthcare’. This exercise resulted in approximately 30 broad terms to describe technologies, and similar for applications. Technologies identified included, for example, robotics, drones, battery technology, ‘Internet of Things’ and so on. Applications included for example entertainment, logistics, medical treatment, health & safety and aerospace.

- This exercise was then augmented by examination of the n = 200 term lists. Some additional categories, which had not been apparent from the n = 50

[9] Application term lists for n = 2 are as follows: Topic 1: ‘base’, ‘power’, ‘identify’, ‘process’ and ‘detect’. Topic 2: ‘time’, ‘water’, ‘service’, ‘drive’ and ‘control’.
[10] An example application term list from n = 400. Topic 272: ‘cure’, ‘disease’, ‘fibre’, ‘implantable’, ‘nerve’. Only one innovation is assigned this topic. The description for this innovation from the original horizon scanning input was: ‘An implantable thread – a sutrode – that could cure disease by stimulating nerve fibres’.
[11] Example application term lists for n = 50 and n = 200 are as follows. N = 50, Topic 43: ‘produce’, ‘cell’, ‘create’, ‘customer’, ‘tissue’. N = 200, Topic 84: ‘food’, ‘cook’, ‘home’, ‘restaurant’, ‘analysis’.

term lists, were added. At this point, the reviewer also considered the individual spreadsheet entries themselves and their topic allocations, ensuring that the broad categorisation was appropriate for each individual line.

## Text Processing Outputs

**Table 4: Term list for applications word-set - top five terms per topic, 20 topics**

| Topic | Top Five Terms | | | | |
|---|---|---|---|---|---|
| 1 | energy | share | brain | information | increase |
| 2 | control | space | vehicle | environment | efficient |
| 3 | power | care | home | digital | compute |
| 4 | cell | therapy | reduce | plastic | edit |
| 5 | treat | disease | cancer | tool | diagnose |
| 6 | detect | walk | smartphone | live | healthcare |
| 7 | drive | app | virtual | online | base |
| 8 | base | hydrogen | time | system | chemical |
| 9 | drug | customer | check | predict | cycle |
| 10 | ai | sensor | patient | measure | mind |
| 11 | image | test | automate | Deep-fake | cancer |
| 12 | material | process | medicine | robot | industry |
| 13 | produce | waste | water | clean | product |
| 14 | delivery | car | global | transport | range |
| 15 | enable | advance | bacterium | lithium | cost |
| 16 | power | quantum | crop | farm | air |
| 17 | platform | health | connect | track | Three dimensional |
| 18 | service | network | business | identify | product |
| 19 | food | heart | analysis | skin | user |
| 20 | autonomous | car | public | electric | start |

Source: Steer-ED, 2020

**Table 5: Term list for technologies word-set - top five terms per topic, 20 topics**

| Topic | Top Five Terms | | | | |
|---|---|---|---|---|---|
| 1 | Robot | smart | IoT | therapeutics | suit |
| 2 | Drone | interface | brain | graphene | synthetic |
| 3 | Chip | protein | satellite | image | cool |
| 4 | material | Three-dimensional printing | sustainable | hybrid | bio |
| 5 | biometrics | Machine learning | aeroponics | implant | retinal |
| 6 | Sensor | Mixed reality | engineer | nanomaterials | immunotherapy |
| 7 | blockchain | space | distribute | cryptocurrency | craft |
| 8 | AI | cloud | software | molecular | algorithm |
| 9 | Battery | recognition | medical | polymer | car |
| 10 | Datum | analytics | Real time | vessel | system |
| 11 | Crispr | compute | genetic | quantum | engine |
| 12 | Neural | process | portable | Three dimensional | vision |
| 13 | platform | wearable | online | coaxial | electrospinning |
| 14 | Cell | therapy | biological | pesticide | fuel |
| 15 | application | smartphone | mobile | wind | multi |
| 16 | Virtual reality | augment | reality | manufacture | prosthetic |
| 17 | Digital | wearables | liquid | air | capture |
| 18 | electric | vehicle | autonomous | aerial | panel |
| 19 | internet | artificial | solar | virtual | sensory |
| 20 | Autonomous vehicle | reactor | filter | microplastics | modular |

Source: Steer-ED, 2020

## Metrics Framework

The table below details all scoring metrics developed for the study. The spreadsheet front-end which was developed by Steer-ED to permit weighted prioritisations is referred to in the table below as the 'control sheet'.

**Table 6: The 28 Metrics Developed for Scoring Innovations**

| Metric & usage | Priority Level | Description | Input Type |
|---|---|---|---|
| **Economic** | | | |
| Predicted global market size<br><br>[contributes to 'economic' score, which can be weighted via control sheet] | High | Annual estimates of the global market in 2025, 2030 and 2050 | 6 banded categories, from zero/trivial to >£3,000bn. |
| UK potential share<br><br>[contributes to 'economic' score, which can be weighted via control sheet] | High | Percentage share of the global market the UK could feasibly capture | Point estimate (%) |
| *Productivity impact*<br><br>*[not available for use]* | *Low* | *Likelihood that economic impacts will result in a significant upward shift to established productivity trends* | *This metric was removed due to insufficient evidence found.* |
| *Job creation impact*<br><br>*[not available for use]* | *Low* | *Likelihood that economic impacts will result in a significant upward shift to established job creation trends* | *This metric was removed due to insufficient evidence found.* |
| *Re-balancing impact* | *Low* | *Likelihood that economic impacts will result in a significant re-balancing of the* | *This metric was removed due to insufficient evidence found.* |

| Metric & usage | Priority Level | Description | Input Type |
|---|---|---|---|
| *[not available for use]* | | *economy away from London and the South East* | |
| *R&D/GVA impact*<br><br>*[not available for use]* | *Low* | *Likelihood that economic impacts will result in a significant upward shift to established R&D/GVA trends* | *This metric was removed due to insufficient evidence found.* |
| *Inward investment impact*<br><br>*[not available for use]* | *Low* | *Likelihood that economic impacts will result in a significant upward shift to the ability to attract inward investment* | *This metric was removed due to insufficient evidence found.* |
| **Social** | | | |
| Health & welfare benefits<br><br>[contributes to 'social' score. % contribution can be adjusted via control sheet] | High | Estimated monetised value of benefits in terms of health, wellbeing and welfare, for the UK in 2050. | 5 banded categories, from zero/trivial to >£50bn |
| Environmental benefits<br><br>[contributes to 'social' score. % contribution can be adjusted via control sheet] | High | Estimated monetised value of environmental benefits (such as improved biodiversity and air quality), for the UK in 2050. | 5 banded categories, from zero/trivial to >£50bn |
| Energy efficiency and de-carbonisation benefits<br><br>[contributes to 'social' score. % contribution can be | High | Estimated monetised value of energy efficiency and de-carbonisation benefits, for the UK in 2050. | 5 banded categories, from zero/trivial to >£50bn |

| Metric & usage | Priority Level | Description | Input Type |
|---|---|---|---|
| adjusted via control sheet] | | | |
| Human security & resilience benefits<br><br>[contributes to 'social' score. % contribution can be adjusted via control sheet] | High | Estimated monetised value of human security and resilience benefits (for example security of life, energy, and other resources, plus disaster prevention and mitigation) for the UK in 2050. | 5 banded categories, from zero/trivial to >£50bn |
| AI in medical diagnosis and treatment<br><br>[not used in Steer-ED's prioritisation controls] | Low | Degree of alignment with current Government Grand Challenges: AI in medical diagnosis and treatment | Basic Ranged Assessment: High, Medium, Low |
| Extending life expectancy and reducing inequality<br><br>[not used in Steer-ED's prioritisation controls] | Low | Degree of alignment with current Government Grand Challenges: Extending average life expectancy by 5 years and reducing inequality | Basic Ranged Assessment: High, Medium, Low |
| Clean growth and net zero<br><br>[not used in Steer-ED's prioritisation controls] | Low | Degree of alignment with current Government Grand Challenges: Clean growth and Net Zero | Basic Ranged Assessment: High, Medium, Low |
| Zero emissions vehicles<br><br>[not used in Steer-ED's prioritisation controls] | Low | Degree of alignment with current Government Grand Challenges: Zero emissions vehicles by 2040 | Basic Ranged Assessment: High, Medium, Low |

| Metric & usage | Priority Level | Description | Input Type |
|---|---|---|---|
| **Regulatory** | | | |
| Regulatory potential: incentives<br><br>[contributes to the 'regulatory' score, equal weighting with other contributors] | High | Scope for added value through changes in Incentives | Basic Ranged Assessment: High, Medium, Low |
| Regulatory potential: constraints<br><br>[contributes to the 'regulatory' score, equal weighting with other contributors] | High | Scope for added value through changes in Constraints | Basic Ranged Assessment: High, Medium, Low |
| Regulatory potential: technical standards<br><br>[contributes to the 'regulatory' score, equal weighting with other contributors] | High | Scope for added value through changes in Technical Standards | Basic Ranged Assessment: High, Medium, Low |
| Regulatory work in progress<br><br>[not used in Steer-ED's prioritisation controls] | Low | Any evidence of on-going or upcoming regulatory 'work-in-progress' relevant to this technology group, as far as we are aware? | Yes/No |
| Existing regulation 'fit for purpose'?<br><br>[contributes to 'regulatory' metric. % contribution can | Low | Extent to which the existing regulatory landscape is sufficiently agile/reactive to be 'fit-for-purpose' | Basic Ranged Assessment: High, Medium, Low |

| Metric & usage | Priority Level | Description | Input Type |
|---|---|---|---|
| be adjusted via control sheet] | | | |
| Regulatory baseline: incentives<br><br>[not used in Steer-ED's prioritisation controls] | Low | Importance of Incentives in the current regulatory stance | Basic Ranged Assessment: High, Medium, Low |
| Regulatory baseline: constraints<br><br>[not used in Steer-ED's prioritisation controls] | Low | Importance of Constraints in the current regulatory stance | Basic Ranged Assessment: High, Medium, Low |
| Regulatory baseline: technical standards<br><br>[not used in Steer-ED's prioritisation controls] | Low | Importance of Technical Standards in the current regulatory stance | Basic Ranged Assessment: High, Medium, Low |
| Novelty of innovation<br><br>[contributes to 'regulatory' metric. % contribution can be adjusted via control sheet] | Low | Degree of novelty of the innovation relative to existing regulatory experience | Basic Ranged Assessment: High, Medium, Low |
| Severity of regulatory inaction<br><br>[contributes to 'regulatory' metric. % contribution can be adjusted via control sheet] | Low | Potential severity of any unintended regulatory inaction | Basic Ranged Assessment: High, Medium, Low, Zero |
| **Uncertainty** | | | |
| Uncertainty over economic benefits | High | Degree of uncertainty over | Basic Ranged Assessment: High, Medium, Low |

| Metric & usage | Priority Level | Description | Input Type |
|---|---|---|---|
| [not used in Steer-ED's prioritisation controls] | | potential economic benefits | |
| Technology Readiness Level<br><br>[can be included in prioritisation as a variable in its own right, with adjustable weighting] | High | TRL Categorisation collapsed into three categories. | High (TRL = 7-9), Medium (TRL = 4-6), Low (TRL =1-3) |
| Information quality<br><br>[can be included in prioritisation as a variable in its own right, with adjustable weighting] | High | Quality of information available to the reviewers | Basic Ranged Assessment: High, Medium, Low |

Source: Steer-ED, 2020

## Scoring Guidelines

Various steps were taken to ensure the scoring exercise was robust and consistently applied across team members. These were as follows:

- The scoring options were designed to be as simple as possible, with scorers choosing between a relatively short list of options.
- Scores were entered into a spreadsheet with restricted input values, to avoid erroneous entries.
- A scoring guideline document was created, which gave specific instructions on how each metrics was to be scored. This also included helpful examples and reference points, such as UK and global market sizes by sector. Scorers were in general advised to take an optimistic view, assuming a 'reasonable best-case scenario' for innovation potential, and assuming that any barriers around adoption or diffusion could be overcome, either through governmental or non-governmental action.
- Where possible, metrics were designed to elicit known quantities (such as the size of a market or expected value of benefits) rather than using abstract measures, which are more open to interpretation.

- Metrics were designed to ask very specific questions, to avoid differences of interpretation between scorers.
- An initial 'trial-run' scoring exercise was carried out, after which a calibration workshop was held for the scorers to discuss their approaches, raise concerns, and identify potential inconsistencies. Following the calibration workshop, a revised and more comprehensive scoring guideline document was created, and scores corrected/modified to ensure consistency across the three scorers.

The scoring guidelines are reproduced in Table 7 below:

**Table 7: Scoring guidelines document**

| Metric Description | Scores Available | Commentary/rules of thumb |
|---|---|---|
| Predicted global market size (2025, 2030, 2050) | Scorers should choose a category band from the following list:<br><br>Zero/trivial<br><br>Fairly significant (£0-£250bn)<br><br>Very significant (£250bn - £500bn)<br><br>Large (500bn-£1000bn)<br><br>Very large/transformational (£1000bn-£3000bn)<br><br>Epoch defining (>£3000bn)<br><br>Estimate is of the annual value for the world market.<br><br>Scorers should give an estimate for the annual value at three points in time: 2025, 2030 and 2050. | Reference points are as follows[12]:<br><br>£0-£250bn: Global water and sewerage industries<br><br>£250bn - £500bn: Global media industry<br><br>500bn-£1000bn: Global car industry<br><br>£1000bn-£3000bn: Global plastics, metals and rubbers sectors<br><br>Global education sector<br><br>Global retail trade (ex. Vehicles) |

[12] Source: World Input-Output Database 2014 (with modifications). Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R. and de Vries, G. J. (2015), "An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production", Review of International Economics., 23: 575–605

| Metric Description | Scores Available | Commentary/rules of thumb |
|---|---|---|
| | No need to adjust for inflation or apply discounting – simply give estimates based on today's prices/values. | ~£3000bn Global finance sector or global construction sector<br><br>Regarding adoption, scorers should take an optimistic viewpoint, assuming that any measures required (whether governmental or non-government) will be taken to ensure the innovation achieves its maximum potential. |
| Potential share the UK could capture | Scorers should enter a percentage if known. If not known, the default assumption is 4%, which is the UK overall share of world GDP. | Note that at present, no UK sector (broadly defined using ONS definitions) exceeds 9% of the world market. However, in some cases – e.g. very niche technologies for which the UK is a leader, up to 20% of world share might be feasible. |
| Degree of uncertainty over potential economic benefits | High (highest level of uncertainty)<br><br>Medium<br><br>Low (lowest level of uncertainty) | This metric encompasses questions such as:<br><br>Was information readily available?<br><br>How new/novel is the technology?<br><br>How much uncertainty is there about adoption? |

<table>
<tr><th>Metric Description</th><th>Scores Available</th><th>Commentary/rules of thumb</th></tr>
<tr><td>Technology Readiness Level</td><td>High (TRL 7, 8, 9)<br><br>Medium (TRL 4, 5, 6)<br><br>Low (TRL 1, 2, 3)</td><td>If the scoring line contains multiple innovations of very different TRL levels, the most appropriate response may be to disaggregate into separate lines, by adding new rows to the spreadsheet.</td></tr>
<tr><td>Quality of information currently available</td><td>High (highest quality of information)<br><br>Medium<br><br>Low (lowest quality of information)</td><td>High – high quality, peer-reviewed sources, for example McKinsey Global Institute.<br><br>Medium – national newspapers, op eds, think pieces.<br><br>Low – local newspapers, promotional material, unverified internet sources.</td></tr>
<tr><td>Scale of potential health & welfare benefits for the UK</td><td rowspan="2">Calculated on a 5-point scale, based on the estimated UK economic value in 2050<br><br>No need to adjust for inflation or apply discounting – simply give estimates based on today’s prices/values.</td><td></td></tr>
<tr><td>Scale of potential environmental benefits for the UK</td><td>Includes for example biodiversity, air quality, water table contamination etc.</td></tr>
</table>

| Metric Description | Scores Available | Commentary/rules of thumb |
|---|---|---|
| Scale of potential energy efficiency and de-carbonisation benefits for the UK | Possible values are as follows:<br><br>0/trivial<br><br>£0-£5bn<br><br>£5bn-£10bn<br><br>£10bn-£20bn<br><br>£20bn-£50bn<br><br>>£50bn<br><br>As a point for reference, the UK car industry is approx. £20bn. | Can include both direct de-carbonisation benefits and measures which significantly reduce energy consumption. |
| Scale of potential human security & resilience benefits for the UK | | |
| Scope for added value through changes in Incentives | Scorers can choose from the following options:<br><br>High – great potential to add value<br><br>Medium – some potential to add value<br><br>Low – limited potential to add value (but more than zero) | Scorers should not be limited by the existing regulatory environment or the feasibility of making changes.<br><br>Instead, the question should be: assuming we could make any changes to the regulatory setup that we wanted, to what extent would it be worthwhile/value-adding to make changes in |
| Scope for added value through changes in Constraints | | |

| Metric Description | Scores Available | Commentary/rules of thumb |
| --- | --- | --- |
| | Zero (not applicable, not possible, not relevant) | incentives/constraints/technical standards to allow this innovation to achieve its full potential? |
| Scope for added value through changes in Technical Standards | | |
| Any evidence of on-going or upcoming regulatory 'work-in-progress' relevant to this technology group, as far as we are aware? | Yes – we have come across ongoing regulatory work<br><br>No – we have not come across any regulatory work | For example, (hypothetical) a review by the Civil Aviation Authority of the use of air space by drones. |
| Extent to which the existing regulatory landscape is sufficiently agile/reactive to be 'fit-for-purpose' | High - unlikely to see 'nasty surprises' in current regime. If regulation is 'loose', potential consequences are low.<br><br>Medium<br><br>Low - there are clear issues with the current approach, leading to potential for 'nasty surprises'. There may be insufficient constraints, regulation which | Scorers need to consider potential for harm in terms of both probability/likelihood and impact/consequences. Should also consider the possibility that the current regime is too tight to allow innovations to flourish. E.g. could regulation be loosened, without potential consequences? |

| Metric Description | Scores Available | Commentary/rules of thumb |
|---|---|---|
| | is not fit for purposes, and/or high consequences from potential issues. | |
| Degree of alignment with current Government Grand Challenges: AI in medical diagnosis and treatment | High – high degree of alignment<br><br>Medium<br><br>Low – some relevance, but marginal/indirect<br><br>Zero – not relevant | We would expect for most cases the score would be either High or Zero. |
| Degree of alignment with current Government Grand Challenges: Extending average life expectancy by 5 years and reducing inequality | | |
| Degree of alignment with current Government Grand Challenges: Clean growth and Net Zero | | |

| Metric Description | Scores Available | Commentary/rules of thumb |
|---|---|---|
| Degree of alignment with current Government Grand Challenges: Zero emissions vehicles by 2040 | | |
| Likelihood that economic impacts will result in a significant upward shift to established productivity trends | We believe it would be feasible to answer these questions, however not within the budget of this project. We therefore recommend that scorers answer these questions only if the information is readily available from the literature reviewed for other questions. In that case, the topics can be scored with the following categories: High/Medium/Low/Zero | |
| Likelihood that economic impacts will result in a significant upward shift to established job creation trends | | |
| Likelihood that economic impacts will result in a significant re-balancing of the economy away | Insufficient evidence was found that addresses these points robustly. We | |

| Metric Description | Scores Available | Commentary/rules of thumb |
| --- | --- | --- |
| from London and the South East | therefore suggest removal of these three metrics. | |
| Likelihood that economic impacts will result in a significant upward shift to established R&D/GVA trends | | |
| Likelihood that economic impacts will result in a significant upward shift to the ability to attract inward investment | | |
| Importance of Incentives in the current regulatory stance | High/Medium/Low/Zero | For example, tax relief, government R&D investment |
| Importance of Constraints in the current regulatory stance | | For example, safety rules and restrictions |

| Metric Description | Scores Available | Commentary/rules of thumb |
| --- | --- | --- |
| Importance of Technical Standards in the current regulatory stance | | For example, vehicle technical standards |
| Degree of uncertainty over impacts of current regulatory stance (if technology not yet to market) | We suggest removal of this metric. Scorers found they were essentially duplicating their answer to question 5. | |
| Degree of novelty of the innovation relative to existing regulatory experience | Regulatory exemplars are provided in the table below<br><br>H – requires radical re-write and 'uncharted territory'<br><br>M – mixed<br><br>L – requires minor tweaks only, and similar to previous regulatory changes. | Scorers should consider two aspects – firstly, the extent to which the current regulatory regime is fit for purpose, and therefore the level of 're-write' required. Secondly, the degree to which the regulatory re-write required is 'uncharted territory' – i.e. has not been encountered before, even in other domains. This will be provided by the exemplars. |
| Potential severity of any unintended regulatory inaction | High – potential for severe issues<br><br>Medium – uncertain risks and/or potential for moderate risks<br><br>Low – some risk (small) | |

| Metric Description | Scores Available | Commentary/rules of thumb |
|---|---|---|
| | Zero – no risk, from what we have seen (and given current situation) | |

**Table 8: Guidance for scoring the field 'Degree of novelty of the innovation relative to existing regulation'**

| Exemplar | Similar to existing technologies (yes/no)? | Alignment with existing regulatory stances | Comments | L | M | H | Uncharted regulatory territory (yes/no)? | Comments on scoring decision |
|---|---|---|---|---|---|---|---|---|
| Hobby & small commercial drones | No | Somewhat aligned | Whilst small civil drones are a novel development that travel in airspace that is subject to regulations & are operated from land that is also subject to regulations regarding uses | | X | | No | Regulatory responses to the novel technology and application area combination can be based on a combination of modified existing regulations with additional specialised components to fill gaps in regulation |
| Self-driving cars | No | Not aligned | There are a wide range of insurance, legal (accident culpability) and large-scale statistical data aspects that point to a novel regulatory challenge | | | X | No | Whilst regulatory responses overlap with existing vehicle standards and road use regulations (etc) the wide range and importance of regulatory connotations point to a radical re-write |

| Exemplar | Similar to existing technologies (yes/no)? | Alignment with existing regulatory stances | Comments | L | M | H | Uncharted regulatory territory (yes/no)? | Comments on scoring decision |
|---|---|---|---|---|---|---|---|---|
| Urban air quality caused by vehicle emissions | Yes | Well aligned | Whilst dangers to health were ‘hidden’ to a large extent until uncovered via health research and better air quality monitoring data the challenge can be addressed via existing regulatory stances | X | | | No | Existing air quality and vehicle emissions regulations can be readily adapted to address this challenge |
| (Hypothetical) Autonomous AI-driven robotic surgical machines requiring no human intervention to conduct surgical interventions once ‘tasked’ via diagnosis | No | Not aligned | Whilst AI and human operated surgical robots are familiar, the combination of autonomous AI-driven decisions and surgical robots poses major ethical issues. Complicated because (human) surgeons are not currently regulated regarding innovation testing (in many circumstances they can try whatever they want in the operating theatre) | | | X | Yes | This enters uncharted regulatory territory because surgeons (whist legally culpable for clinical errors) are not regulated regarding testing innovative mechanisms outside of devices requiring rigorous clinical trials. Consequently, substituting a human with an AI decision-maker enters uncharted territory in |

| Exemplar | Similar to existing technologies (yes/no)? | Alignment with existing regulatory stances | Comments | L | M | H | Uncharted regulatory territory (yes/no)? | Comments on scoring decision |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | this life-or-death context. |

# Methodology for calculating ‘top 44 Groupings’

Following the first stage of scoring, an aggregation process was carried out to generate a prioritised list of 44 groupings for further scoring. This aggregation involved the following processes:

## Economic Benefits

Mid-points of the estimated global market size band were calculated. Straight line interpolation was used to estimate market size in the intervening years between the three points in time. Discounting was applied at a rate of 3.5% as recommended in the Green Book.[13] Benefits were then summed over the period 2025 to 2050 and multiplied by the estimated percentage share the UK could capture. An uncertainty adjustment was made to account for TRL, with low TRL innovations being deprioritised compared with high TRL innovations.[14] Finally, the values were converted to a score out of five based on their placement in the overall set of 151 scores. Those scoring 80-100% of the maximum value in the set were assigned a score of five, those scoring 60-80% a score of four, and so on.

## Social Benefits

Social Benefits were calculated using the four estimates of UK non-market benefits (health & wellbeing, environment, decarbonisation and human security & resilience). Mid-points of the ranges were applied, and the four benefits summed. The TRL multiplier, as described above, was then applied. The categories were designed to be mutually exclusive so that this summing would not generate spurious results through double counting. A transformation into a score out of five was applied, as above.

## Regulatory Dimension

Feasibility was calculated using the three high-priority regulatory metrics – scope for added value through regulatory change in incentives, constraints and technical standards. In this case, additional emphasis was placed on those innovations scoring ‘High’, and therefore the translation into numerical values was on the basis: High = 5, Medium = 3, Low = 1, Zero = 0. After transforming into numerical values, the three scores were averaged, to give a final score out of five.

## Aggregation

Having obtained three scores all scored out of five, an average was taken, to give a final, single, score out of five. This score was then used to sort the combinations in priority order. The highest scoring 44 combinations were taken forward to the next stage of scoring.

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[13] HMT. "The Green Book. Appraisal and Evaluation in Central Government Treasury Guidance. Her Majesty's Treasury." (2007).

[14] The following multipliers were used: TRL scores 1-3 were given a multiplier of 0.17, TRL scores 4-6 were given a multiplier of 0.5, and TRL scores of 7-9 were given a multiplier of 0.83.

The process described above was undertaken as a relatively straightforward, ‘neutral’ first attempt at ranking the application/technology combinations. Clearly, the way this process was undertaken (the transformation into numerical values, the relative weightings applied to different metrics, and the use of uncertainty adjustments) all affect the final prioritisation of innovations. Nonetheless, this was considered a suitable ‘first attempt’ to identify innovations worthy of taking forward to the second stage of scoring.

## Summary of the RHC weightings Workshop

Below is a brief summary of the points raised by participants in discussion at the RHC weightings workshop:

On the overall ‘balance’:

- Some felt that equal weighting between economic, social and regulatory domains would be easiest to justify, and strong evidence would be needed to move away from this.
- An alternative view was that, as a regulatory body, the RHC should focus more heavily on the regulatory domain, since this enables it to capture areas where it can be of greatest use. The suggestion was to apply a weighting of 50% to the regulatory domain (The RHC’s primary concern), and 50% to impact (social and economic value).
- One participant suggested that input data quality should be a factor when considering weightings. Economic forecasts may not be robust, and so this may be an argument for reducing the weighting on the economic variable.
- It was suggested that, in light of COVID-19 and its effects on the global economy, there may be requirement to reorient some of the weighting to focus on economic recovery.

On the Economic Domain:

- Productivity and job creation metrics are of interest to participants. It would be worth exploring further whether these can be included in the scoring.
- There may be other data sources of use/interest which could be explored. For example, data on patents, research publications and Venture Capital funding could be used as proxies for economic value.

On the Social Domain:

- There was concern about potential overlap between environmental and de-carbonisation benefits. There was also significant discussion around, and some disagreement, around whether including two separate environmental measures might detract from the welfare/safety domains.
- There was discussion of the value of including metrics to cover social cohesion and economic rebalancing in future work.

On the Regulatory Domain:

- Participants discussed the likelihood of overlap between the regulatory metrics, and therefore decided that it would be unnecessary to include all four. ‘Scope for added value’ and ‘novelty of regulation required’ were the most useful, given the RHC’s role.
- Additional questions of interest were around Free Trade Agreements and intersection points (between sectors or regulatory regimes) which can often be areas where regulation is found to be lacking. Future work could focus on identifying these issues and how they can be reflected in the scoring.

On the subject of Uncertainty and Discounting:

- Participants raised that while Government best practice is normally to apply discounting, it may not be appropriate to apply discounting for this exercise. The RHC may wish to focus on innovations with far future benefits rather than those which will bring nearer term benefits.
- One participant explained that in an exercise such as this, much is unknown and the quality of forward-looking data is often poor. Therefore, it may not be appropriate to penalise groupings for which information quality is poor.
- One alternative option, however, would be to penalise groupings where TRL is high but information quality is low. These should be considered ‘risky options’. Whereas for low TRL combinations, low quality information is to be expected.

This publication is available from: https://www.gov.uk/government/groups/regulatory-horizons-council-rhc