Data enhancement and analysis of the REF 2021 Impact Case Studies

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Preface

The Research Excellence Framework (REF) is a process of expert review to assess the excellence of academic research conducted at universities in the United Kingdom (UK), undertaken by the four UK higher education funding bodies. Research England and UK Research and Innovation (UKRI) commissioned RAND Europe, together with Electric Data Solutions and Different Angles, to conduct a study to understand the research impact of the UK higher education sector as represented by the REF 2021 Impact Case Studies (ICSs). The study aimed to address the following two objectives:

- Collect and enhance 2021 REF ICS data to provide the REF team with a structured dataset supporting further development of the REF 2021 online database[1]; and
- Quantitatively and qualitatively analyse the ICSs to examine the broader societal impacts of research at Higher Education Institutions (HEIs).

The study provides an in-depth examination of UK higher education Impact Case Studies using a mixed-methods research approach that involved a range of quantitative and qualitative analyses such as topic modelling, geotagging, text searches, bibliometric analysis, infographics and deep dives. This report is intended for a range of stakeholders including those interested in the REF and research assessment, higher education research as well as those interested in the impact of HEIs on society.

We would like to thank the project team at Research England and UKRI for their valuable feedback and support throughout this project. In particular we would like to thank Duncan Shermer, Julianne Pigott, Steven Hill, Catriona Firth, Marie-Helene Nienaltowski, and Jennifer Moloney. We would also like to thank our quality assurance reviewers at RAND Europe, Kate Morley and Joe Francombe, for their critical review and feedback on the report. We would like to thank Clarivate for providing access to bibliometric information from the Web of Science and bespoke institution-to-sector mappings which supported analysis of the underpinning research provided in this report In addition, we are grateful to Soapbox for their work in designing some of the data visualisations, and Overton for providing access to their database. Finally, we would like to thank Jess Plumridge for helping to lay out the report and Clare Watkinson for copy-editing.

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1 Research Excellence Framework (2023a).

Executive summary

The Research Excellence Framework (REF)[2] is a system for assessing the quality of research undertaken in UK Higher Education Institutions (HEIs) and a key aspect of the UK research landscape. Institutions make submissions that are assessed through expert review by subpanels for the 34 subject-based Units of Assessment (UoAs) under the guidance of four main panels: Panel A (Medicine, health and life sciences), Panel B (Physical sciences, engineering and mathematics), Panel C (Social sciences) and Panel D (Arts and humanities). This assessment is based on the quality of research outputs, the impact of research beyond academia, and the environment supporting research. REF defines impact as 'the effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia'.[3] REF 2014 and REF 2021 used Impact Case Studies (ICSs) to help assess research impact beyond academia. ICSs are short five-page documents detailing a project's impact and underpinning research.

The corpus of over 6,000 REF 2021 ICSs provides a rich resource for analysis and showcases the research undertaken at UK HEIs. This study aimed to analyse these ICSs to investigate their research impact's nature and beneficiaries, underpinning research and relationship to the UK government's priority policy areas. Where appropriate, the study also analyses the differences between REF ICSs submitted in 2021 vs. 2014.

We used a diverse methodological approach building on a previous analysis of the 2014 REF ICSs.[4] The work comprises a mix of quantitative and qualitative methods, including topic modelling, text searches, analysis of ICS-associated metadata, bibliometric analysis and qualitative analysis of ICS content. We also conducted several deep dives examining ICSs relating to three policy priorities: COVID-19, net zero and Place.[5] Below, we outline our key findings from the analysis.

UK HEIs have had a significant and diverse societal impact

One key observation when reading and reviewing a sample of ICSs is that research at UK HEIs has significantly impacted society and the economy in the UK and globally. This study's analyses reinforce this conclusion. HEIs' research impacts were diverse, spanning 79 unique impact topics ranging from 'cancer diagnostics and therapy' and 'intelligence and cyber security' to 'pollution and air quality' and 'language and linguistics'.

2 Research Excellence Framework (2023d).

3 Research Excellence Framework (2022).

4 King's College London and Digital Science (2015).

5 This refers to the broad political priority area around regional and geographical inequality, also referred to as 'levelling up'.

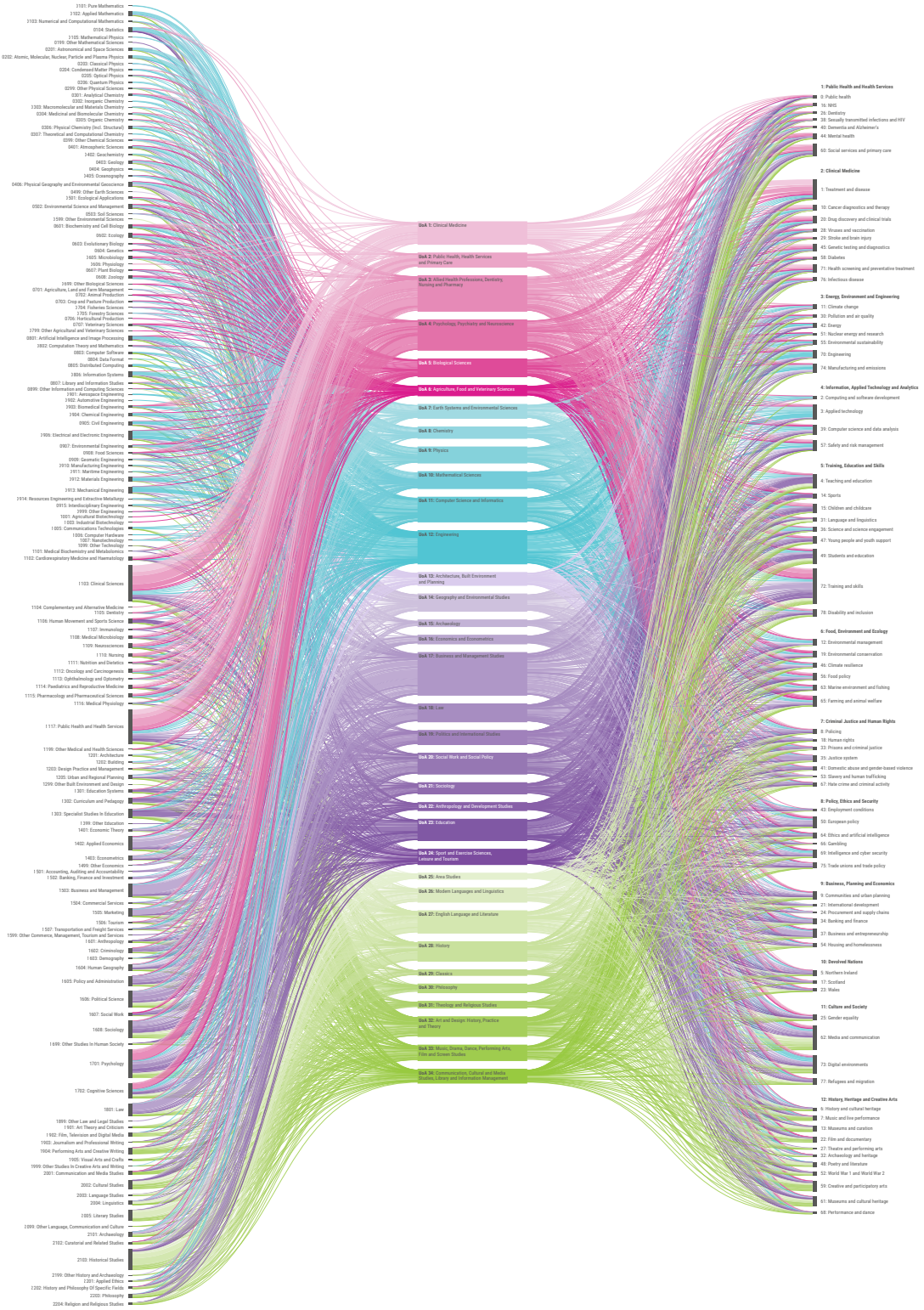
Impact pathways are complex, diverse and unique

We explored pathways from research to impact by linking the underpinning research in the ICSs with the corresponding impact topics and UoAs. The detailed alluvial diagram in Figure 1 illustrates the results, showing that impact arises from various disciplines; ICSs across all four main REF Panels (A–D) contributed to the impact topics. Examining the underpinning research disciplines showed that 72% of ICSs were based on publications with two or more Fields of Research (FoRs). Mapping out the different impact routes shows that no single pathway exists. Given the diversity of impact pathways, developing a balanced and comprehensive set of impact metrics to capture this range of activities would be challenging.

Impact was global, national and local

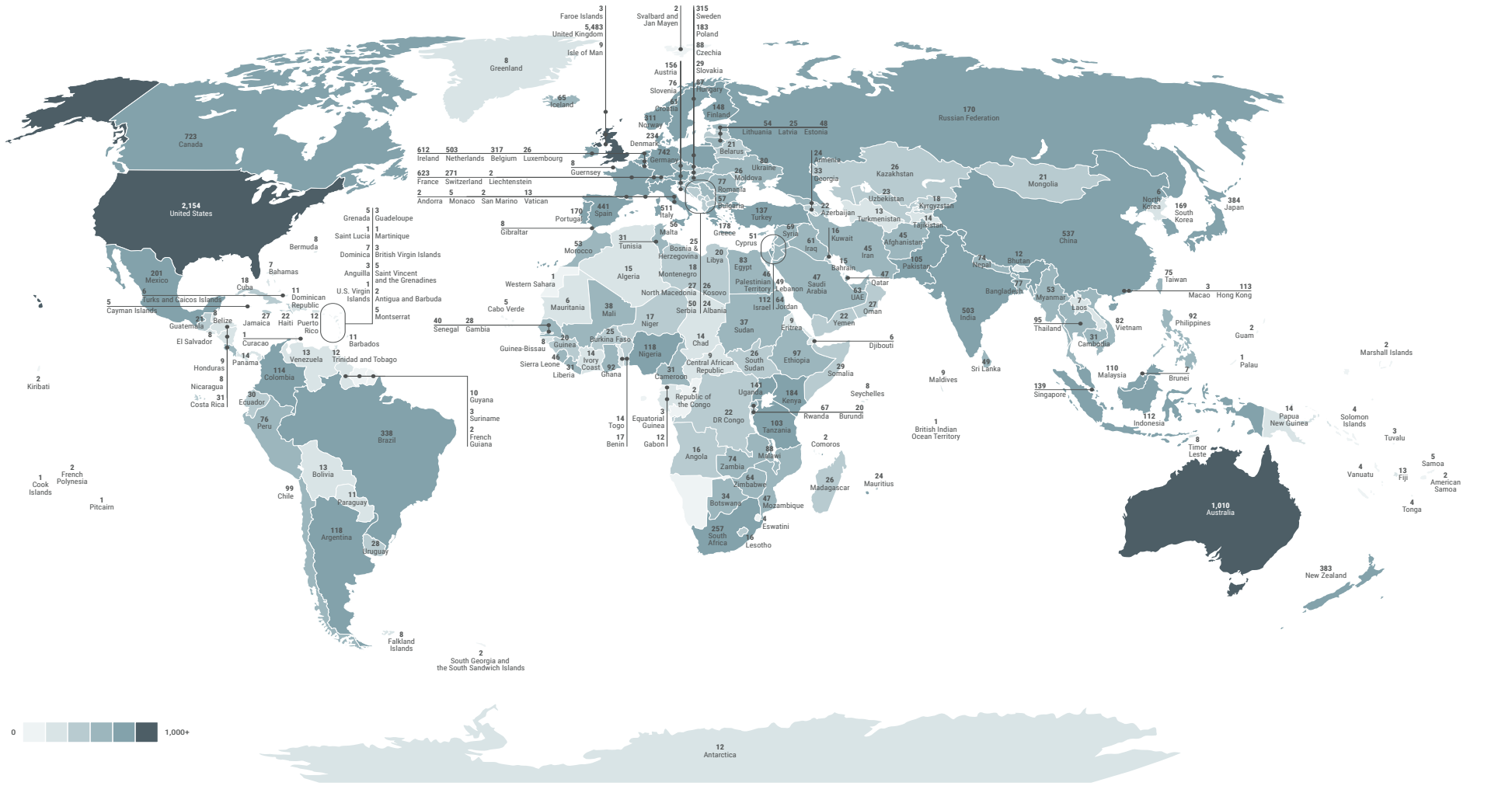
Research at UK HEIs has had an impact globally, with almost every country benefitting from the research (Figure 2). Moreover, exploring the 'flow' of impact between UK regions showed that impact was often 'exported' from the region where the research was conducted to other UK areas. The South East of England was the biggest 'exporter', distributing 69% of its impact to other regions. This finding is particularly relevant for the 'levelling up' discussion, where many metrics typically used to explore research and innovation (R&I) focus on input measures (e.g. the research investment location). As this impact analysis shows, examining which institutions receive funding provides a partial picture of the role R&I plays across UK regions.

Figure 1. Alluvial diagram illustrating pathways to impact from underpinning research to resulting impact



Note: The alluvial diagram above links the underpinning research (extreme left, classified by FoR) with the resulting impacts (extreme right) by panel and UoA (middle). The colours represent the four main Panels: Panel A (pink), Panel B (blue), Panel C (purple), and Panel D (green). Readers can zoom into specific sections of this figure to read the text. A high-resolution file of this image can also be downloaded alongside the report.

Figure 2. The global impact of ICSs



ICSs offer data for analysing research impact characteristics

Analysing the ICSs provided useful information on the research impact's broader characteristics. For example, the average time lag from the start of research to the end of impact was approximately ten years. However, research in Panels A and B took an average of three years longer than in Panels C and D. ICSs also provided many valuable examples of returns on investment (ROI) from research; overall, 2,146 ICSs (approximately 34%) mentioned currency or ROI within the impact section, although the varied expressions of it made it difficult to aggregate the results systematically and meaningfully.

Research benefited many different groups

We identified evidence of 59 different beneficiary types across the ICSs. The top five beneficiary groups identified comprised 'governments', 'communities', 'policymakers', 'practitioners' and 'industry'. We also identified several specific beneficiary groups, including 'nurses' and 'farmers', highlighting the diversity of beneficiary groups within the ICSs.

Analysis revealed differing interdisciplinarity and collaboration levels across ICSs

As highlighted previously, research impacts draw on insights from multiple FoRs. However, we also compared across ICSs to understand the portfolio's interdisciplinary or collaborative levels by analysing the underpinning research's characteristics, revealing differences in the concentration of Interdisciplinary Research (IDR) between impact topics. Impact topics associated with societal challenges were more likely to have high IDR levels, whereas those within the 'clinical medicine' cluster were likelier to have lower IDR levels.

ICSs were underpinned by highly cited research

Most ICSs underpinning research performed better than the global average citation counts for the relevant FoR, with the highest citation counts associated with research from Panel A. Across all panels, the percentage of highly cited papers was significantly higher than the global average of 1%. Panel A was the highest at 9.7%.

There was significant consistency between REF 2021 and REF 2014

Analysis of the 2021 ICSs shows considerable consistency with the ICSs from REF 2014. Our findings are broadly similar to those in 2014, suggesting that a range of disciplines support impact along numerous unique pathways. UK HEIs' global impact in 2021 was also consistent with that in 2014, evidencing a similarly rich and diverse impact portfolio.

Some differences from the 2014 analyses stemmed from the approach taken. For example, as expected, the topic model was different and should not be interpreted as reflecting a decline or increase in specific impact types. Consequently, a like-for-like detailed comparison between the two is not appropriate. However, the high-level picture remains consistent: impact is a complex, bespoke activity.

We also looked at how REF 2021 rule changes had affected the nature of ICSs. Generally, our results show that HEIs did not significantly utilise these rule changes. For example, very few HEIs took the opportunity to submit case studies focusing on impacts on students and teaching.

It is interesting to see the remarkable consistency between the findings from our analysis of the REF 2021 ICSs and the analysis of the REF 2014 ICSs. This consistency reinforces the strength of these conclusions, providing a unique insight into the complexity, diversity and importance of UK HEIs' impact on society and the economy in the UK and beyond.

We also explored the contribution of ICSs underpinned by UKRI funding[6] as a separate analysis for UKRI. UKRI funding significantly contributed to the research underpinning the REF ICSs; of 6,361 ICSs, 3,032 (46%) were underpinned by UKRI funding. These case studies helped address priority policies, including COVID-19, net zero and Place and benefited multiple beneficiary groups, including governments, communities and policymakers. Research funded by multiple UKRI councils was more likely to be interdisciplinary and collaborative, and case studies supported by multiple UKRI research councils' funding reported a diverse range of impacts, including contributions to environmental sustainability, energy and applied technology.

Photo by Harry Grout on Unsplash

6 Beyond Quality-related Research (QR) funding.

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Abbreviations

AAC	Augmentative and Alternative Communication
ACT	Adoptive Cell Therapy
AHRC	Arts and Humanities Research Council
AI	Artificial Intelligence
ANZSRC	Australian and New Zealand Standard Research Classification
ATTC	Advanced Therapy Treatment Centres
BA	Bachelor of Arts
BBC	British Broadcasting Corporation
BBSRC	Biotechnology and Biological Sciences Research Council
BEIS	Department for Business, Energy and Industrial Strategy
BMW	Bayerische Motoren Werke
BRC	Manchester Biomedical Research Centre
CCC	Climate Change Committee
CCLW	Climate Change Laws of the World
CEP	Strathclyde's Centre for Energy Policy
CLAHRC	Collaboration for Leadership in Applied Health Research and Care
CMOS	Complementary metal-oxide-semiconductor
CNCI	Clarivate as Category Normalised Citation Impact
COP26	2021 United Nations Climate Change Conference
CPAP	Continuous Positive Airway Pressure
CPU	The Complexity Planning and Urbanism Lab at Manchester Metropolitan University
CSSC	The Centre for the Study of Sexuality and Culture at the University of Manchester
DECC	Department of Energy and Climate Change
DSR	Demand Side Response
EBF	Exclusive Breastfeeding
EBRI	Aston University Energy and Bioproducts Research Institute
EDF	The European Defence Fund
EHL	Salford's Energy House Laboratories
ENT	Ear, Nose and Throat medicine
EPSRC	Engineering and Physical Sciences Research Council
ERA	Excellence in Research for Australia
ESRC	Economic and Social Research Council
FDA	Food and Drug Administration (US)
FoR	Field of Research

FRAP	Future Research Assessment Programme
GCRF	Global Challenges Research Fund
GGRSG	The Leicester Greenhouse Gas Remote Sensing Group
GHG	Greenhouse Gas
GM	Greater Manchester
GMCA	Greater Manchester Combined Authority
GMYJUP	Greater Manchester Youth Justice University Partnership
GOSAT	Greenhouse gases Observing SATellite
GP	General Practice (health service)
GRI	London School of Economics and Political Science's Grantham Research Institute
HCP	Highly Cited Papers
HE	Higher Education
HEFCE	Higher Education Funding Council for England
HEFCW	Higher Education Funding Council for Wales
HEI	Higher Education Institution
HM Treasury	His Majesty's Treasury
ICS	Impact Case Study
IDR	Interdisciplinary Research
IGO	Intergovernmental Organisation
iMATCH	Innovate Manchester Advanced Therapy Centre Hub
IPCC	Intergovernmental Panel on Climate Change
IPM	Institute of Place Management at Manchester Metropolitan University
IQR	Interquartile range
ISFET	Ion-Sensitive Field-Effect Transistor-based microsystems
ITT	Invitation to Tender
KWIC	Keyword-in-Context approach
LGBTQ	Lesbian, Gay, Bisexual, Transgender, Queer or Questioning, Intersex, Asexual, and more
MANDRAKE	MANchester DRug Analysis and Knowledge Exchange
MCCA	Manchester Climate Change Agency
MCGS	Manchester Centre for Gothic Studies
MCYS	Manchester Centre for Youth Studies
MMU	Manchester Metropolitan University
MRC	Medical Research Council
MSW	Multi-Story Water
NASA	The National Aeronautics and Space Administration
NCCPE	National Coordinating Centre for Public Engagement
NDC	National Decommissioning Centre
NERC	Natural Environment Research Council
NGO	Non-governmental Organisation

NICE	National Institute for Health and Care Excellence
NIHR	National Institute for Health and Care Research
NMF	Nonnegative Matrix Factorization
NPS	New Psychoactive Substances
NUTS	Nomenclature of Territorial Units for Statistics
OFGEM	The Office of Gas and Electricity Markets
ORCID	Open Researcher and Contributor Identifier
PAR	Participatory Action Research
PEM	Polymer Electrolyte Membrane
PHE	Public Health England
POC	Point-Of-Care
PPE	Personal Protective Equipment
PV	Photovoltaic
PYP	Participatory Youth Practice
QR	Quality-related
R&I	Research and Innovation
REF	Research Excellence Framework
REG	Research Excellence Grant
REMAP-CAP	A Randomised, Embedded, Multi-factorial, Adaptive Platform Trial for Community-Acquired Pneumonia
RESIN	Climate-Resilient Cities and Infrastructures
ROI	Return On Investment
RS-IDR	Rao-Sterling metric
SAGE	UK Government's Scientific Advisory Group on Emergencies
SME	Small-to-Medium-sized Enterprise
SSS	Sexuality Summer School by The Centre for the Study of Sexuality and Culture
STFC	Science and Technology Facilities Council
SVEC	Oxford Brookes University's Sustainable Vehicle Engineering Centre
TF-IDF	Term Frequency - Inverse Document Frequency
T-MACS	Troponin-only Manchester Acute Coronary Syndromes
TRAC	Transparent Approach to Costing
UCL	University College London
UK	United Kingdom
UKRI	UK Research and Innovation
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UoA	Unit of Assessment
USW	University of South Wales
WHO	World Health Organization

Chapter 1

Introduction

1.1. Context

The Research Excellence Framework (REF)[7] is a system for assessing the quality of research undertaken in UK Higher Education Institutions (HEIs) and is a key aspect of the UK research landscape. First carried out in 2014, the REF replaced the Research Assessment Exercise and is managed by Research England on behalf of the four UK higher education funding bodies: Research England, the Scottish Funding Council (SFC), the Higher Education Funding Council for Wales (HEFCW), and the Department for the Economy, Northern Ireland (DfE). The REF aims to (i) provide accountability for public investment in research by demonstrating evidence-based benefit, (ii) provide benchmarking information for the HE sector and public information, and (iii) inform the selective allocation of research funding.[8] The REF is conducted by a process of expert review by subpanels for each of the 34 subject-based Units of Assessment (UoAs), guided by four main panels of senior UK and international academics and research users.[9] The REF assesses three elements for each institutional submission: output quality, research impact beyond academia, and the environment supporting research.

The REF defines impact as 'the effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia'.[10] As part of the REF 2014 and REF 2021, HEIs were required to submit Impact Case Studies (hereafter abbreviated as ICSs) demonstrating their research's impacts beyond academia. ICSs are short five-page documents detailing the research's impact and underpinning research. Box 1 (below) summarises the ICS submission structure. Each REF submission must include at least two ICSs.

The corpus of 6,361 published REF 2021 ICSs provides a rich analysis resource for showcasing the impact of research undertaken at UK HEIs. A previous comprehensive analysis of the REF 2014 ICSs conducted by members of our study team reported that the societal impact of research at UK HEIs was 'considerable, diverse, and fascinating' with both UK and global reach and underpinned by multidisciplinary research.[11] Participants in REF 2014 also highlighted the benefits of the increased focus on assessing impact, including increasing their ability to identify and understand research impact, stimulating broader strategic thinking and increasing HEIs' recognition of impact.[12]

In REF 2021, 157 UK higher education institutions made submissions[13] across the 34 UoAs. High-level analysis of the results showed that 50% of the impact component was considered 'outstanding', with a further 38% deemed 'considerable'.[14] The ICSs reflect the diversity and reach of research conducted at UK HEIs.

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7 Research Excellence Framework (2023d).

8 Research Excellence Framework (2023b).

9 More information on the UoAs and how they are clustered into the four panels can be found in Annex C.

10 Research Excellence Framework (2022).

11 King's College London and Digital Science (2015).

12 Manville et al. (2015).

13 Technically, only 155 institutions made direct submissions: two were included as joint submissions by other HEIs.

14 Research Excellence Framework (2023c).

1.2. Purpose of the report

Research England commissioned this report on behalf of the four higher education funding bodies and UK Research and Innovation (UKRI) as part of a study on the REF 2021 ICSs. The study aims to support the funding bodies and UKRI and the higher education sector more generally in better understanding the impact of research at UK HEIs. The study's two main objectives are to:

- Collect and enhance 2021 REF ICS data to provide the REF team with a structured dataset supporting further development of the REF 2021 online database[15]; and
- Quantitatively and qualitatively analyse the ICSs to examine the broader societal impacts of research at HEIs.

We achieved the first objective by delivering an enhanced dataset to Research England and UKRI for public availability via the ICS repository.[16] This report aims to address the second objective. Annex B lists and summarises the questions in full. However, we used these questions as a guide, deviating from them where appropriate. UKRI also asked us to undertake quantitative and qualitative analysis of the ICSs to examine the UKRI-specific elements of the Research and Innovation (R&I) system. Annex A sets out this work. We have conducted all analyses in this report exclusively on the 2021 ICS dataset, although we compare it to the 2014 analysis and results where appropriate to draw out key findings.

1.3. Overview of method

This study's analysis focuses on the information provided in ICSs submitted to REF 2021. Box 1 shows the standard format for each ICS. We also drew upon the metadata supplied alongside each ICS (not used in the REF assessment), which included:

- Name(s) of funder(s)
- Global Research Identifier of funder(s): https://www.grid.ac/
- Name(s) of funding programme(s)
- Grant number(s)
- Grant amount (in GBP)
- Each named researcher's Open Researcher and Contributor ID (ORCID) where held
- name(s) of formal partner(s)
- Country/countries where the impact occurred.

This information and any additional datasets linked to the case studies (e.g. via publications referenced in the 'references to the research' section) formed the basis for our analysis.

We developed a bespoke, mixed-methods approach comprising diverse analytical tools for this study. Box 2 provides an overview of the analytical approaches used.

15 Research Excellence Framework (2023a).

16 Research Excellence Framework (2023a).

Box 1. REF 2021 ICS template

The template for ICS submissions is as follows. This information forms the basis of our analysis.

<table>
<tr><td colspan="3">Institution:</td></tr>
<tr><td colspan="3">Unit of Assessment:</td></tr>
<tr><td colspan="3">Title of case study:</td></tr>
<tr><td colspan="3">Period when the underpinning research was undertaken:</td></tr>
<tr><td colspan="3">Details of staff conducting the underpinning research from the submitting unit:</td></tr>
<tr><td>Name(s):</td><td>Role(s) (e.g. job title):</td><td>Period(s) employed by submitting Higher Education Institution (HEI):</td></tr>
<tr><td colspan="3">Period when the claimed impact occurred:</td></tr>
<tr><td colspan="3">Is this case study continued from a case study submitted in 2014? Y/N</td></tr>
<tr><td colspan="3">1. Summary of the impact (indicative maximum 100 words)</td></tr>
<tr><td colspan="3">2. Underpinning research (indicative maximum 500 words)</td></tr>
<tr><td colspan="3">3. References to the research (indicative maximum of six references)</td></tr>
<tr><td colspan="3">4. Details of the impact (indicative maximum 750 words)</td></tr>
<tr><td colspan="3">5. Sources to corroborate the impact (indicative maximum of 10 references)</td></tr>
</table>

Box 2. Overview of analytical approaches

Topic modelling
Topic modelling is a natural language processing technique that determines how researchers can use specific clusters of related words (topics) to categorise underlying data. We used this approach to generate 79 impact topics for other aspects of our analysis.

Text searches
We used text searches to identify relevant ICSs relating to matching sets of keywords or phrases. This method was particularly relevant for our deep dives into areas of policy interest, such as net zero or COVID-19.

Metadata
We linked the ICSs with their associated submission information, scholarly data, grey literature and custom fields to enhance the data and support further analysis. This included bibliometric analysis and Overton data, as listed below.

Bibliometric analysis
We used data from OpenAlex and Clarivate to analyse the publications listed in Section 3 of the ICSs, exploring aspects of collaboration modes, interdisciplinarity and complimentary classification systems, e.g. Fields of Research (FoRs).

Overton
We linked ICSs to Overton, the grey literature database. Overton indexes more than 30,000 international sources and links more than five million documents to scholarly literature via a network of 14 million citations.

1.4. Caveats and limitations

We encountered several caveats during this study that should be considered when interpreting the findings, as outlined below.

Comparison to the 2014 analysis: It is helpful to compare this analysis with the 2014 ICS analysis to understand what (if anything) has changed and test the findings' robustness. We draw several such comparisons throughout the report, highlighting areas of similarity and difference. However, making like-for-like comparisons between the two analyses is not possible or appropriate in certain aspects, particularly regarding topic modelling. As outlined above and detailed below, topic modelling is inherently data-driven, meaning that the topic model for this set of ICSs will naturally differ from that produced for the 2014 data. For example, the most significant topic in the 2014 ICSs was 'Informing Government Policy'. Although there does not appear to be a comparable topic in the 2021 ICS data, this does not necessarily mean that the impact on policy has decreased. Instead, the 2021 ICSs' content falls into a different set of groupings, with impacts on policy clustered together with other types of impacts in this particular topic model. Thus, the changes in the topic model should not be over-interpreted as differences in specific impact types' prevalence between the two ICS sets. Secondly, this analysis uses new and improved approaches based on the latest available tools and techniques (e.g. more sophisticated geotagging), enabling an analysis of 'hyperlocal' impacts not possible in the 2014 analysis. Therefore, comparisons of the two studies' findings should be interpreted cautiously (highlighted where appropriate in the report).

REF ICSs are only a subset of research impact: REF ICSs provide a detailed and diverse illustration of the impacts realised through research conducted at UK HEIs. However, they do not represent the entirety of UK HEIs' research impacts. Instead, they are only a sub-sample selected with the REF eligibility and assessment criteria in mind. Therefore, we urge caution in generalising these findings more broadly.

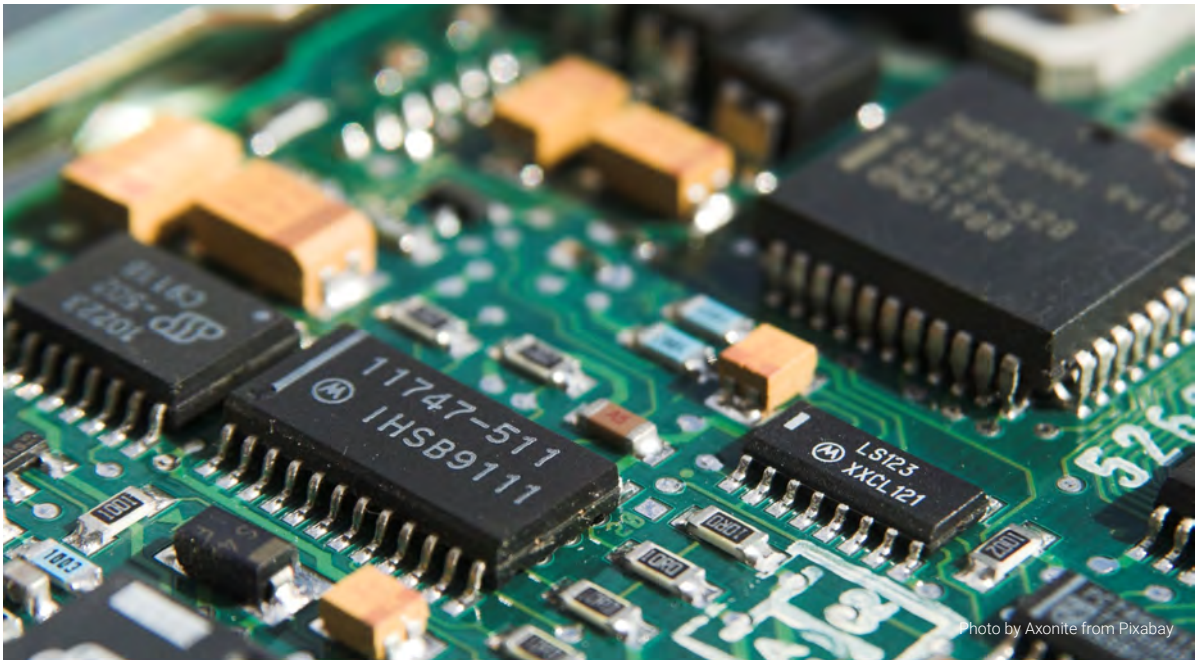


Photo by Axonite from Pixabay

Limitations of underlying data sets: Where we draw on broader scientometric datasets (including Overton, Open Alex and Clarivate) in some aspects of this analysis, the analyses are subject to the underlying datasets' limitations. Bibliometric database coverage is better for some disciplinary areas than others. For example, bibliometric databases do not comprehensively cover Panel D disciplines because non-journal outputs (e.g. monographs) are more common. Therefore, where relevant, we have highlighted caveats regarding these datasets' quality and completeness, which may have implications for the analysis.

Size of the ICS dataset: With over 6,000 ICSs submitted to REF 2021, it was impossible to read and hand-code every study. Therefore, we have relied on techniques such as topic modelling and keyword searches to examine the case studies at the portfolio level, supplemented by a full qualitative review of around 267 ICSs via deep dives. This approach means we may have missed some ICSs that might have been relevant to some of this report's analysis and observations. Although we aimed to illustrate this dataset's richness, there inevitably remain aspects we have not included and further analyses could offer new insights into areas not covered.

Subjectivity: Some aspects of this analysis are inevitably subjective. For example, although we selected topic labels based on a review of the keywords and ICS content associated with each topic, we could have chosen other labels. Similarly, we identified key themes for the deep dives, illustrated with example ICSs, whose focus and emphasis were subject to the study team's judgement. While we chose our analyses and metrics to best address the study questions, we could have used numerous alternatives depending on the questions of interest. We hope others will take the opportunity to build on this work and analyse the ICS data in novel ways.

Chapter 2

The nature and beneficiaries of research impact

Box 3. Key findings

The ICSs demonstrated significant and diverse societal impacts. We identified 79 unique impact topics ranging from 'cancer diagnostics and therapy' and 'intelligence and cyber security' to 'history and cultural heritage'.

Our examination of impact pathways showed that impact depended on various disciplines, with ICSs spanning the four main panels (A–D). Mapping out the different routes to impact demonstrated that no single pathway exists. Instead, the impact pathways were complex, diverse and unique.

Our review of ICSs highlighted that UK HEIs had impacts worldwide, with almost every country benefiting from UK research. Our exploration of the 'flow' between UK regions showed that impact was often 'exported' from the region where the research was conducted to other UK areas.

Our examination showed that research benefited many groups, including governments, communities and industry.

The REF ICSs provide a unique picture of the range and nature of the benefits from research conducted at UK HEIs. We identified 132,777 unique words in the 'Details of the impact' section (Section 4) across the 6,361 published ICSs.[17,18] The word cloud in Figure 3 includes the top 600 words mentioned more than 400 times, illustrating the range of issues and themes in these ICSs. Investigating them in more detail offered interesting insights into what impact looked like and how it occurred in different contexts.

This chapter explores the nature and beneficiaries of research impact in more detail, including the range and nature of impact types described in ICSs, the pathways they occur through, their geographic distribution, the time lags involved (i.e. how long they take to happen), how far we can provide a quantitative estimate of the returns on investment (ROI) and the range and nature of the impacts' beneficiaries.

2.1.1. Impact types described in the REF ICSs

We used a topic modelling approach to explore the impact types described in the 2021 REF ICSs. Topic modelling is a language processing technique applied to document sets to understand the different combinations of words or phrases (topics) present. Because it is data-driven, results are derived from the data itself and thus not dependent on subjective notions of structure or conceptual categorisations of impact. We conducted the topic modelling based on the text provided in Section 4 of the ICS ('Details of the impact'), meaning the analysis focused on the impact rather than other aspects of the case study.

17 Note that this is not the full portfolio of submitted ICSs, as some were not published on the request of the HEI in line with REF guidance.

18 Excluding 'stop words' such as 'a' or 'the' from the data.

Figure 3. A word cloud of the most frequently used words in Section 4 of the ICSs ('Details of impact')

Annex E provides more details on the topic modelling approach.

Based on this empirically-driven topic modelling approach, we identified 79 impact 'topics', as summarised in Table 1. Each case study can contribute to multiple topics. We also examined how these topics were connected, as shown in Figure 4: topics are numbered according to Table 1, and each 'dot' represents an ICS. The weight allocated to each of the 79 topics determines each dot's position. ICSs that appear close together shared similar topic profiles, i.e. most highly weighted topics. Diffuse clusters show more significant variation in topic weight profiles. The colours indicate 12 cognate 'clusters', i.e. groupings of closely related topics, as listed in Table 2. Interestingly, the topics provided quite different content groupings. For example, some described broad areas such as 'public health', while others were more specific, e.g. 'World War 1 and World War 2'. Moreover, some were grouped around geographies (e.g. Wales) or entities (e.g. the NHS) rather than thematic impact types. Clusters positioned more closely to one another – e.g. 'energy and environment' (purple) and 'food, environment & ecology' (dark blue) – reflect their close alignment of topics .

The three topics within the 'devolved nations' cluster (Scotland, Wales and Northern Ireland) were somewhat different because they did not target a traditional impact area like the others. These topics were likely formed due to the frequent use of location names within the text. Their clustered position in the centre of Figure 4 demonstrates that the impacts outlined in those specific ICSs were not exclusive to one impact area but likely related to a range of health, environmental and social impacts. As a result, the topics and resulting clusters went beyond typical discipline areas, covering multivarious impacts relating to health, society and the environment.

Table 1. The 79 impact topics

Topic no.	Label	Topic no.	Label	Topic no.	Label
0	Public health	27	Theatre and performing arts	54	Housing and homelessness
1	Treatment and disease	28	Viruses and vaccination	55	Environmental sustainability
2	Computing and software development	29	Stroke and brain injury	56	Food policy
3	Applied technology	30	Pollution and air quality	57	Safety and risk management
4	Teaching and education	31	Language and linguistics	58	Diabetes
5	Northern Ireland	32	Archaeology and heritage	59	Creative and participatory arts
6	History and cultural heritage	33	Prisons and criminal justice	60	Social services and primary care
7	Music and live performance	34	Banking and finance	61	Museums and cultural heritage
8	Policing	35	Justice system	62	Media and communication
9	Communities and urban planning	36	Science and science engagement	63	Marine environment and fishing
10	Cancer diagnostics and therapy	37	Business and entrepreneurship	64	Ethics and artificial intelligence
11	Climate change	38	Sexually transmitted infections and HIV	65	Farming and animal welfare
12	Environmental management	39	Computer science and data analysis	66	Gambling
13	Museums and curation	40	Dementia and Alzheimer's	67	Hate crime and criminal activity
14	Sports	41	Domestic abuse and gender-based violence	68	Performance and dance
15	Children and childcare	42	Energy	69	Intelligence and cyber security
16	NHS	43	Employment conditions	70	Engineering
17	Scotland	44	Mental health	71	Health screening and preventative treatment
18	Human rights	45	Genetic testing and diagnostics	72	Training and skills
19	Environmental conservation	46	Climate resilience	73	Digital environments
20	Drug discovery and clinical trials	47	Young people and youth support	74	Manufacturing and emissions
21	International development	48	Poetry and literature	75	Trade unions and trade policy
22	Film and documentary	49	Students and education	76	Infectious disease
23	Wales	50	European policy	77	Refugees and migration
24	Procurement and supply chains	51	Nuclear energy and research	78	Disability and inclusion
25	Gender equality	52	World War 1 and World War 2		
26	Dentistry	53	Slavery and human trafficking		


Photo by Viktor Forgacs on Unsplash

Table 2. The 12 impact clusters

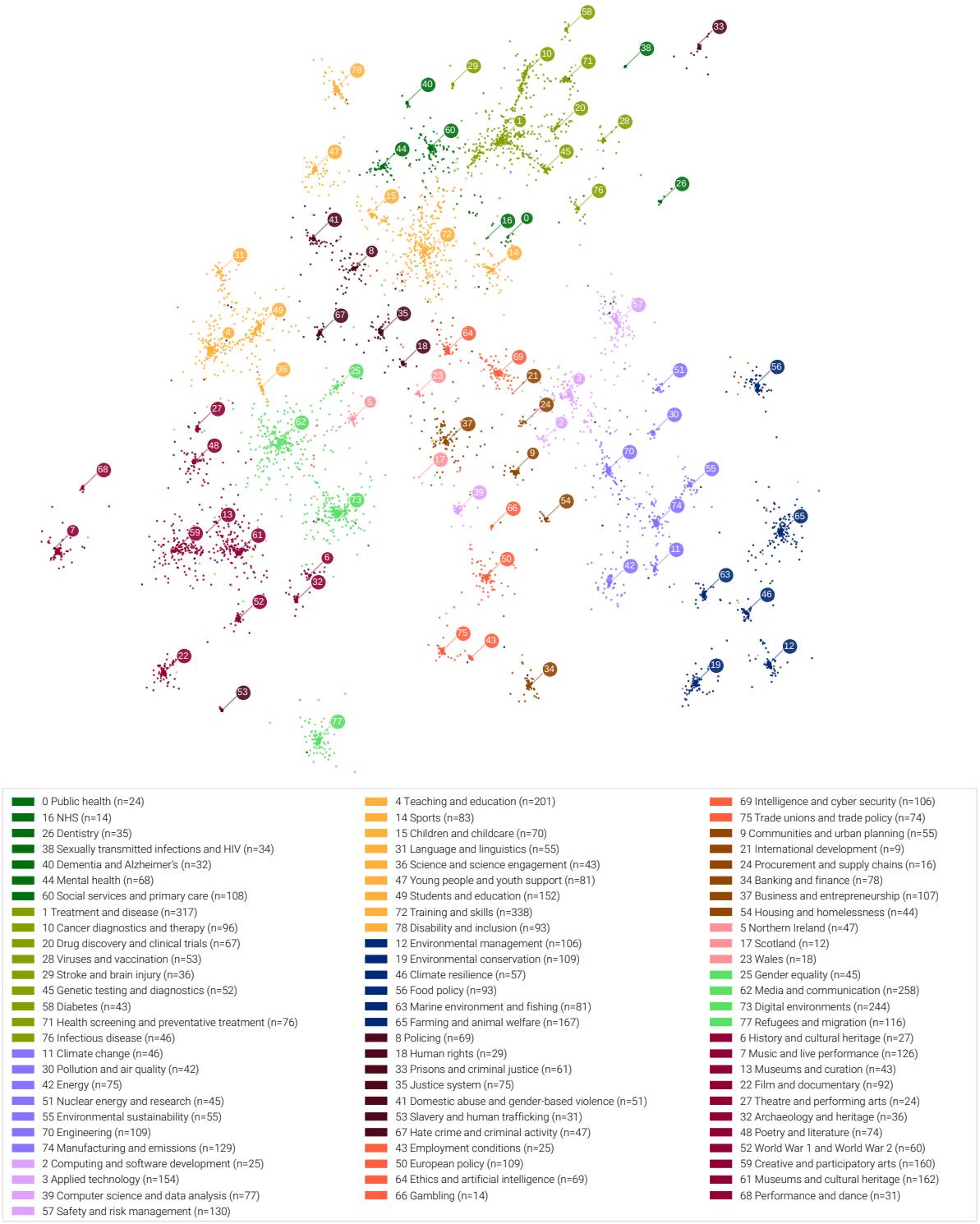
Number	Cluster label
1	Public Health and Health Services
2	Clinical Medicine
3	Energy, Environment and Engineering
4	Information, Applied Technology and Analytics
5	Training, Education and Skills
6	Food, Environment & Ecology
7	Criminal Justice and Human Rights
8	Policy, Ethics and Security
9	Business, Planning and Economics
10	Devolved Nations
11	Culture and Society
12	History, Heritage and Creative Arts

Figure 5 uses 'impact wheels' to show the distribution of Panels and UoAs within two example impact topics, illustrating that all four REF Panels (A–D) were represented. However, as expected, each panel's contribution level varied by impact topic. For example, most ICSs for Topic 1, 'treatment and disease', came from Panel A.[19] In contrast, a higher proportion of ICSs relating to 'digital environments' came from Panel D.[20] This diversity and mix of contributing UoAs was evident across most impact topics, highlighting that impact derived from multiple research disciplines. Figure 6 summarises the relationship between topics and UoAs in a bubble plot, showing the distribution of ICSs across impact topics and UoAs and demonstrating a relationship between the impact type (represented by the impact topic) and the UoA. For example, topics in Panel A (represented by the pink bubbles) tended to be associated with health impacts, e.g. 'public health' (Topic 0), the 'NHS' (Topic 16) and 'dentistry' (Topic 26). In contrast, topics in Panel D (represented by the green bubbles) were more closely associated with impacts on culture and society, such as 'media and communication' (Topic 62) and 'museums and cultural heritage' (Topic 61).

19 Panel A covers UoAs 1–6, which include 'Clinical Medicine', 'Public Health', 'Health Services and Primary Care', and 'Biological Sciences'. See Annex C for a full list of the UoAs in Panel A.

20 Panel D covers UoAs 25–34, which include 'modern languages and linguistics', 'history', 'classics', and 'art and design'. See Annex C for full list of the UoAs in Panel D.

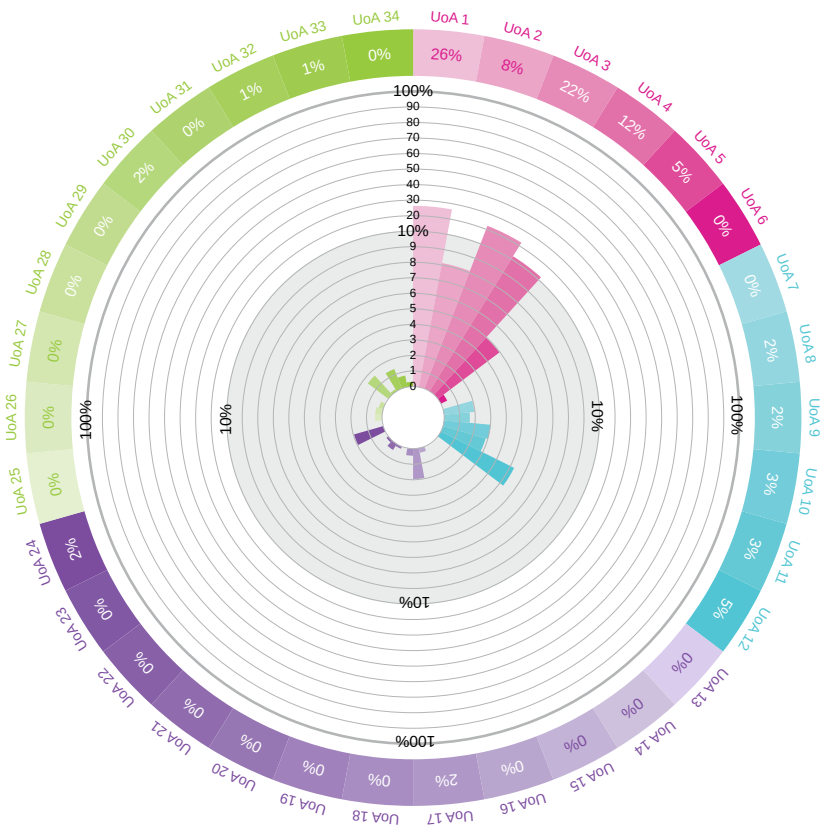
Figure 4. The relationship between the 79 impact topics



Notes: Each 'dot' represents an ICS. The topics are numbered according to Table 1, with different colours differentiating the 12 cognate 'clusters'. The 'n' values beside each topic represent the number of ICSs with that topic as the primary topic.

Figure 5. Impact wheels showing the UoAs contributing to impact topics for two example topics

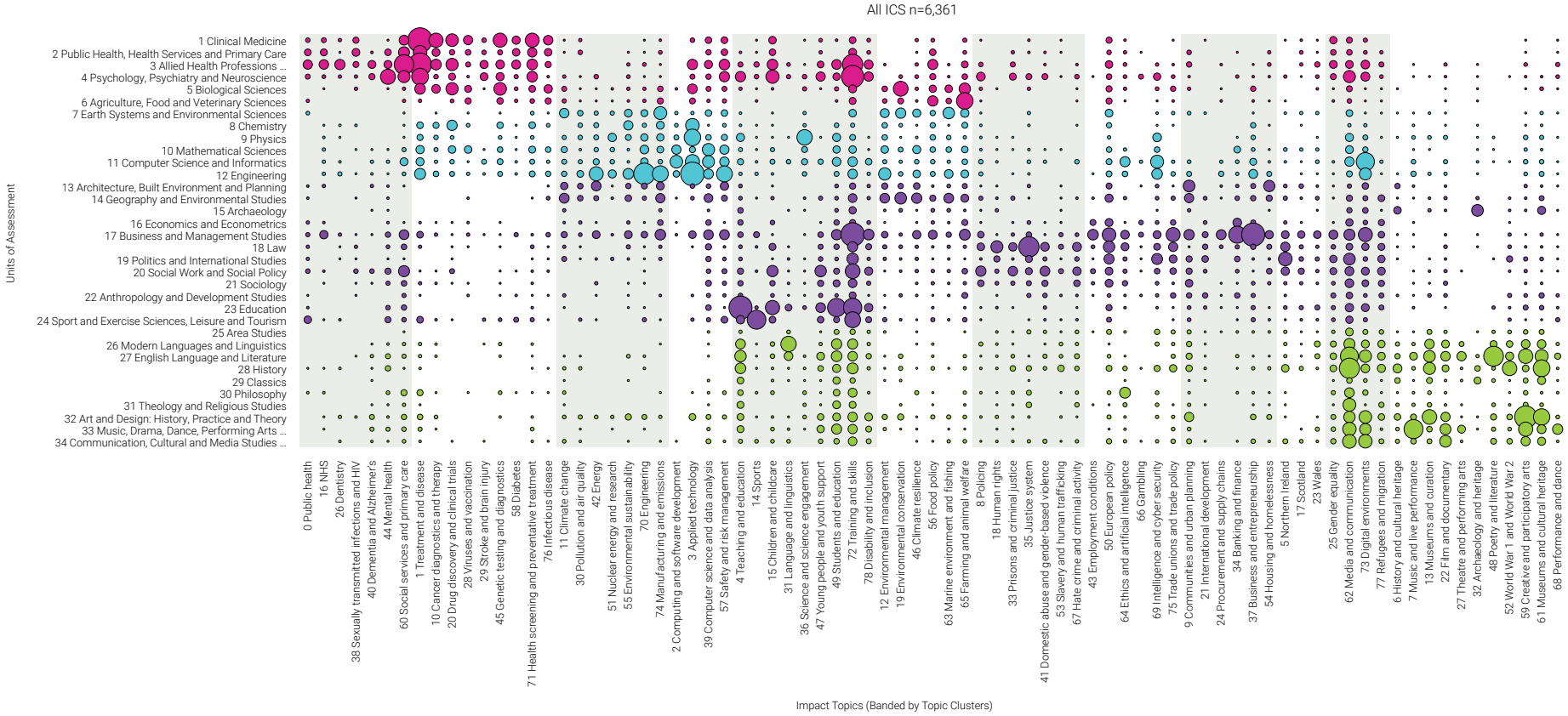
Treatment and disease, n=665



Digital environments, n=619

Notes: This figure shows the impact wheels for Topic 1 (Treatment and disease) and Topic 73 (Digital environments). The 'n' value represents the number of ICS associated with each. The four colours represent each panel: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green). Different shades of the same colour denote the 34 UoAs. The impact wheels' spoke sizes reflect how frequently that topic occurred in that UoA. The longest spoke in the 'treatment and disease' impact wheel is for UoA 1 (Clinical Medicine), with 26% of the ICSs assigned to that UoA.

Figure 6. A bubble plot mapping impact topics against UoAs



Notes: This figure shows a bubble plot mapping the 79 impact topics (x-axis) against the 34 UoAs (y-axis). The size of the bubble indicates the number of ICSs assigned to that topic and found within that UoA. For example, ICSs submitted within UoA 12 (Engineering) were distributed across numerous impact topics but at higher proportions for Topic 55 (Environmental sustainability), Topic 70 (Engineering) and Topic 3 (Technology transfer). As before, the four colours denote the four panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green).

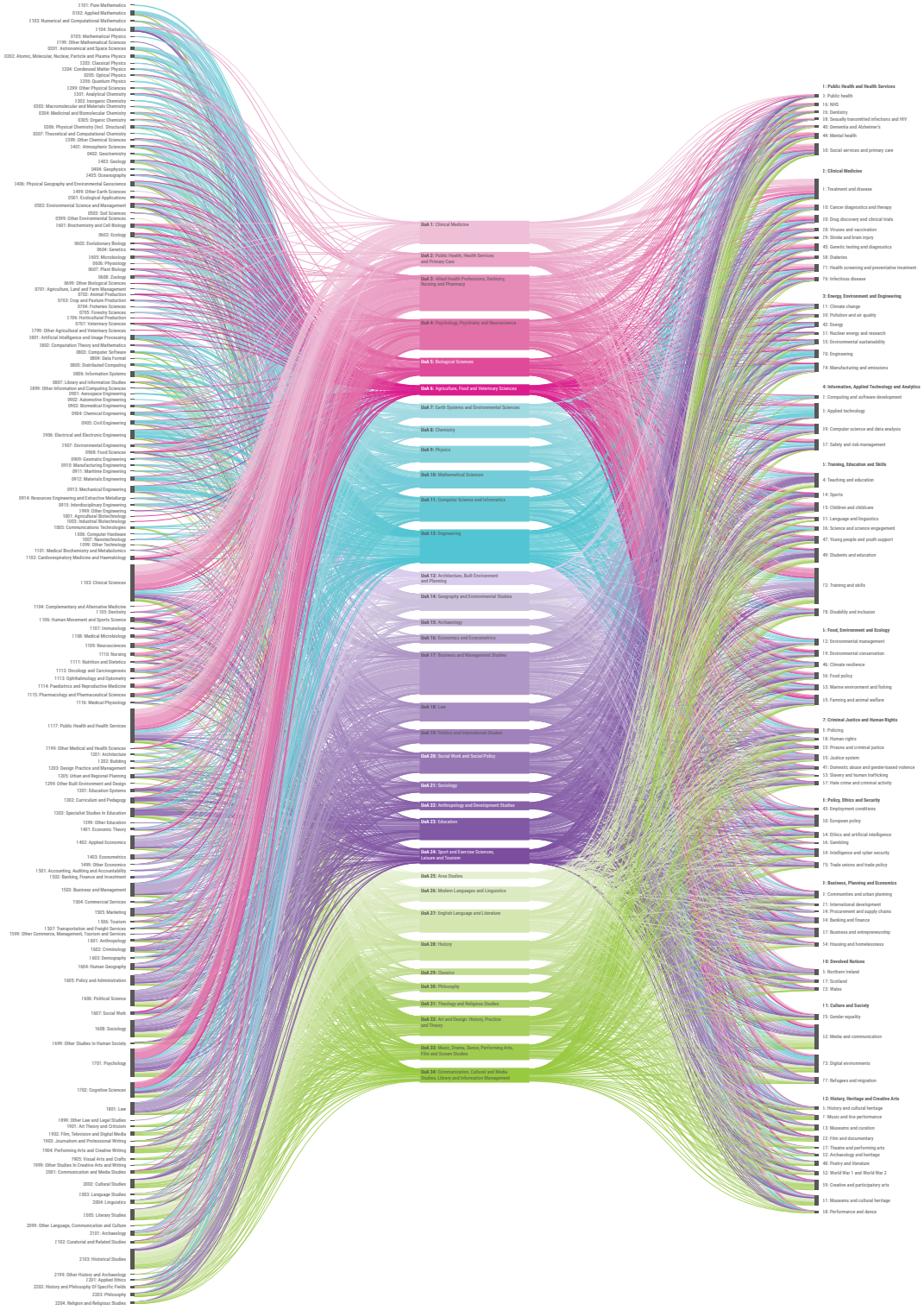
2.1.2. Impact pathways

Combining impact topics with the related ICSs' UoAs and underpinning research fields allowed us to identify pathways from research to impact, as illustrated in the alluvial diagram in Figure 7. This diagram shows a total of 48,571 impact pathways, comprising 5,397 unique impact pathways, demonstrating several impact characteristics similar to the REF 2014 analysis.[21] Firstly, the research underpinning the impact was multidisciplinary. Overall, 72% of ICSs featured two or more FoRs (two-digit)[22] in their underpinning research and 18% featured three. Moreover, no ICS reported a single pathway to impact. Instead, the results showed significant diversity in the fields contributing to ICSs within each UoA, with case studies from each UoA contributing to multivarious impact topics. For example, 98 of the 157 FoRs associated with the underpinning research publications were included in Panel A ICSs, 124 in Panel B, 119 in Panel C and 108 in Panel D, illustrating that impact was often a bespoke activity. Given these impact pathways' diversity, developing a balanced and comprehensive set of impact metrics that capture this range of activities would be challenging. The results demonstrate the numerous, complex and often unique impact pathways involved.

21 King's College London and Digital Science (2015).

22 FoR codes are a classification system managed by the Australia and New Zealand Classification (ANZSRC) to group research, researchers and their outputs by discipline. They are commonly used in bibliometric analyses to classify research outputs' disciplines, and can be applied at three nested levels reflecting the classification's granularity: six-digit codes (the most granular), four-digit codes and two-digit codes (the least granular). We used four-digit codes in this analysis.

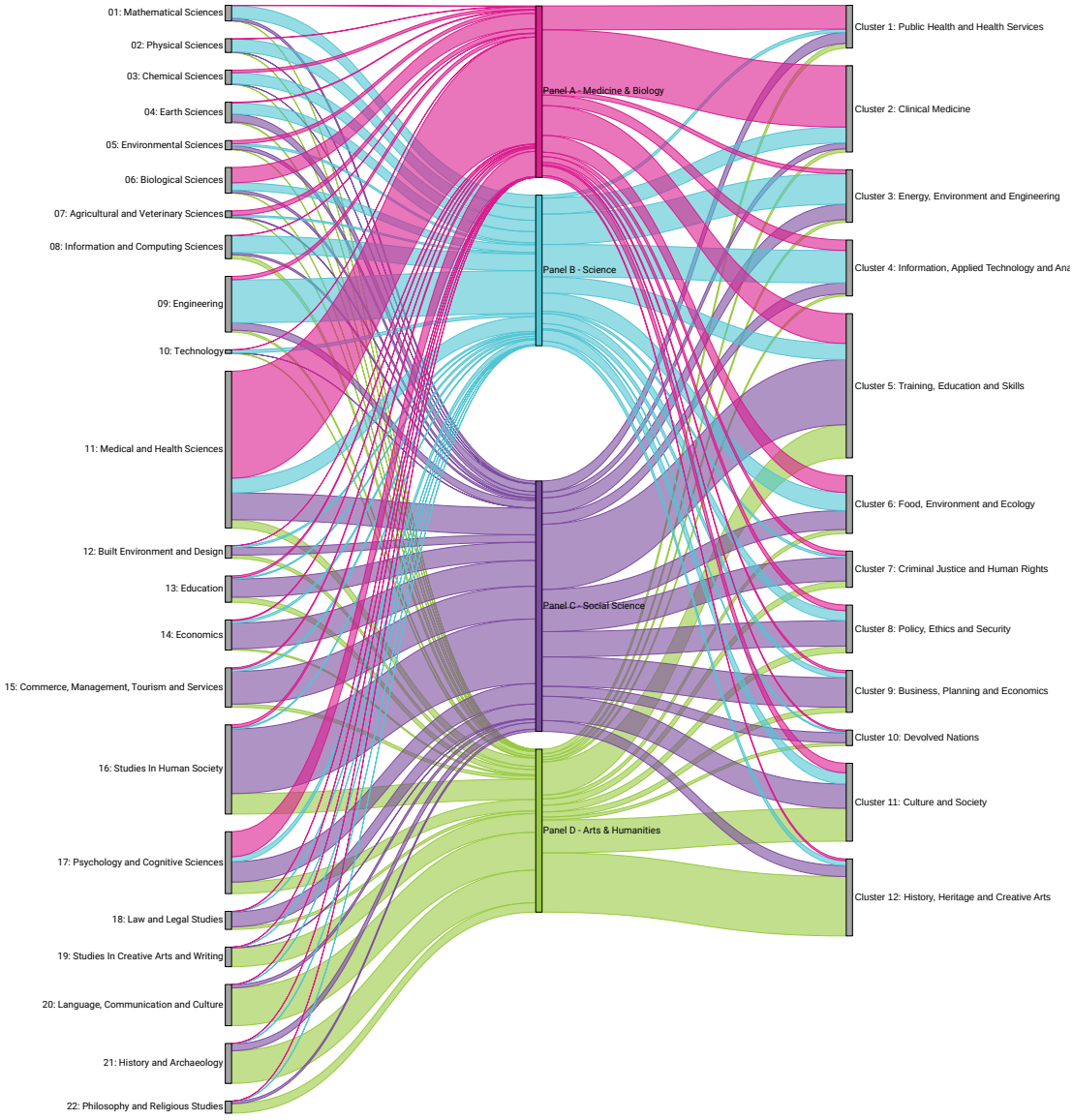
Figure 7. Alluvial diagram illustrating pathways to impact from the underpinning research to the resulting impact



Notes: The alluvial diagram above links the underpinning research (extreme left, classified by FoR) with the resulting impacts (extreme right) by panel and UoA (middle). The colours represent the four main Panels: Panel A (pink), Panel B (blue), Panel C (purple), and Panel D (green). The 79 impact topics are clustered within the 12 impact clusters shown in Figure 3. Readers can zoom into specific sections of this figure to read the text. A high-resolution file of this image can also be downloaded alongside the report.

The simplified presentation of impact pathways in Figure 8 reemphasises this complexity, linking the underpinning research's FoRs[23] with the four REF panels and the 12 impact clusters (as shown in Table 2) and showing a similar diversity of pathways and research fields in each Panel.

Figure 8. A simplified alluvial diagram showing higher-level impact pathways from the underpinning research to the resulting impact clusters by Panel



Notes: The figure above shows a simplified alluvial diagram outlining higher-level impact pathways (extreme left) to resulting impact clusters (extreme right), organised by the four main panels (middle). It links the underpinning research's FoRs with the four REF panels and the 12 impact clusters shown in Table 2. The colours represent the four Panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green).

23 This analysis uses two-digit (more aggregate) FoR codes.

2.1.3. The geographic spread of impact

We used geotagging to identify all mentions of geographic locations in Section 4 of the ICS ('Details of the impact'). As with the 2014 analysis, the results showed that research conducted at UK HEIs has had a global impact. Figure 9 illustrates that ICSs reference almost every country in the world, of which the UK, the US and Australia are the top three (Table 3). The top ten are broadly consistent with the REF 2014 analysis.

We also explored the distribution of impact across the UK in more detail. Figure 10 shows the number of ICSs reporting impact in each Nomenclature of Territorial Units for Statistics (NUTS) 1 region across the UK,[24] demonstrating the proportion of impact from ICSs submitted by institutions in that region. Figure 10 shows the spread of research impact across the UK and the proportion of locally submitted ICSs impacting each region (i.e. impacting the same region in which the research was conducted). For example, of the 503 ICSs impacting South West England, 180 (36%) were submitted by institutions from that region.

Table 3. The top ten countries where impact has occurred

	2014 ICS count	2021 ICS count	% of 2014 ICS count	% of 2021 ICS count
United Kingdom	3,315	5,483	50	86
United States	1,545	2,154	23	34
Australia	1,013	1,010	15	16
Germany	684	742	10	12
Canada	806	723	12	11
France	518	623	8	10
Ireland	556	612	8	10
China	597	537	9	8
Italy	415	511	6	8
Netherlands	550	503	8	8
India	473	503	7	8

Note: percentages may total more than 100% since many ICSs mention more than one country.

24 The NUTS classification is a geographical nomenclature subdividing the European Union's (EU's) economic territory into three different regional levels (NUTS 1, 2 and 3, respectively), from larger (NUTS 1) to smaller (NUTS 3) areas.

Figure 9. The global impact of ICSs

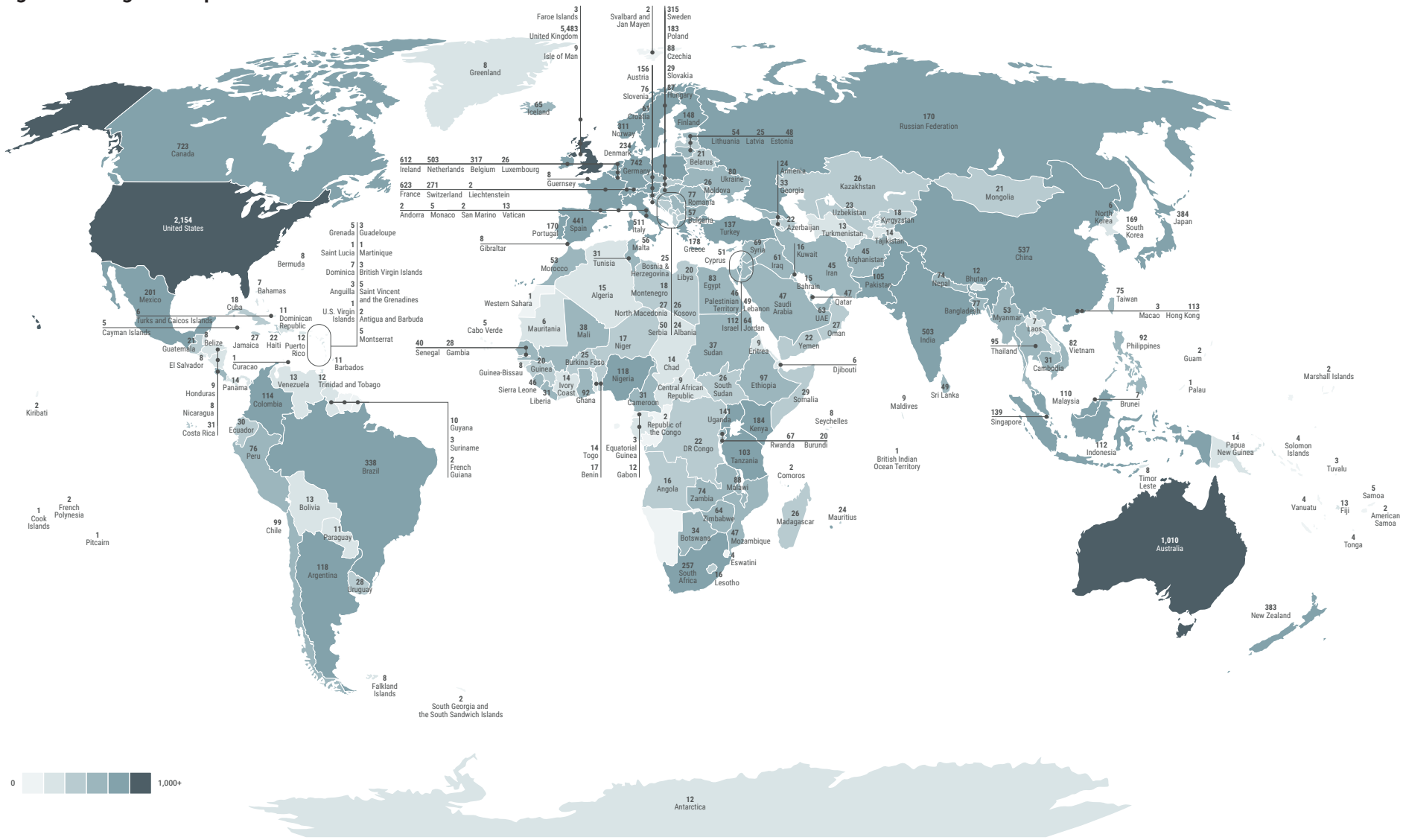


Figure 10. UK map illustrating the regions in which impact has occurred

Notes: This figure shows the NUTS 1 regions within the UK where impact has occurred. The shading within this figure represents the number of ICSs impacting each region, with darker shading representing higher numbers of ICSs and lighter shading representing lower numbers of ICSs. The number represents the number of ICSs that have impacted that region.

We also compared the impact across NUTS 1 regions with the funding amounts (Research Grants and QR funding combined).[25] Table 4 shows that London received 24% of the funding, and 19.2% of ICSs had impacts there (1,222 out of 6,361). Looking across regional clusters, only 35.3% of ICSs had impacts in London, the South East and the East of England (the 'Golden Triangle'), despite them receiving 49% of research funding.

Table 4. Regional impact across UK NUTS 1 regions compared to funding levels

NUTS 1 ID	NUTS 1 name	HEI count	£m research 2015/2016–2019/2020	% funding	Number of ICSs with impact in the region	% impact (no. of ICSs with impact in the region/total number of ICSs (6,361))
UKC	North East (England)	5	224	2.8	304	4.8
UKD	North West (England)	14	653	8.3	732	11.5
UKE	Yorkshire and the Humber	11	535	6.8	487	7.7
UKF	East Midlands (England)	9	315	4.0	293	4.6
UKG	West Midlands (England)	11	402	5.1	432	6.8
UKH	East of England	9	807	10.2	382	6.0
UKI	London	36	1,894	24	1,222	19.2
UKJ	South East (England)	17	1,139	14.4	644	10.1
UKK	South West (England)	14	401	5.1	503	7.9
UKL	Wales	8	297	3.8	258	4.1
UKM	Scotland	17	1,064	13.5	502	7.9
UKN	Northern Ireland	2	163	2.1	94	1.5

25 Average from 2015-2016 to 2019-2020, see HESA (2023).

We also explored the flow of impacts between regions. This dimension is particularly interesting in the context of 'levelling up', where many metrics typically used to analyse R&I focus on input measures. Therefore, we explored the proportion of ICSs that had an impact in the region of investment versus the proportion where the impact was 'exported' to other UK regions. Figure 11 shows that 60% of research ICSs report impacts that were 'exported' from the region where the research took place, with the biggest 'exporter' being South East England (which exported 69% of its impact). Although Scotland was the lowest exporter of impact, just under half (46%) of ICSs still reported impact occurring in other parts of the UK beyond Scotland.

Figure 12 maps research impacts at the NUTS 3 level, illustrating effects at a more granular level. Labels showing the top three locations from each NUTS 1 region are overlaid to highlight specific impact locations. For example, 314 ICSs had impacts in Manchester compared to only 104 in York. Analysis of geotagging data allowed us to investigate 'hyperlocal impact', defined in this analysis as impact occurring within 25km of the HEI that submitted the ICS. Based on this definition, there were only 19 HEIs with over half of their ICSs demonstrating hyperlocal impact, as illustrated in Table 5. Notably, many were specialist arts institutions, where the total number of ICSs is typically small. However, 143 of the 155 submitting institutions had at least one ICS with hyperlocal impact, and hyperlocal impacts occurred across the UK.

Figure 11. Impact flows across UK regions

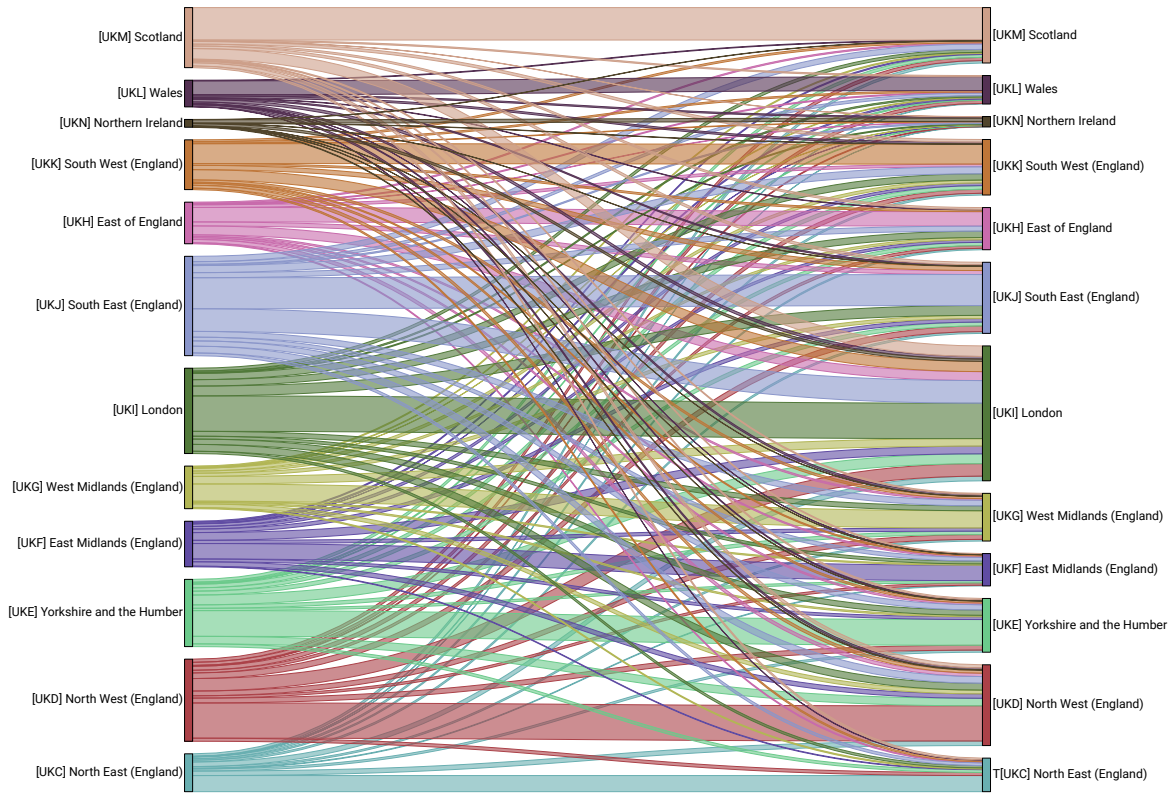
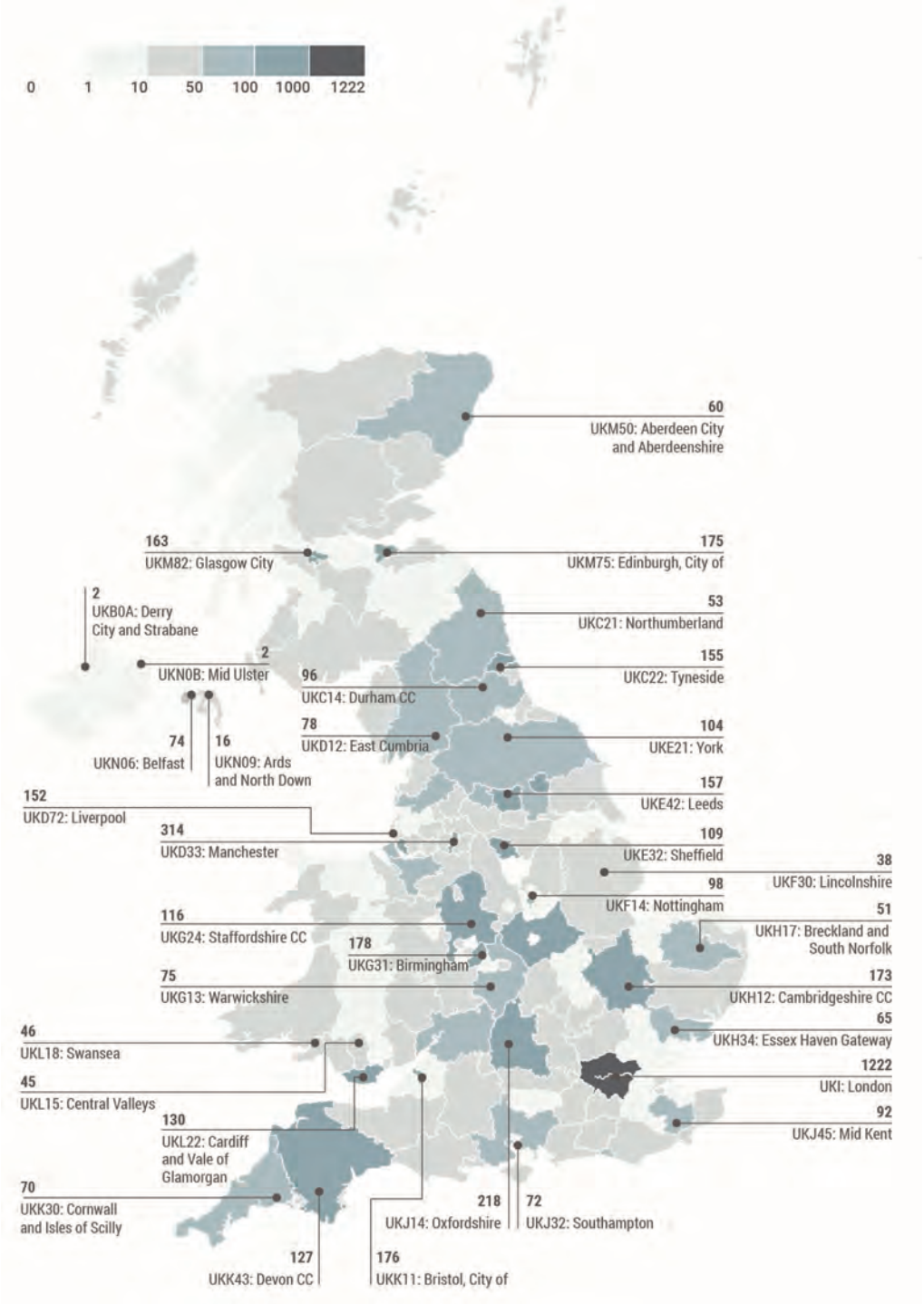


Figure 12. Local impact across the UK at the NUTS 3 level



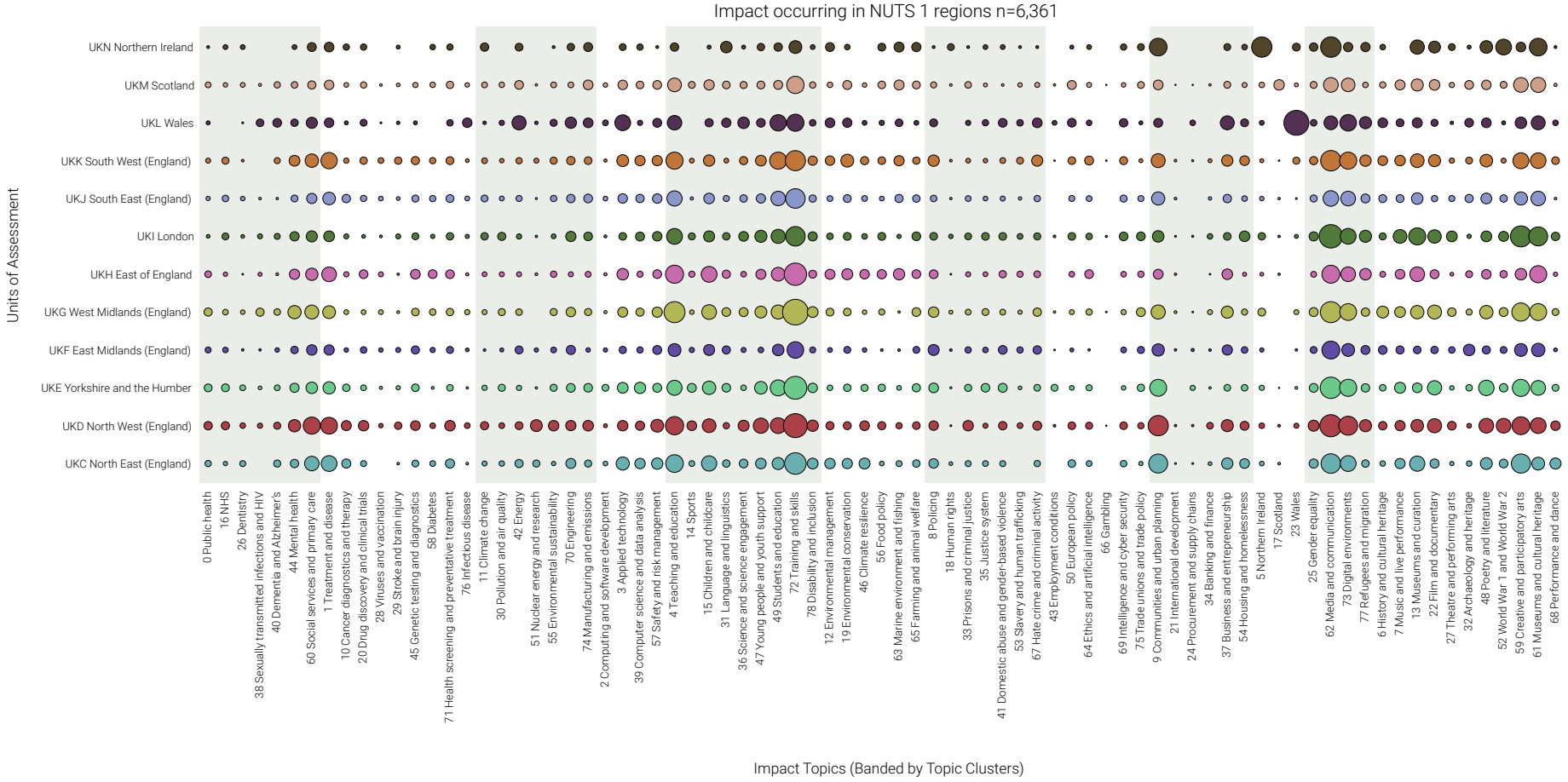
Notes: This figure shows the UK NUTS 3 regions where the impacts occurred. The shading represents the number of ICSs that had impacts in each region, with darker shading representing higher numbers of ICSs and lighter shading representing lower numbers of ICSs. As NUTS 3 regions are dense, we have overlaid this map with labels showing the top three locations from each NUTS 1 region to highlight specific areas where impact has occurred. For example, 70 ICSs had impacts in Cornwall and the Isles of Scilly.

Table 5. HEIs where more than half of their submitted ICSs reported hyperlocal impacts (≤25km from the institution)

Institution name	No. of ICSs with hyperlocal impact	Total no. of ICSs	Proportion of ICSs reporting hyperlocal impact
Ravensbourne University London	2	2	100%
The Royal Central School of Speech and Drama	3	3	100%
Rose Bruford College of Theatre and Performance	2	2	100%
Norwich University of the Arts	2	2	100%
Royal Northern College of Music	2	2	100%
University of the Arts, London	8	10	80%
Falmouth University	4	5	80%
Manchester Metropolitan University	39	49	80%
Royal College of Art	6	8	75%
University of St Mark & St John	3	4	75%
Royal Conservatoire of Scotland	2	3	67%
Royal College of Music	2	3	67%
The University of Bolton	9	14	64%
University of Sunderland	10	18	56%
School of Oriental and African Studies	16	30	53%
University of Salford	16	30	53%
London South Bank University	11	21	52%
University of St Andrews	36	69	52%
University of Durham	50	96	52%

We also mapped impact types across UK regions. Figure 13 shows the impact in NUTS 1 regions; although minor differences exist across the bubbles, the impact topics covering the Devolved Nations had the most impact within their respective regions.

Figure 13. Impact topic by NUTS 1 region

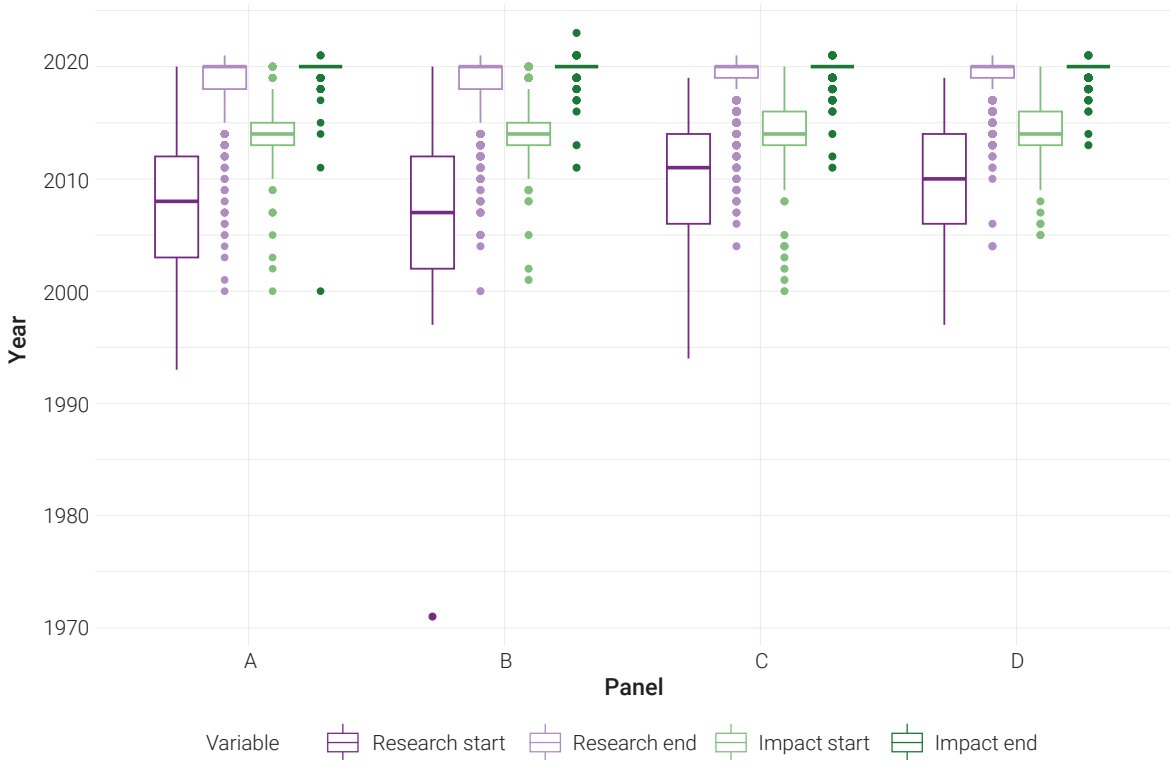


Note: This figure shows a bubble plot mapping the 79 impact topics (x-axis) against the 12 NUTS1 regions (y-axis). Each bubble's size indicates the number of ICSs assigned to that topic within that region.

2.1.4. Time lags

Based on the contextual information provided with ICSs, we examined when the research started and ended (using the dates associated with the grants ICSs referenced) and when the *impact* started and ended (using the dates listed in the sources corroborating impact in the ICSs). The average time lag from the beginning of the research to the end of impact (2020) across the ICSs was ten years (Figure 14). This figure is comparable with previous estimates of the time lag associated with research translation, noting that our estimates typically start from the beginning of the research funding rather than the first publication.[26] There were also differences by Panel. On average, research in Panels A and B took an additional three years to translate into impact than in Panels C and D. However, the true time lags were likely longer as HEIs often list more recent grants in an ICS.

Figure 14. The time lag between research and impact by Panel



Notes: The above boxplot shows the time lags between research and impact across Panels. Boxes represent the median and interquartile range (IQR), with the whiskers extending to 1.5 multiplied by the IQR. Colours represent the variables: the research start date (dark purple), the research end date (light purple), the date impact started (light green), and the date impact ended (dark green). Dots represent the outliers, thus the full range of data values.

26 E.g. Morris et al. (2011).

2.1.5. Overall ROI

To analyse overall ROI as evidenced by the REF 2021 ICSs, we used a text search approach identifying mentions of currency, financial figures or the term 'return on investment'. We then assessed whether it was possible to aggregate this information across the ICSs. Using this approach, we identified 2,146 ICSs that mentioned currency or 'return on investment'. Of these, we reviewed ICSs that specifically mentioned 'return on investment' in Section 4 (n=58). However, the various ways of expressing this made the results challenging to aggregate systematically and meaningfully. Nonetheless, sizable returns were clearly evident, as shown in Box 4.

Box 4. ROI examples reported in ICSs

- Developed by researchers at Glasgow Caledonian University, the Implementation and adoption of the Falls Management Exercise (FaME) programme aimed to reduce the rate of falls and increase physical activity in older adults and demonstrated an ROI between £2.89 and £50.59 for every £1 spent.[27]
- A risk stratification approach for back pain developed by researchers at the University of Keele aimed to match patients to appropriate treatment packages and has been estimated to have delivered an ROI of up to £226.23 for every £1 spent.[28]
- Wigan Council implemented a sensing product to transform winter road maintenance decision-making developed by researchers at the University of Birmingham with the ROI of a 27-sensor network 'within half a winter season'.[29]
- A project undertaken by researchers at Loughborough University to improve child nutrition and breastfeeding policies and programmes in Kenya estimated a social ROI of $71 (£58.40) for every $1 (£0.82) spent for an intervention supporting community health workers to increase Exclusive Breastfeeding (EBF) in urban poor communities.[30]
- A digital marketing agency used statistical algorithms developed by researchers at Cardiff University to improve the efficiency of online advertising for clients was calculated to provide an ROI of £18 for every £1 spent on the campaign.[31]
- A decision support tool developed by researchers at Liverpool John Moores University for maritime engineering systems demonstrated an ROI of 'approximately 14 times' when used for lubricating oil condition monitoring.[32]

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27 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/fb530e35-7447-4169-b735-184e65d1dd0f?page=1

28 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/85d321a1-49bc-4ede-a1fa-0a70b1bc57a5?page=1

29 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/b3e9dd8f-de20-49ba-b955-0ccfd5620190?page=1

30 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/50cf86bd-d862-4b86-8692-84ebf7636d3f?page=1

31 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/a28b15d3-b95c-494b-9a1c-5edd868c9219?page=1

32 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/cd8108bc-09f1-4727-9d19-69ca32f752a3?page=1

- A case study submitted by Edge Hill University on mental health promotion through sport demonstrated that the Tackling the Blues programme (a prevention and early intervention sport and education-based mental health awareness programme) had a social ROI of £9.75m between 2016 and 2018.[33]
- A project from the University of the West of England to improve agricultural support services and smallholder livelihoods in Laos demonstrated ROI in the range of '16-21 to 1' for services provided to rice farmers, enabling improved productivity and marketing.[34]
- The Centre for Global Eco-Innovation at The University of Liverpool helped support small businesses in the Liverpool City Region in achieving low-carbon growth, resulting in an estimated ROI ratio of 5.5:1 (by the end of 2017) compared to the regional ratio of 1.8:1 and the national average of 2.8:1.[35]
- Based on research undertaken at Cardiff University, the Adopting Together Service established in Wales to support the adoption of siblings and hard-to-place children in care secured an ROI of £14.4m by successfully placing children in permanent homes.[36]

2.1.6. Research beneficiaries

To identify potential beneficiaries of the research, we used a keyword-in-context (KWIC) approach to generate nouns or noun phrases that appear near the words 'stakeholder', 'beneficiary' or 'user' in Section 4 of the ICS. This approach identified 59 different beneficiary types. Figure 15 shows the top 15 most prevalent (see Annex D for the complete list). The top five identified beneficiary groups were relatively broad, comprising 'governments', 'communities', 'policymakers', 'practitioners' and the 'public'. However, we also identified more specific beneficiary groups, highlighting the range of groups addressed within ICSs. Contributions to all beneficiary groups within the top 15 from all Panels further emphasised the disciplinary spread of impact.

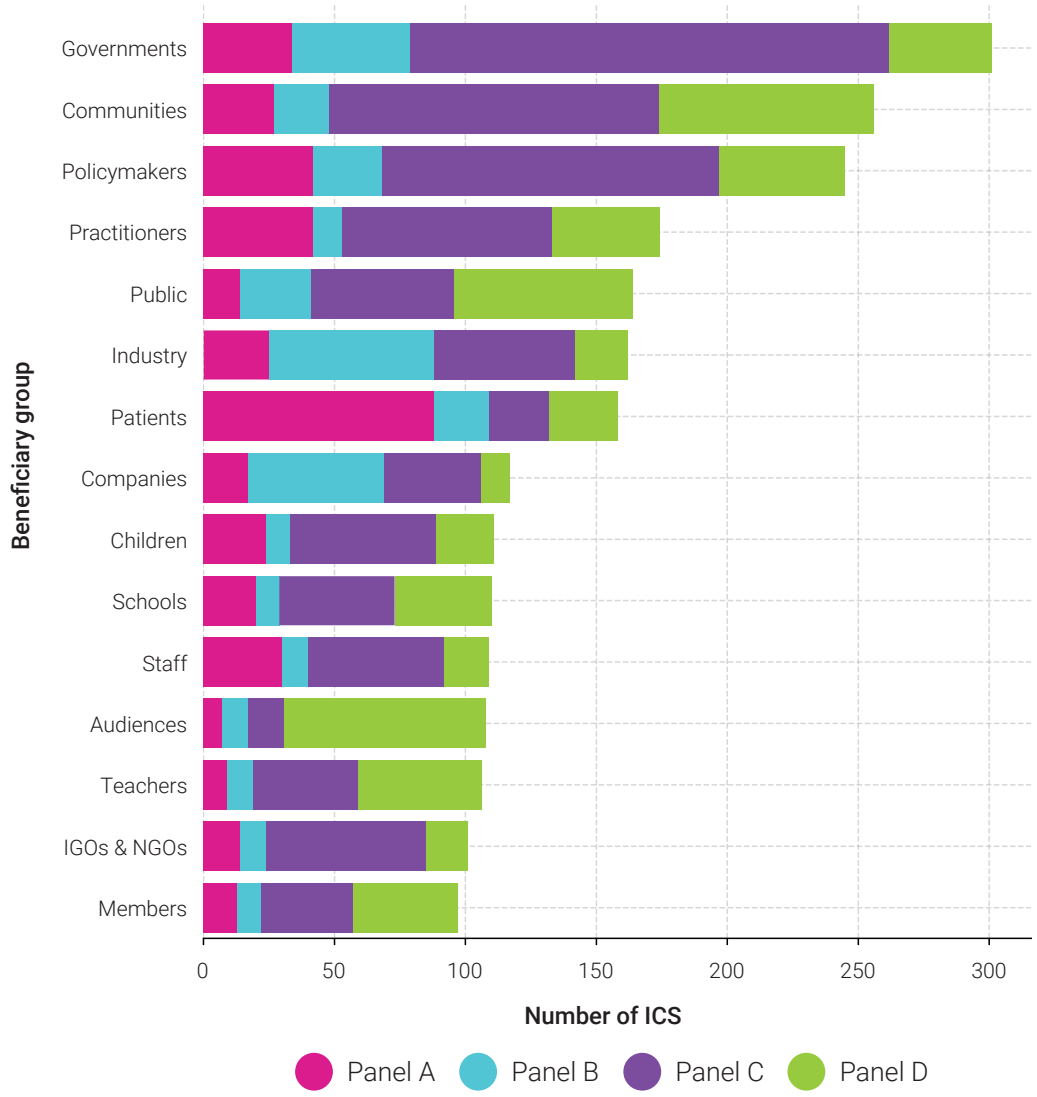
33 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/3a3782a8-fa69-47f7-b2ad-0f2fd13e5a23?page=1

34 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/5d75ab48-db98-458c-bc0d-5adc22d41eee?page=1

35 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/71222532-5346-425f-8588-566ed07d8897?page=1

36 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/94926fc6-279c-4956-aad2-c5081bb564f4?page=1

Figure 15. Research impact beneficiaries by Panel



Chapter 3

Research underpinning the impact

Box 5. Key findings

Our examination of ICSs' underpinning research references highlighted differences in interdisciplinarity across impact topics. Those associated with societal challenges – such as climate change, and the environment – tended to have higher levels of interdisciplinarity, whereas impact topics relating to disciplines like Clinical Medicine typically had lower interdisciplinary levels.

Our analysis of ICSs' underpinning research showed that most research performed better than the global average when looking at bibliometric indicators such as the Category Normalised Citation Impact (CNCI) and highly-cited papers.

3.1.1. Underpinning research

ICSs included a description of the underpinning research that led to the reported impact (Section 2) and a list of research artefacts (such as publications, patents and grant awards) exemplifying the research (Section 3). We used text mining to identify and extract fragments from the ICS documents that matched patterns typically seen in bibliographic referencing. We associated each ICS with a list of underpinning research DOIs by searching for mentions or hyperlinks to DOIs in these text fragments or using the CrossRef Simple Text Query Service[37] to match them with CrossRef records. Using this approach, we identified a total of 25,433 unique DOIs.

We cross-referenced each DOI with corresponding Web of Science bibliographic records, of which we matched 20,548 (81%) with a unique tag (UT) code. The related literature largely comprised original research articles, as summarised in Table 6, although reviews, proceedings papers, and books also featured, albeit in much smaller numbers. Annex D shows the top publication venues by the number of unique DOIs mentioned and the earliest and latest publication year referenced. As might be expected, much of the output was concentrated in flagship multidisciplinary journals covering medical, physical and social sciences.

Table 6. Breakdown of underpinning research article types

Count	Name
18,631	Article
954	Review
324	Editorial Material
319	Proceedings Paper
154	Book
73	Letter
44	Book Review
22	Meeting Abstract
14	Data Paper
7	Book Chapter
2	Correction, Addition

Source: Data from Web of Science, provided by Clarivate

37 Crossref (2023).

3.1.2. The role of interdisciplinary and multidisciplinary work

Despite differing views on the definition and nature of inter, multi and transdisciplinary research, there is broad agreement that research disciplinarity varies. Some research remains exclusively within established subject boundaries, while others integrate knowledge from multiple fields or combine research teams from varying backgrounds. The Rao-Sterling (RS-IDR) metric is a commonly used bibliometric indicator for multi and interdisciplinarity[38] that defines interdisciplinarity according to three aspects: variety (the number of subjects), balance (the skew towards particular subjects) and disparity (how unusual the subject combination is). The value produced ranges from '0' (least interdisciplinary) to '1.0' (most interdisciplinary). For this analysis, we used the term Interdisciplinary Research (IDR) to refer to inter, multi and transdisciplinary research as operationalised by the RS-IDR metric without attempting to differentiate them.

For each ICS, we used the proportion of subject categories referenced by the underpinning research articles to calculate interdisciplinarity. Based on their associated journals, we assigned four-digit FoR codes to the underpinning research articles. Since we only used publications containing at least ten cited references, we could not calculate the metric for all ICSs, as summarised in Table 7. Panels A, B and C showed good coverage of the RS-IDR metric. However, the metric was lower for Panel D because some ICSs do not link to bibliographic items.[39]

Figure 16 uses a box-and-whisker plot to show the RS-IDR metric's distribution by Panel, illustrating some variation across panels. This variation was not unexpected, given the disciplinary differences. While other studies using RS-IDR typically normalise by discipline, this analysis compares IDR using a Panel-normalised percentile denoted *percentile*. Figure 16 shows that ICSs in Panels B and D featured the most interdisciplinarity in their underpinning research, while ICSs in Panel A featured the least.

Table 7. Number of ICSs with RS-IDR metric by Panel

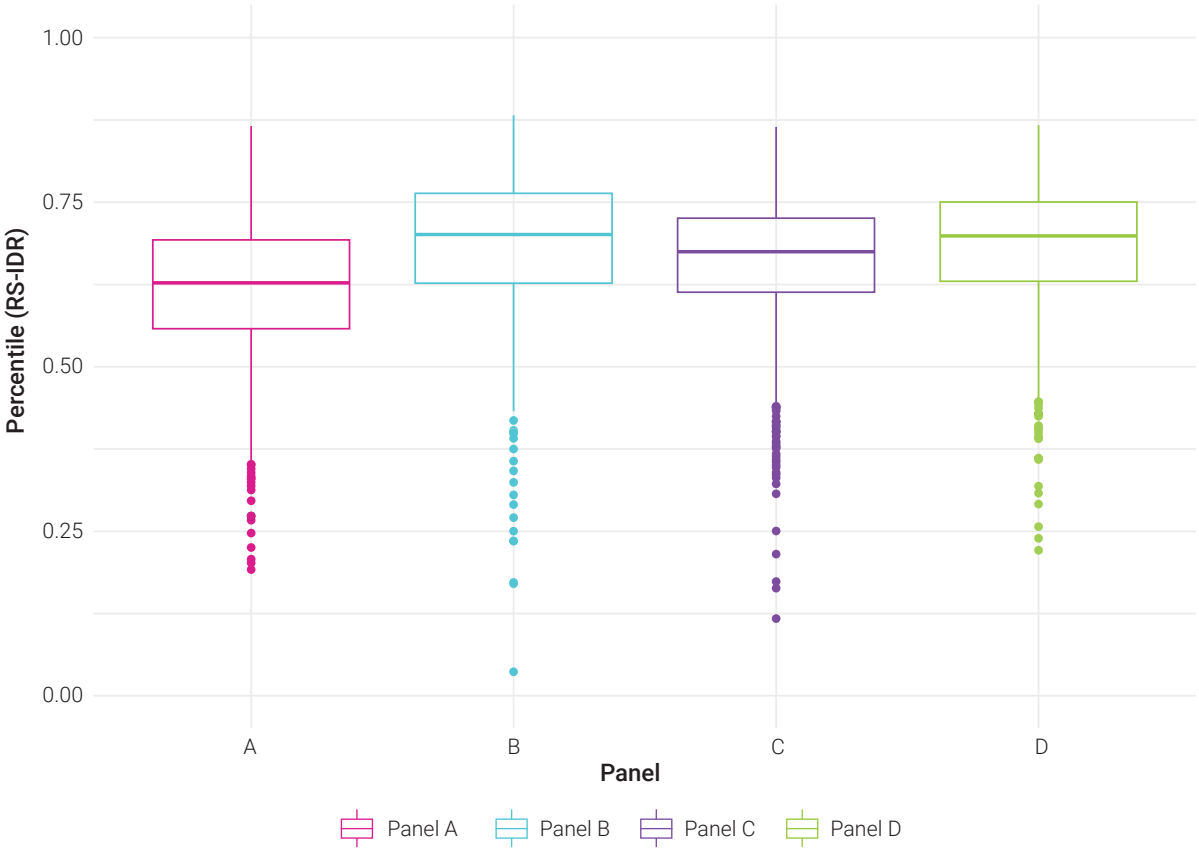
Panel	Total no. of ICSs	No. of articles linked to appropriate bibliometric items	% coverage
A	1,419	1,418	99.9
B	1,268	1,262	99.5
C	2,146	2,110	98.3
D	1,528	1,266	82.9

Source: Data from Web of Science, provided by Clarivate

38 Stirling (2007).

39 Panel A covers UoAs 1–6, which include 'clinical medicine', 'public health', 'health services and primary care', and 'biological sciences'. Panel B covers UoAs 7–12, which include 'chemistry' and 'physics and engineering'. Panel C covers UoAs 13–24, which include 'archaeology' and 'law and sociology'. Panel D covers UoAs 25–34, which include 'modern languages and linguistics', 'history', 'classics', and 'art and design'. See Annex C for the complete list of UoAs in each Panel.

Figure 16. Distribution of the RS-IDR metric by Panel



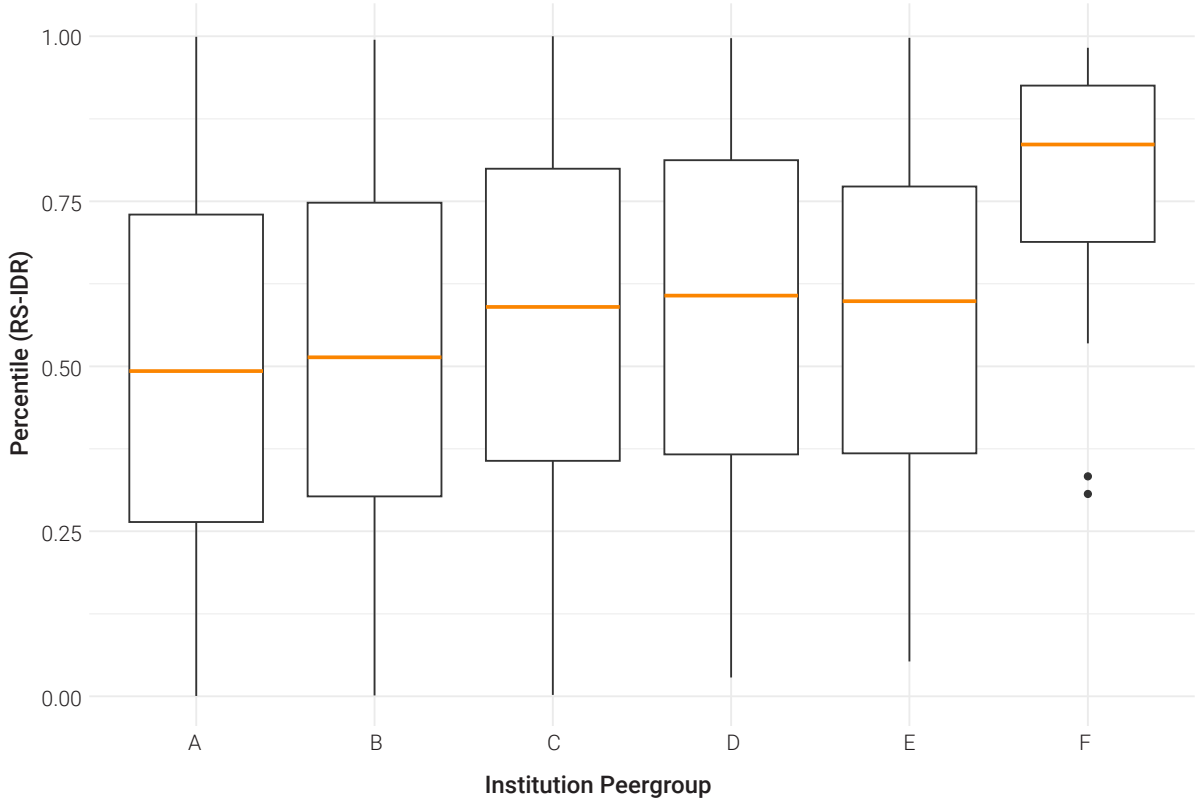
Notes: The boxplot above shows the RS-IDR metric's distribution across ICSs underpinning research by REF panel. Boxes represent the median and interquartile range (IQR), with the whiskers extending to 1.5 multiplied by the IQR. Colours represent the four panels: Panel A (Pink), Panel B (Blue), Panel C (Purple) and Panel D (Green).

Figure 17 compares the RS-IDR metric across Transparent-Approach-to-Costing (TRAC) peer groups, a grouping of UK HEIs based on research income.[40] The figure shows the higher concentration of IDR research underpinning ICSs in peer groups C, D and E.[41] Although the plot shows much higher IDR values for peer group F, its sample size is significantly smaller than the other groups.

40 TRAC (2023).

41 Peer Group A: Institutions with a medical school and research income of 20% or more of total income; Peer Group B: All other institutions with research income of 15% or more of total income; Peer Group C: Institutions with a research income of between 5% and 15% of total income; Peer Group D: Institutions with a research income less than 5% of total income and total income greater than £150m; Peer Group E: Institutions with a research income less than 5% of total income and total income less than or equal to £150m; Peer Group F: Specialist music/arts teaching institutions

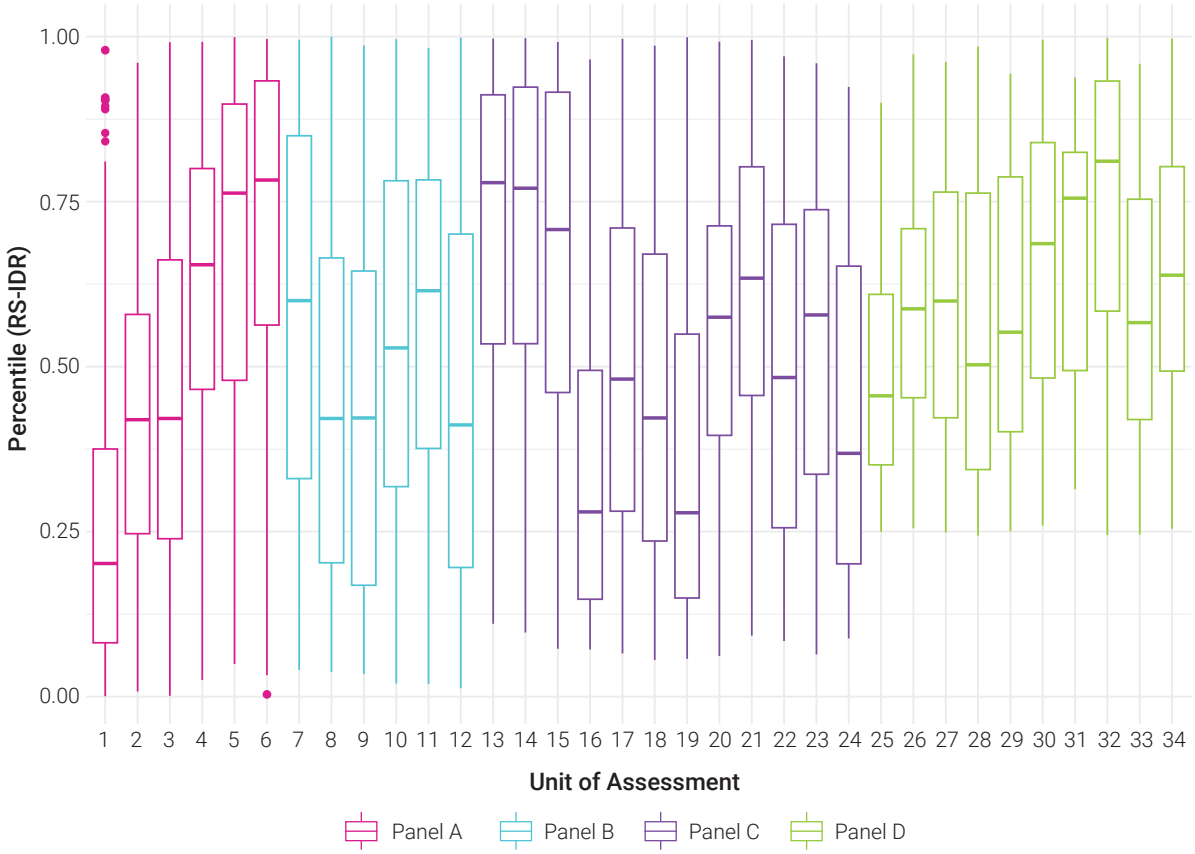
Figure 17. Distribution of the RS-IDR metric by TRAC peer group



Notes: The boxplot above shows the distribution of the RS-IDR metric across TRAC Institution Peer Groups. Boxes represent the median and interquartile range (IQR), with the whiskers extending to 1.5 multiplied by the IQR.

The relative difference in the concentration of high IDR research was more significant at the UoA level (see Figure 18) than at the Panel level, with evident differences between UoAs. For example, UoA 5 (Biological Sciences) and UoA 32 (Art and Design: History, Practice and Theory) had high levels of IDR research underpinning the ICSs, whereas UoA 1 (Clinical Medicine) and UoA 16 (Economics and Econometrics) had lower levels.

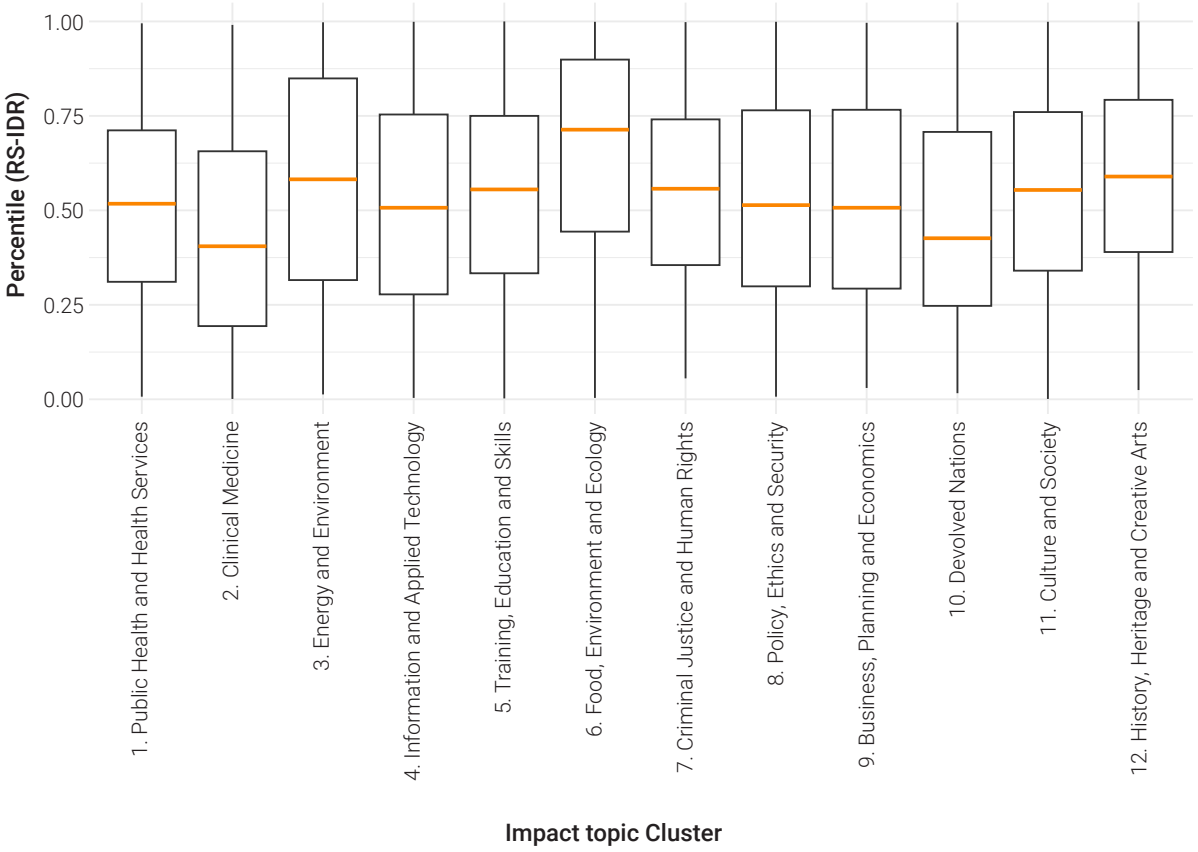
Figure 18. Distribution of the RS-IDR metric by UoA



Notes: The boxplot above shows the distribution of the RS-IDR metric across the 34 UoAs. Boxes represent the median and interquartile range (IQR), with the whiskers extending to 1.5 multiplied by the IQR. Colours represent the four panels: Panel A (Pink), Panel B (Blue), Panel C (Purple) and Panel D (Green).

We identified the relative concentration of IDR research by impact type by cross-referencing ICSs with the Impact Topic Model presented earlier (in Table 1). The concentration of interdisciplinary research in 'Food, Environment and Ecology' is evident when summarised at the Topic Cluster level (see Figure 19). A more nuanced picture emerges when calculated at the Impact Topic level, as summarised in Tables 8 and 9, which list the top and bottom ten, respectively. Topics associated with societal challenges featured prominently in the top ten, while Clinical Medicine topics dominated the bottom ten.

Figure 19. Distribution of RS-IDR metric by Topic Cluster



Notes: The boxplot above shows the distribution of the RS-IDR metric across the 12 Impact Topic Clusters. Boxes represent the median and interquartile range (IQR), with the whiskers extending to 1.5 multiplied by the IQR.

Table 8. RS-IDR metric by impact topic: top ten topics[42]

Topic	Topic Label	Cluster	Cluster Label	Median percentile (RS-IDR)
19	Environmental conservation	6	Food, Environment and Ecology	0.82
11	Climate change	3	Energy and Environment	0.79
56	Food policy	6	Food, Environment and Ecology	0.77
32	Archaeology and heritage	12	History, Heritage and Creative Arts	0.73
65	Farming and animal welfare	6	Food, Environment and Ecology	0.70
12	Environmental management	6	Food, Environment and Ecology	0.70
46	Climate resilience	6	Food, Environment and Ecology	0.68
64	Ethics and artificial intelligence	8	Policy, Ethics and Security	0.68
40	Dementia and Alzheimer's	1	Public Health and Health Services	0.67
63	Marine environment and fishing	6	Food, Environment and Ecology	0.67

Table 9. RS-IDR metric by impact topic: bottom ten topics

Topic	Topic Label	Cluster	Cluster Label	Median percentile (RS-IDR)
29	Stroke and brain injury	2	Clinical Medicine	0.39
20	Drug discovery and clinical trials	2	Clinical Medicine	0.39
17	Scotland	10	Devolved Nations	0.38
18	Human rights	7	Criminal Justice and Human Rights	0.37
71	Health screening and preventative treatment	2	Clinical Medicine	0.36
34	Banking and finance	9	Business, Planning and Economics	0.36
58	Diabetes	2	Clinical Medicine	0.35
5	Northern Ireland	10	Devolved Nations	0.35
1	Treatment and disease	2	Clinical Medicine	0.31
10	Cancer diagnostics and therapy	2	Clinical Medicine	0.19

42 Annex F provides RS-IDR metrics for all topics.

While this analysis highlights relative differences in the concentration of IDR research across the REF 2021 ICS portfolio, no other reference benchmark is available. A more comprehensive analysis benchmarking research underpinning impact to that submitted as outputs to REF (and to the UK and global context more generally) would provide greater insight. Nonetheless, the analysis presented here indicates that some impact pathways relied more on IDR research than others and that the disciplinarity makeup of the underpinning research generally varied.

3.1.2. Research collaboration

Since underpinning research publications record authors' affiliations, we were able to measure two aspects of collaboration:

- **Collaboration mode**: whether the research was conducted exclusively at the submitting institution ('none'), with domestic collaborators ('domestic'), with international collaborators ('international'), or with a large number of international collaborators from at least five countries ('multilateral').
- **Collaboration sectors**: whether collaboration organisations came from outside academia, e.g. healthcare facilities (hospitals and clinics), governmental labs, private companies or non-profit organisations.

We analysed the DOIs listed in Section 3 of the ICSs to classify ICSs by collaboration mode and sector. Using bibliographic information from the Web of Science and bespoke institution-to-sector mappings provided by Clarivate, we inspected each author affiliation for an underpinning research article, using it to classify which collaboration modes and sectors contributed to each ICS. Table 10 summarises the percentage of ICSs in each Panel by collaboration mode and sector, showing that single institution research and collaboration featured across Panels A to C. The only exception was Panel D, which featured less multilateral collaboration (i.e. from five or more countries). Overall, 36% of ICSs submitted to Panel A featured multilateral collaboration. Unsurprisingly, Panel A also featured the most collaboration with health-sector organisations, whereas Panel B featured the most collaboration with corporate organisations (21% of ICSs). Panel A also featured the most cooperation with government organisations (38% of ICSs), closely followed by Panel B (36%). ICSs in Panels C and D showed minimal collaboration with other sectors, partly due to their lower linkage rate to research articles with sufficient bibliographic data.

Table 11 presents the same statistics by TRAC group, showing some triangulation across the findings. As most Panel A submissions were from TRAC Group A institutions (namely those with medical schools), there are similar results across the two tables, with higher levels of domestic, international and multilateral collaboration across those groups (see Table 11).

Table 10. Collaboration by Panel

		Collaboration Mode (% of ICSs)				Collaboration Sectors (% of ICSs)			
Panel	Total no. of ICSs	% None	% Domestic	% International	% Multilateral	% Health	% Corporate	% Government	% Non-profit
All	6,361	42	56	52	16	15	9	20	9
Panel A	1,419	33	77	75	36	51	17	38	20
Panel B	1,268	49	65	73	25	9	21	36	15
Panel C	2,146	48	58	50	9	5	2	11	5
Panel D	1,528	36	25	15	1	1	0	2	1

Source: Data from Web of Science, provided by Clarivate. Notes: Shading indicates the percentage of ICSs, with darker green indicating higher ICS numbers with that collaboration mode. Panel A covers UoAs 1–6, which include 'clinical medicine', 'public health', 'health services and primary care', and 'biological sciences'. Panel B covers UoAs 7–12, which include 'chemistry', 'physics' and 'engineering'. Panel C covers UoAs 13–24, which include 'archaeology', 'law' and 'sociology'. Panel D covers UoAs 25–34, which include 'modern languages and linguistics', 'history', 'classics', and 'art and design'. Annex C provides a full list of UoAs within each Panel. The collaboration mode and sectors were determined from the underpinning research publications linked to each ICS; any one ICS can have multiple publications, thus multiple collaboration modes/sectors.

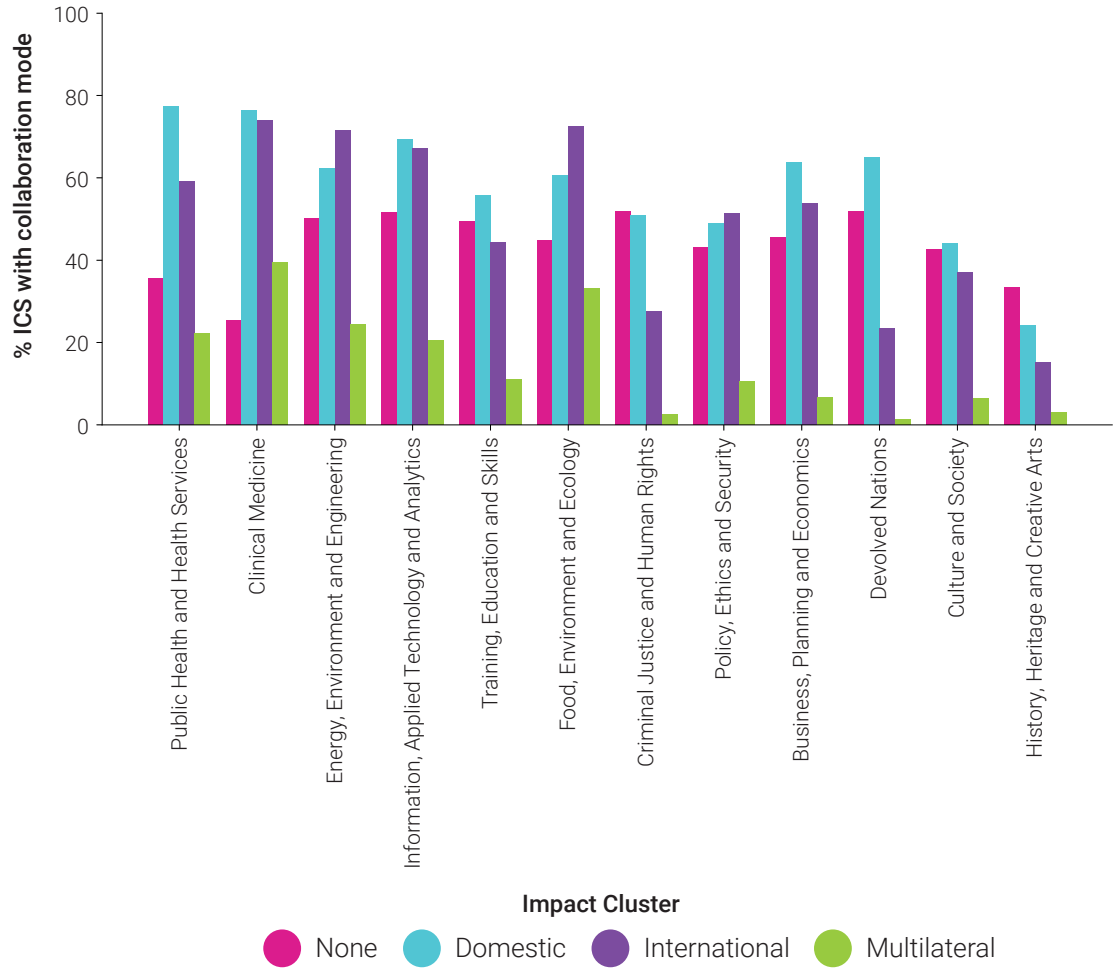
Table 11. Collaboration by TRAC peer group

		Collaboration Mode (% of ICSs)				Collaboration Sectors (% of ICSs)			
Peer Group	Total no. of ICSs	% None	% Domestic	% International	% Multilateral	% Health	% Corporate	% Government	% Non-profit
A	3,052	36	60	57	21	21	12	28	13
B	1,081	51	54	54	15	9	8	19	8
C	864	47	51	49	12	11	7	13	5
D	593	49	52	41	12	11	4	8	4
E	695	45	49	40	9	9	3	7	5
F	72	18	14	4	1	1	0	0	0

Source: Data from Web of Science, provided by Clarivate. Notes: Shading indicates the percentage of ICSs, with darker green indicating higher ICS numbers with that collaboration mode. TRAC Group A had the highest research income, while TRAC Group F had the lowest.

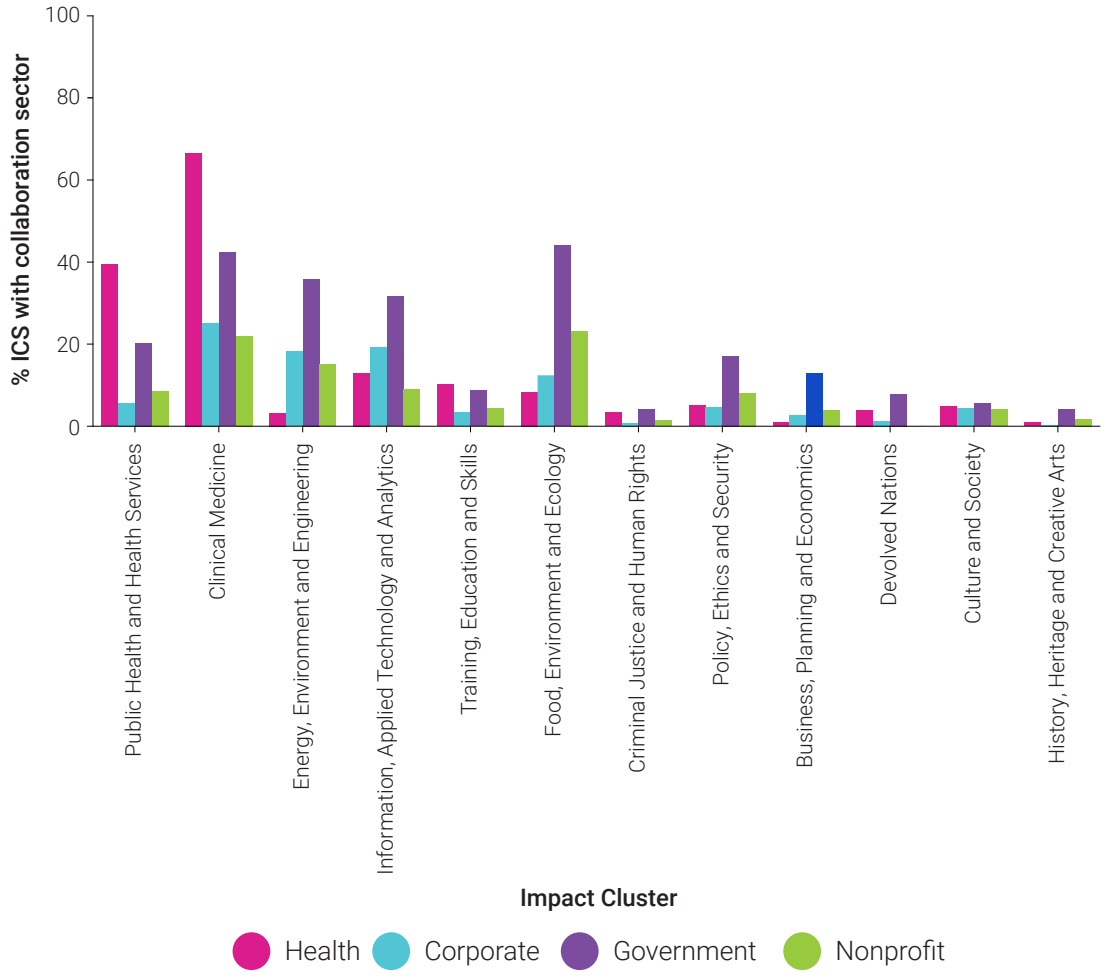
Lastly, we examined the relationship between collaboration and impact clusters. The results are summarised in Figures 20 and 21, showing that while all collaboration forms occurred across topics, some areas featured higher levels. For example, there were high multilateral and international collaboration rates within Cluster 2 (Clinical Medicine) and Cluster 6 (Food, Environment and Ecology), and more collaboration with health-sector organisations occurred in Clusters 1 (Public Health and Health Services) and 2 (Clinical Medicine). Conversely, collaboration with the corporate sector occurred in just under 20% of the ICSs associated with Cluster 3 (Energy and Environment) and Cluster 4 (Information and Applied Technology). Impact topics relating to medicine, treatment and public health tended to feature more collaboration with healthcare-sector organisations. In contrast, collaboration with the corporate sector occurred more frequently in topics relating to IT, engineering, drug discovery and clinical trials. Topics around clinical medicine and energy tended to have higher levels of collaboration with government organisations. Finally, collaboration with non-profit organisations typically related to environmental and energy-related topics, infectious disease, genetic testing, and vaccination. For further details on collaboration across the 79 impact topics, see Annex D.

Figure 20. Collaboration Mode by impact topic Cluster



Source: Data from Web of Science, provided by Clarivate

Figure 21. Collaboration Sector by impact topic Cluster



Source: Data from Web of Science, provided by Clarivate

3.1.3. Bibliometric impact

As reported in Section 3.1.1, we matched 20,548 DOIs to records in the Web of Science. The Web of Science database tracks citations to articles and provides a range of citation indicators that bibliometricians use to report on citation impact. 'Best practice' uses a normalised metric that accounts for relative differences in citation behaviour across disciplines, publication type (article, reviews, books, etc.) and publication year. Citations are either expressed as a fraction of the global average – defined by Clarivate as Category Normalised Citation Impact (CNCI) – or as a percentile.

Table 12 summarises the citation impact of underpinning research, providing the mean and median CNCI and the percentage of Highly Cited Papers (HCPs). In this context, HCPs are defined as those in the top one percentile for the field and year of publication. Most underpinning research performed better than the global average CNCI of '1.0', with the highest citation counts associated with research from Panel A. The percentage of HCPs was well above the global 1% average and significantly higher across all panels.

Table 12. Citation Impact by Panel

Panel	No. of DOIs	No. of Web of Science records	No. of HCPs	Mean CNCI	Median CNCI	% HCP
All	25,433	20,548	2,008	4.52	1.61	9.77
A	7,333	6,818	1,021	5.88	1.98	14.98
B	6,230	5,425	469	4.84	1.35	8.65
C	8,351	6,580	446	3.19	1.51	6.78
D	3,811	1,976	104	3.3	1.48	5.26

Source: Data from Web of Science, provided by Clarivate

Table 14 summarises the results analysed at the UoA level, showing that the underpinning research's citation impact was above the global average in all areas and notably high (with a median CNCI greater than twice the global average) in UoAs 1, 2, 9, 15, 19, 21 and 30.

We note, however, that the analysis of global trends in citation performance shows that international collaboration typically leads to higher citation impact.[43] To test this against the underpinning research submitted to REF 2021, we calculated citation indicators for various subgroups associated with particular collaboration modes or sectors, as presented in Table 13. The results show a clear tendency for a higher CNCI when examining international or multilateral publications and those with health, corporate, government and non-profit partners.

Table 13. Citation Impact by Collaboration Mode/Sector

Collaboration Mode/Sector	ICS count	No. of Web of Science records	Mean CNCI	Median CNCI
None	2,687	4,845	2.81	1.25
Domestic	3,538	7,565	3.86	1.49
International	3,288	7,891	6.17	2.04
Multilateral	675	1,085	15.5	4.93
With Health	955	2,426	9.57	2.84
With Corporate	556	896	8.28	2.26
With Government	1,266	2,695	9.83	2.54
With Non-profit	593	1,016	15	3.42

Source: Data from Web of Science, provided by Clarivate

43 Adams et al. (2019).

Table 14. Citation Impact by UoA

UoA	UoA Label	No. of DOIs	No. of Web of Science records	No. of HCPs	Mean CNCI	Median CNCI	% HCP
1	Clinical Medicine	1,384	1,316	385	10.64	3.7	29.26
2	Public Health, Health Services and Primary Care	824	755	151	9.28	2.71	20
3	Allied Health Professions, Dentistry, Nursing and Pharmacy	2,038	1,859	140	3.03	1.29	7.53
4	Psychology, Psychiatry and Neuroscience	1,668	1,544	196	4.55	1.84	12.69
5	Biological Sciences	1,024	980	158	5.58	1.96	16.12
6	Agriculture, Food and Veterinary Sciences	554	516	46	3.39	1.83	8.91
7	Earth Systems and Environmental Sciences	802	762	96	4.5	1.86	12.6
8	Chemistry	584	561	61	6.06	1.67	10.87
9	Physics	835	794	121	11.52	2.06	15.24
10	Mathematical Sciences	835	735	49	3.83	1.22	6.67
11	Computer Science and Informatics	1,288	918	62	3.44	1.14	6.75
12	Engineering	1,960	1,724	86	2.5	1.1	4.99
13	Architecture, Built Environment and Planning	546	460	24	2.55	1.01	5.22
14	Geography and Environmental Studies	868	772	79	3.76	1.72	10.23
15	Archaeology	229	142	23	10.18	2.32	16.2
16	Economics and Econometrics	308	257	21	3.31	1.61	8.17
17	Business and Management Studies	2,009	1,654	74	2.66	1.32	4.47
18	Law	622	351	27	3.71	1.89	7.69
19	Politics and International Studies	616	449	31	3.72	2.09	6.9
20	Social Work and Social Policy	825	660	48	2.87	1.47	7.27
21	Sociology	433	321	48	5.38	2.23	14.95
22	Anthropology and Development Studies	280	196	14	2.98	1.54	7.14
23	Education	912	683	32	2.56	1.52	4.69
24	Sport and Exercise Sciences, Leisure and Tourism	806	721	39	2.19	1.27	5.41
25	Area Studies	180	113	6	2.64	1.86	5.31

UoA	UoA Label	No. of DOIs	No. of Web of Science records	No. of HCPs	Mean CNCI	Median CNCI	% HCP
26	Modern Languages and Linguistics	435	221	13	2.79	1.49	5.88
27	English Language and Literature	664	285	6	2.19	1.01	2.11
28	History	624	353	28	3.89	1.96	7.93
29	Classics	152	56	1	1.56	1.15	1.79
30	Philosophy	345	214	21	5.64	2.23	9.81
31	Theology and Religious Studies	194	103	1	1.97	1.41	0.97
32	Art and Design: History, Practice and Theory	417	214	7	2.81	1.23	3.27
33	Music, Drama, Dance, Performing Arts, Film and Screen Studies	373	174	7	4.26	1.6	4.02
34	Communication, Cultural and Media Studies, Library and Information Management	443	253	15	3.12	1.32	5.93

Source: Data from Web of Science, provided by Clarivate

Like the interdisciplinarity analysis presented in Section 3.1.1, it is impossible to state whether research leading to impact is more or less well cited than others without a benchmark dataset to compare these metrics against. However, it is possible to compare it to a global benchmark by using the way the citation indicator is implemented. The outputs submitted to REF represent one possible benchmark for future analysis.

3.1.4. Funding characteristics

As noted above, collaborations with industry expressed through co-authorship on publications were relatively low across the publication set. However, we also identified collaboration with industry through industry funding. Several industrial funders were identifiable from the contextual data, although few case studies tended to acknowledge industry funding specifically. Box 8 presents the key industry funders identified in ICSs.

Box 6. The top ten commonly mentioned industry funders identified in ICSs

GlaxoSmithKline
Pfizer
AstraZeneca
Google
Boehringer Ingelheim
Novartis
EDF
BAE Systems
Rolls Royce
Siemens

Chapter 4

Change and continuity relative to REF 2014

Box 7. Key findings

There were a few key differences between REF 2014 and REF 2021, including allowing the submission of continued ICSs and including impacts on teaching and students.

Our analysis suggests that the HEIs found this guidance on continued case studies challenging to interpret, as some ICSs submitted as 'continued' did not meet the criteria as understood by the study team. Conversely, others that did appear to meet the criteria were not submitted as such.

Regarding the inclusion of impacts on teaching and students, we identified only nine ICSs submitted to REF 2021 that would likely have been ineligible in REF 2014, suggesting that HEIs did not take advantage of this rule change.

4.1.Changes between REF 2014 and REF 2021

Several changes were made to REF 2021 after implementing recommendations from Lord Stern's independent review of REF 2014,[44] as summarised in Box 8. Regarding the REF's impact component, the most significant change was the increase in weighting from 20% to 25%.

Alongside these core changes, the 2021 guidance documents contained a small number of technical changes, including the ability to re-submit case studies from 2014 if they met the 2021 eligibility criteria (i.e. the revised window for underpinning research and the assessment period for the impact described).[45] As detailed below, the Guidance on Submissions document notes that 'submitting units will be required to identify continued case studies in the case study template'.[46] In addition, the 2021 REF guidance document specified that 'impacts on students, teaching or other activities both within and/or beyond the submitting HEI are included'[47] within the definition of impact, representing another change from REF 2014. Additional panel-specific guidance was provided for submitting continued case studies and including impacts on teaching and students. Below, we review these two changes' impact on the REF 2021 submission types.

4.1.1. Continued case studies

Of the 6,361 ICSs submitted to REF 2021, a total of 322 (5.1%) were presented as a continuation from a REF 2014 submission. Table 15 shows some differences by Panel. It is hard to interpret whether these differences were discipline-related due to different panel-level guidance or reflected an insufficient understanding of what was meant by 'continued case studies'. For example, Panel A asked 'to receive information on how any

44 Stern (2016).

45 Research England (2020a).

46 Research England (2020a).

47 Research England (2020a).

Box 8. Key differences between REF 2014 and REF 2021

- REF 2021 required institutions to submit all staff with significant responsibility for research, whereas REF 2014 allowed them to choose staff for submission. As a result, there was a 46% increase in staff submitted to REF 2021.
- REF 2021 featured a more flexible output requirement for each submitted staff member, with a minimum of one output but no more than five outputs attributed to them. In contrast, REF 2014 required all submitted staff members to have four outputs.
- REF 2021 allowed institutions to submit any former staff's outputs if the results became publicly available while the submitting HEI still employed the staff member, whereas REF 2014 did not.
- The impact weighting increased from 20% to 25% between REF 2014 and REF 2021. REF 2021 assessed impacts solely from the submitted ICSs; information about the environmental factors facilitating impact was submitted in separate environment statements.
- The number and make-up of a small number of UoAs changed between REF 2014 and REF 2021.

continued case study relates to that submitted in REF 2014. Panel members will have access to the REF 2014 database and may refer to this to understand the context of the 2021 case study', whilst Panels B, C and D requested the opposite, stating they did 'not wish to receive information on how any continued case study relates to that submitted to REF 2014'.[48]

Table 15. Distribution of self-reported ICS 'continuations' by panel

Panel	Number of 'continued' ICSs	Total number of ICSs	% of 'continued' ICSs
A	85	1419	6.0%
B	128	1268	10.1%
C	64	2146	3.0%
D	45	1528	2.9%
Total	322	6361	5.1%

48 Research England (2020b).

Further analysis examining the similarity of text and DOIs associated with the ICSs suggests there may have been some confusion about what a 'continued case study' meant. The guidance notes that:

> 'Case studies will be considered to be continued if **both**:
>
> (a) The body of underpinning research is the same as described in a 2014 case study. This should not be understood solely in relation to the referenced outputs, but means that the continued case study does not describe any new research having taken place since the previous case study that has made a distinct and material contribution to the impact **and**
>
> (b) there is significant overlap in the impact described, so that the impact types and beneficiaries are broadly the same as described in the 2014 case study.'[49]

To understand how HEIs interpreted the guidance, we analysed the 322 self-declared continued ICSs and the remaining 6,039 in REF 2021 to assess how far they could be considered a continuation of a REF 2014 ICSs. This involved examining the number of references cited in the underpinning research for 2014 and 2021, covering point (a) in the above definition, and the similarity of the text, covering (b). We measured the texts' similarity on a scale from '0' to '1', where '1' indicates identical text and '0' indicates total dissimilarity. The findings are shown in Table 16.

Based on the above definition of a 'continued case study', the similarity level between the 322 ICSs labelled as 'continued' from REF 2014 to REF 2021 is lower than expected. The underpinning research shows that only four of the ICSs cited all six of the same publications in 2021 as in 2014. Given that the guidance specifies that the underpinning research should be the 'same', we would expect this to be higher. Even taking a lower threshold where three of the six submitted references are the same in 2021 as in 2014, only 72 of the 322 (22%) met these criteria. Looking at the similarity of ICS text, we took a threshold of 50% similarity or more as describing 'significant overlap in the impact described', whereby 182 of the 322 (57%) self-declared continued ICSs were similar.

We also applied the same criteria for ICSs not reported as 'continued', finding that 85 out of 6,039 (1.4%) cite three or more of the same underpinning research publications as a 2014 ICS. When we examined the similarity of the text, we found that 1,175 of the 6,039 ICSs (19%) were at least 50% similar to a 2014 case study.

When we combined those two rules (i.e. three or more identical references and a text-similarity score above 50%), 17% of continued ICSs (55 of the 322) meet the criteria, versus 1% of ICSs illustrated in the greyed-out areas in Table 16 (64 of 6,039). Although this is an approximation, this analysis suggests that HEIs that submitted to REF 2021 may have found this guidance difficult to interpret, as ICSs submitted as 'continued' did not meet the criteria (based on our definition), while others that did were not submitted as 'continued'.

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49 Research England (2020a).

Table 16. The application of guidance on continued ICSs

322 self-declared 'continued' ICSs									6,039 original ICSs								
	No. of identical references in the underpinning research									No. of identical references in the underpinning research							
Text similarity score	0	1	2	3	4	5	6	Total	Text similarity score	0	1	2	3	4	5	6	Total
0.0<=s<0.1	0	0	0	0	0	0	0	0	0.0<=s<0.1	1	0	0	0	0	0	0	1
0.1<=s<0.2	4	0	0	0	0	0	0	4	0.1<=s<0.2	420	2	1	0	0	0	0	423
0.2<=s<0.3	23	2	3	2	0	0	0	30	0.2<=s<0.3	1,694	24	7	1	1	0	0	1,727
0.3<=s<0.4	22	7	6	2	3	0	0	40	0.3<=s<0.4	1,606	46	25	4	4	0	0	1,685
0.4<=s<0.5	29	17	10	5	4	0	1	66	0.4<=s<0.5	916	70	31	11	0	0	0	1,028
0.5<=s<0.6	30	6	8	11	4	0	1	60	0.5<=s<0.6	505	70	44	14	3	1	0	737
0.6<=s<0.7	24	15	15	7	8	4	2	75	0.6<=s<0.7	263	46	38	13	7	2	1	370
0.7<=s<0.8	10	7	7	4	5	1	0	34	0.7<=s<0.8	72	27	17	10	6	0	0	132
0.8<=s<0.9	2	2	1	2	4	2	0	13	0.8<=s<0.9	21	4	4	3	0	1	1	34
0.9<=s<1.0	0	0	0	0	0	0	0	0	0.9<=s<1.0	0	0	0	2	0	0	0	2
Total	144	56	50	33	28	7	4		Total	5,489	289	167	58	21	4	2	

Note: The grey boxes indicate ICSs deemed as 'continued' from REF 2014 based on our definition.

4.1.2. The inclusion of teaching

We reviewed the 152 ICSs submitted to REF 2021 within the impact topic 'students and education' to determine how many were likely to have been submitted due to the changed rules about impacts on students and teaching between REF 2014 and REF 2021. As Table 17 illustrates, we identified only nine ICSs likely to have been ineligible in 2014 that could be submitted under the new rules in 2021, suggesting that HEIs did not take advantage of this rule change.

Table 17. Examples where impacts on teaching were submitted (HEI and ICS titles)

Liverpool Hope University	Improving Health and Nutrition of University Students - Change in Practice in Response to the Local Assessment of Nutritional Status
Liverpool Hope University	Improving Professional and Public Understandings of Life in Palestine
London Metropolitan University	Research-informed pedagogy for social justice in Higher Education
Ravensbourne University London	Learning Technology Research Centre
The Open University	Transforming individual informal readers into communities of reader-researchers
The Open University	Open Justice: new pathways for promoting legal understanding and access to justice
University of Bristol	Transforming clinical understanding and the practice of health professionals through the Intercalated BA in Medical Humanities
University of Edinburgh	Massive Open Online Learning in Philosophy: Engaging new learners, enhancing the effectiveness of teachers, and improving strategies for online learning
University of Winchester	Promoting responsible management and sustainability through Higher Education

Chapter 5

Government policy and strategy

5.1. Relation to government strategies

To explore how the impact described in ICSs related to government economic and industrial strategies, we used Overton data (Box 9) to assess how much the DOIs referenced in ICSs were also referenced in policy documents within Overton.

Table 18 lists the sources for policy documents in Overton, including the total number of unique policy documents from those sources, the total number of unique DOIs cited by those policy documents, the total number of unique ICSs linked to the policy documents through those DOIs, the number of unique ICSs linked to the policy documents across the four Panels, and the number of ICSs referencing a policy document within Section 5 of the ICS ('Sources to corroborate the impact'). Table 18 shows that the ICSs were linked to several broad policy areas. Most of the listed sources were linkable to ICSs through shared DOIs. Certain sources linked to more ICSs than others through this shared evidence base. For example, the National Institute for Health and Care Excellence (NICE), which provides national guidance and advice to improve human health and social care, links to 2014 ICSs through common DOIs. Most of these are in Panel A.

As well as linking through common DOIs, ICSs may reference policy documents through Section 5 ('Sources to corroborate impact'). Interestingly, although many sources listed below shared common DOIs with numerous ICSs, a far smaller proportion of ICSs specifically referenced policy sources in Section 5. One possible reason is that ICSs can only list a certain number of sources and thus may have had insufficient space to reference the policy documents. Another is that, despite having the underpinning research in common, the impact the ICS described may not have linked to the policy area or paper. Table 18 also shows that some sources were more likely to contain large numbers of DOIs in the policy documents, making it more likely they will cite ICSs. This is particularly true of sources within the clinical and health space, such as the NHS and NICE, whose policy documents contained large numbers of DOIs due to the need to cite research evidence to support medical practices – a norm that may apply less in other policy areas.

Box 9. The Overton grey literature database

Overton[50] is a grey literature database providing a searchable index of policy documents from UK and international sources. It indexes more than 30,000 international sources within a database that links more than five million documents to scholarly literature via a network of 14 million citations. It is possible to filter the database to select policy documents from specific sources (such as UK-based organisations). We explored the degree to which DOIs referenced in ICSs were also referenced in policy documents within Overton.

50 Overton (2023).

Table 18. A list of UK Overton sources

Source	No. of unique policy documents	No. of unique DOIs cited by policy docs	No. of unique ICSs linked to policy docs	No. of unique ICSs linked to policy docs – Panel A	No. of unique ICSs linked to policy docs – Panel B	No. of unique ICSs linked to policy docs – Panel C	No. of unique ICSs linked to policy docs – Panel D	No. of unique ICSs referencing policy doc in Section 5
Hansard UK	11	0	0	0	0	0	0	0
Law Commission	191	563	12	1	0	9	2	13
NHS Clinical Commissioning Groups	1,047	2,157	42	36	0	6	0	0
NHS England	749	1,743	41	34	1	6	0	31
NHS Scotland	102	12	2	2	0	0	0	0
NHS Trusts	1,550	5,016	52	39	0	12	1	0
NICE	1,115	87,525	204	177	7	20	0	97
National Audit Office	204	18	2	0	0	2	0	2
Northern Ireland Assembly Research and Information Service	10	11	0	0	0	0	0	0
Northern Ireland Executive	300	225	4	0	0	4	0	2
Scottish Parliament Official Reports	37	1	0	0	0	0	0	0
Scottish Parliament Research Briefings	20	35	1	0	0	1	0	0
The Equality and Human Rights Commission	11	55	2	0	0	2	0	0
The Scottish Government	289	576	16	7	1	7	1	3
The UK Government	5,815	20,976	305	136	40	124	5	91
The Welsh Government	977	3,004	48	25	4	18	1	16
UK Parliament Research Briefings	1,999	1,854	59	25	8	26	0	23
UK Parliament Select Committee Publications	3,185	3,222	156	51	19	75	11	71

Further analysis showed that common DOIs in the UK Government sources linked to 305 ICSs. Table 19 lists the top 20 sources (regarding the number of unique ICSs they link to), demonstrating a broad link to different policy areas. However, there was no apparent concentration in specific areas. Public Health England (PHE) linked to the highest number of ICSs, and a high proportion of case studies also referenced PHE in Section 5.

Different sources tended to link to ICS from particular main panels. In general, a high number of sources linked to ICSs from Panels A and C. The Government Office for Science and the Department for Education tended to link to more ICSs from Panel C, whereas the Department of Health and Social Care linked to more ICSs from Panel A.

5.2. How HEIs contribute to government policy priorities

We conducted deep dives on three policy priorities – COVID-19, net zero and Place[51] – for a more in-depth analysis of ICS data across these three areas. Our approach combined quantitative text mining with a more in-depth qualitative review of ICSs. Although text mining is a valuable approach, ICSs provide considerable rich, nuanced qualitative information relating to the various impact types demonstrated. Reading the ICS enabled us to collect more detailed information supporting our thematic analysis.

This approach involved defining a search strategy for the policy area, identifying the relevant ICSs, undertaking initial quantitative data analysis on the identified subsets and reading the case studies in detail.

5.3. The impact of UK university research on COVID-19

The COVID-19 pandemic directly impacted the REF in two substantive ways. First, it necessitated an extension of the submission date to March 2021 and, importantly for this study, an extension of the assessment period for ICSs to 31 December 2020, explicitly allowing the inclusion of COVID-19-related ICSs. This deep dive examines how UK universities contributed to the pandemic based on 66 ICSs identified through keyword searches of all 6,361 ICSs, as described in Box 10.

51 This refers to the broad political priority area around regional and geographical inequality, also referred to as 'levelling up'.

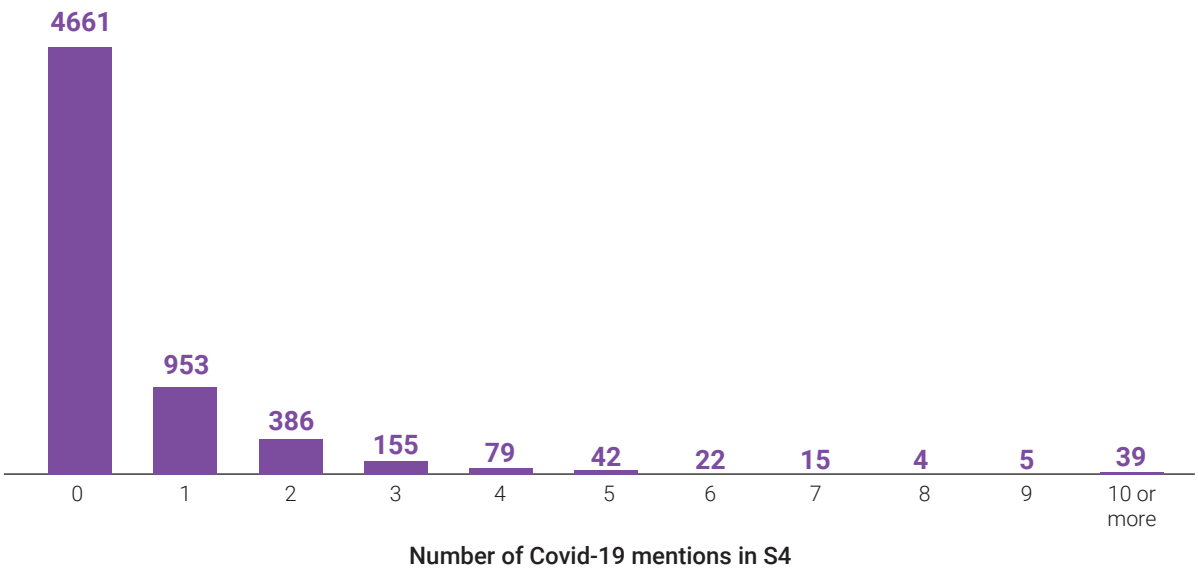
Table 19. A list of UK Government Overton sources

Source	No. of unique policy documents	No. of unique DOIs cited by policy docs	No.of unique ICSs linked to policy docs	No. unique of ICSs linked to policy docs – Panel A	No. of unique ICSs linked to policy docs – Panel B	No. of unique ICSs linked to policy docs – Panel C	No. of unique ICSs linked to policy docs – Panel D	No. of unique ICSs referencing policy doc in Section 5
Public Health England	608	4,012	81	72	6	3	0	17
Government Office for Science	47	1,225	28	7	7	14	0	3
Department for Education	456	919	26	6	1	19	0	8
Department of Health and Social Care	199	999	25	18	5	2	0	10
Scientific Advisory Group for Emergencies	66	640	20	13	4	3	0	2
Department for Business, Energy & Industrial Strategy	348	1,187	18	5	6	7	0	6
Department for Environment, Food & Rural Affairs	197	494	12	8	3	1	0	4
Department for Digital, Culture, Media & Sport	123	358	11	2	0	7	2	6
Department for Transport	211	358	11	1	5	5	0	6
Offshore Petroleum Regulator for Environment and Decommissioning	6	334	10	1	6	3	0	0
Environment Agency	142	460	10	3	1	6	0	1
Migration Advisory Committee	34	44	9	0	0	9	0	0
HM Treasury	231	79	9	1	1	7	0	4
Home Office	182	206	8	3	0	5	0	6
Government Equalities Office	21	243	8	0	0	8	0	1
Marine Management Organisation	76	372	7	1	5	1	0	1
Ministry of Justice	118	302	6	3	0	3	0	0
Social Mobility Commission	17	404	6	2	1	3	0	2
Centre for Environment, Fisheries and Aquaculture Science	38	990	5	2	1	2	0	0
Centre for Data Ethics and Innovation	2	84	5	0	1	3	1	0

Box 10. Keyword searches of ICSs

We searched for the key terms 'covid' and 'coronavirus' and calculated the number of times they were mentioned in Section 4 ('Details of impact') of the ICS. As Figure 22 illustrates, the distribution of mentions ranged from 15% for a single mention to 0.6% for ten or more mentions. About a third of ICSs mentioned COVID-19 once or more, but in most cases, these were in passing (e.g. the pandemic's impact on data collection) and not central to the ICS. Therefore, we reviewed some ICSs and agreed that a threshold of eight or more mentions was the most appropriate, identifying no false positives. Using this approach, we identified 48 ICSs. We also included ICSs that mentioned 'covid' or 'coronavirus' at least once in the ICS title, as these were also likely to describe impacts related to COVID-19. This yielded a further 44 ICSs. After removing duplicate ICSs, we reviewed a total of 66 ICSs for this deep dive.

Figure 22. Number of ICSs mentioning COVID-19-related terms



The impact wheel in Figure 23 illustrates how COVID-19-related ICSs were distributed across the four REF Panels, highlighting the cross-disciplinary nature of COVID-19 research. Perhaps unsurprisingly, most case studies were distributed across Panels A (n=25) and B (n=25), where most ICSs came under UoA 1 (Clinical Medicine), UoA 2 (Public Health, Health Services and Primary Care), UoA 10 (Mathematical sciences) and UoA 12 (Engineering). For example, 23% of the 66 COVID-19-related ICSs fell within UoA 1 (Clinical Medicine), and 17% of the Case Studies fell within UoA 10 (Mathematical Sciences).

Figure 23. Impact wheel for the COVID-19-related deep dive

This figure shows the impact wheels for the COVID-19 deep dive. The 'n' represents the number of ICSs. The four colours represent the four panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green). Different shades of the same colour represent the 34 UoAs. The impact wheel's spoke sizes reflect how frequently impact within that UoA occurred. Table 20 highlights several features of ICSs regarding the nature of impact, location, underpinning research and funder and provides the percentage of case studies within the COVID-19 cluster tagged with these characteristics. Regarding the nature of the impact, the top two topic-model topics ICSs came under were 'clinical trials' (15%) and 'viruses and vaccination' (15%). Most case studies reported impacts in Europe (92%), although impacts occurred across all continents. Regarding the underpinning research, the top FoR codes tagged across ICSs included 'public health and health services' (67%) and 'clinical sciences' (62%), with 'medical microbiology, 'statistics' and

'microbiology' all featuring in the top five. Approximately half of the ICSs were funded by a UKRI funder (53%, n=35); 35% via funding from the Medical Research Council (MRC), 32% from the Engineering and Physical Sciences Research Council (EPSRC) and 17% funding from the Biotechnology and Biological Sciences Research Council (BBSRC).

Table 20. Features of the COVID-19-related ICSs

Nature of impact: Top five primary topics	% of cluster ICSs (n=66)	% of all ICSs (n=6,361)
Clinical trials	15%	5%
Viruses and vaccination	15%	1%
Computer science and data analysis	9%	1%
Patient care	9%	2%
Digital environments	9%	4%
Location of impact: Continent		
Europe	92%	91%
North America	44%	40%
Asia	30%	31%
Africa	20%	14%
Oceania	17%	19%
South America	11%	10%
Underpinning research: Top five fields		
Public health and health services	67%	18%
Clinical sciences	62%	20%
Medical microbiology	20%	2%
Statistics	12%	2%
Microbiology	8%	1%
UKRI research funder		
All	53%	48%
Central funding (inc. Research England funding, Global Challenges Research Fund (GCRF), Newton Fund, etc.)	15%	8%
Arts and Humanities Research Council (AHRC)	0%	11%
BBSRC	17%	5%
EPSRC	32%	15%
Economic and Social Research Council (ESRC)	14%	16%
Innovate	11%	8%
MRC	35%	8%
Natural Environment Research Council (NERC)	6%	6%
Science and Technology Facilities Council (STFC)	6%	3%

The COVID-19 pandemic presented a global health emergency, disrupting societies worldwide. Alongside its clinical challenges, the pandemic also presented logistical challenges, as disease control largely depended on appropriate regulations and public guidelines. Research at UK universities significantly impacted medical advancements, enabling the treatment of the disease. In addition, research also impacted UK and international government policy responses regarding strategy, planning and communication, with critical components including preventative interventions, surveillance and effective public communication. HEIs initiated new research projects to combat the challenges associated with the pandemic and adapted or reappropriated existing research efforts towards addressing the pandemic's challenges. The pandemic's unprecedented reach and severity required novel solutions, generating innovative technologies and surveillance and diagnostic tools through UK research. Alongside the quantitative analysis above, we read and reviewed 66 ICSs focused on COVID-19 and identified several salient themes, as described below.

5.3.1. Research conducted at UK HEIs informed global clinical guidelines and practice relating to treating COVID-19, saving lives and easing patients' symptoms worldwide

As early as 2 January 2020, researchers at the University of Oxford initiated the first clinical trials for COVID-19 treatments in collaboration with Chinese partners. By 19 March, they had launched the ground-breaking RECOVERY (Randomised Evaluation of COVID-19 Therapy) trial led by the University of Oxford[52] and designed in collaboration with Lancaster University[53] and the University of Nottingham.[54] By June 2020, RECOVERY had proven that dexamethasone reduces death rates among seriously ill patients, while hydroxychloroquine and lopinavir-ritonavir were ineffective. These findings rapidly changed clinical guidelines and practice globally, including in the NHS and the US National Institutes of Health, and informed WHO recommendations. As a result, dexamethasone use increased COVID-19 patients' survival chances and decreased hospitalisation, estimated to have saved 650,000 lives in 2020 alone. Additionally, it prevented potential harm and wasted resources by proving that hydroxychloroquine and lopinavir-ritonavir were ineffective.[55]

Research at UK HEIs made other impactful contributions to clinical practice related to COVID-19. For example, the REMAP-CAP trial at Imperial College London showed that hydrocortisone could help reduce mortality, informing national and global treatment recommendations (including those by WHO and NICE) and saving lives.[56] Additionally, non-pharmaceutical discoveries supported international medical practices, such as 'UCL-Ventura', a continuous positive airway pressure (CPAP) device used to treat respiratory

52 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/1c4caf3b-6c0d-432a-b8a5-a4d4279498a8?page=1

53 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d7f99118-a800-46dc-a77e-cce32d0e2588?page=1

54 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/742295f6-f139-4369-85c0-2d95a38cba00?page=1

55 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/1c4caf3b-6c0d-432a-b8a5-a4d4279498a8?page=1

56 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/b1400fd3-4687-453f-a939-49d9e6b76f50?page=1

distress safely and effectively in COVID-19 patients. Researchers at University College London (UCL) produced and delivered over 10,000 devices to 125 UK hospitals in under a month from inception in collaboration with Mercedes-AMG HPP, a Formula One engine manufacturer owned by Mercedes-Benz. The devices were subsequently supplied and manufactured through openly available design and manufacturing in 20 other countries.[57]

Researchers at the University of Birmingham led the CovidSurg collaborative, an initiative that collected and consolidated empirical data and expert views to formulate early surgical guidance during the COVID-19 pandemic. These guidelines were used worldwide, particularly in the UK, Austria, Brazil, Canada and Italy. Topics included safety around performing surgery in COVID-19-exposed hospitals, the continuation of elective surgery, and strategies to make surgery safer during the pandemic. Where applied, these guidelines are estimated to have contributed to a 50% reduced risk of death for surgical patients with peri-operative COVID-19 infections and a 33% reduced risk of developing respiratory complications.[58]

Moreover, this public health emergency's unique nature required the rapid reassessment of ethical standards for clinical research. UCL played a crucial role in this process globally by providing ethics advice, e.g. to the APANDEMIC initiative that aims to inform and support real-world evidence for COVID-19 research and decision-making, and informing discussions with the US Food and Drug Administration (FDA), helping approve medicines for broader use at earlier clinical-trial stages.[59]

5.3.2. Developing productive policy interventions required extensive and accurate data, which UK HEIs contributed to through tools and methods related to diagnostics, contact tracing and other surveillance forms

To help keep track of COVID-19's progression, UK HEIs conducted and facilitated different forms of large-scale data collection. These included diagnostics tools such as CovidNudge, a platform for rapid point-of-care (POC) testing of SARS-CoV-2 developed at Imperial College London. As the platform did not require sample handling, tests could be conducted without skilled administrators, enabling sensitive, specific and rapid testing on a large scale. As such, CovidNudge was included in PHE's testing strategy and by the end of December 2021, it had enabled 62,000 tests across 87 NHS sites.[60] Another critical HEI response relating to diagnostics was King's College London's COVID-19 Symptom Study smartphone app, developed in collaboration with ZOE Global, a health technology spinoff from King's that developed a mobile platform to gather users' nutrition data. Up to four million people globally used the app and recorded real-time data on known or potential COVID-19 symptoms, data subsequently used to update national and global public and clinical guidance, inform UK national strategies for containing infection, identify UK COVID-19 hotspots, and

57 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/03cf0e47-ac71-41f7-aa8a-d9dc6061d527?page=1

58 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/bbb9a65f-5cee-4520-8d24-c4c36aa260c1?page=1

59 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/999f7328-c0ea-441f-8808-bee2281a2c27?page=1

60 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/3721ab97-3924-439c-9fcf-45b23e25ec94?page=1

help identify key traits of Long COVID in a non-clinical population for the first time.[61]

Research at UK HEIs also helped facilitate contact tracing, another component in tracking potential infection. Research at the University of Oxford provided NHSX (a joint UK government organisation for digital transformation across the NHS) with evidence supporting contact tracing's potential to reduce transmission, helping establish the necessary prerequisites for a contract tracing app.[62] Moreover, contact tracing operated in a complicated legislative environment that required careful consideration to facilitate the tool's use and acceptance. UCL helped achieve this through global and local analysis of privacy and data protection laws, informing private and public actors in designing and implementing these apps in the UK and worldwide.[63]

5.3.3. Modelling was prominent in research impacting COVID-19, enabling better monitoring of the pandemic's rapid and unpredictable developments

As the impact wheel in Figure 23 illustrates, mathematics and modelling were major UK HEI contributions to combating the pandemic. Effective modelling was imperative for transforming the surveillance data collected through the methods described earlier and other surveillance techniques[64,65,66] into actionable insights. For example, research at the University of Oxford supporting contact tracing apps involved modelling, adopting a previously developed agent-based mathematical model for social networks to understand COVID-19 transmission.[67,68] A team at the London School of Hygiene and Tropical Medicine (LSHTM) developed mathematical models to estimate the comparative impacts of control measures on the number of COVID-19 cases, deaths and demands for hospital services.[69] Modelling these different scenarios directly informed the UK government in strategy decisions concerning lockdowns, school closures and NHS capacity.[70] Other significant contributions came from research at the University of Manchester, where modelling identified a three-day infection doubling time rather than the previously followed five-to-six-day model, driving the timing of the first national lockdown in the UK and continuing to inform the implementation of measures

61 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/3940934b-c878-477a-bb79-9e65de2701a2?page=1

62 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d3d20ce5-b625-4da5-9e0e-8e4bf87ef238?page=1

63 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/9b97d849-3e5f-4b33-8069-e90ef8e37d2f?page=1

64 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/5968e456-e3b5-4601-bc36-3aa83df8381e?page=1

65 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/ee8ae278-b0a5-4b20-94c0-4858273fa796?page=1

66 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d54c7e46-dee1-4228-8382-38f25f4e5b90?page=1

67 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d3d20ce5-b625-4da5-9e0e-8e4bf87ef238?page=1

68 Hinch et al. (2020).

69 Davies et al. (2020).

70 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/f5ae0f0b-865d-46a9-918c-2eecb4111487?page=1

throughout the pandemic.[71] These are just some of UK HEIs' scientific contributions towards modelling and evidenced-based policies that helped contain COVID-19 and prevent infection.

5.3.4. A large proportion of HEI research impacting COVID-19 was explicitly conceived to address the crisis, while other research was reappropriated or adapted to meet the pandemic's challenges

The COVID-19 pandemic's disruptive nature turned many sectors' attention towards tackling emerging challenges, and UK research was no exception. Most of the research efforts listed above (and many more) responded to the global crisis by initiating new projects explicitly addressing the new challenges. Examples include the RECOVERY trial,[72] CovidNudge[73] and other diagnostics tools, contact tracing[74] and novel epidemiological models,[75,76,77] all initiated explicitly to address COVID-19-related challenges. The Oxford-AstraZeneca COVID-19 vaccine is another well-known example of research initiated as a direct response to COVID-19, developed by a collaborative partnership between the University of Oxford and the pharmaceutical company AstraZeneca. Immediately after SARS-CoV-2's genetic code was released in January 2020, researchers at the University of Oxford started designing the novel coronavirus antigen, subsequently producing the Oxford C-19 vaccine in their laboratory.[78] These researchers designed and implemented several rounds of clinical trials, demonstrating the vaccine's 70% efficacy and showing that a longer interval between the first and second dose was associated with higher efficacy. By the end of 2020, over 2.5 billion doses of the Oxford vaccine were provided worldwide, more than double that of any other vaccine provider when the ICS was written.[79]

Alongside the remarkable amounts of new research initiated in direct response to COVID-19, other significant impacts came from adapting existing research and research findings to the pandemic's challenges. For example, earlier research at King's College London on online misinformation was used to counter the impact of harmful and misleading information related to COVID-19. As the first pandemic in the online age, information spread through multiple channels in new and unpredictable ways (often without scientific evidence), increasing the risk of misinformation. Research at King's helped reduce this issue by influencing social media companies' content moderation, including

71 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d03d2b76-004f-4472-9821-a00927a75ac5?page=1

72 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/742295f6-f139-4369-85c0-2d95a38cba00?page=1

73 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d03d2b76-004f-4472-9821-a00927a75ac5?page=1

74 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d3d20ce5-b625-4da5-9e0e-8e4bf87ef238?page=1

75 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d3d20ce5-b625-4da5-9e0e-8e4bf87ef238?page=1

76 Hinch et al. (2020).

77 Davies et al. (2020).

78 van Doremalen et al. (2020).

79 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/52cf7a8d-5f6b-45bf-80b5-e4783723fd58?page=1

'de-platforming' key purveyors of conspiracy theories and 'fake news' related to COVID-19.[80] Another example of repurposed research is the medical device technologies developed at Imperial College based on ultra-low power complementary metal-oxide-semiconductor (CMOS) and ion-sensitive field-effect transistor-based microsystem (ISFET) electronics and biomedical microsystems. These enabled rapid and low-cost disease diagnosis, monitoring and treatment. After quick clinical-trial validation, these technologies were repurposed to enable 90-minute, lab-free COVID-19 tests routinely used in 500 NHS hospitals by December 2020.[81]

5.3.5. UK HEI responses to COVID-19 were characterised by speed, reflecting the pandemic's urgent nature

As demonstrated above, UK HEIs met the COVID-19 pandemic with a rapid response to develop new research projects and applications. The Oxford COVID-19 vaccine's clinical trials were designed and implemented at unprecedented speed, enrolling 1,077 participants between April 23 and May 21 in phase I/II clinical trials while simultaneously identifying vaccine manufacturers, industrial partners and licenses. By November 4, a total of 11,636 individuals had been vaccinated with the Oxford-developed ChAdOx1 nCoV-19 in clinical trials and in August 2020, AstraZeneca enrolled 32,449 US participants in a Phase III clinical trial. The vaccine received regulatory approval in December 2020. Moreover, the researchers developed the vaccine to be quick and easy to manufacture in different contexts, including low-or-middle-income countries.[82]

The COVID Symptom Study smartphone app King's and ZOEGlobal developed is another example of HEIs' rapid responses to the pandemic. The team engineered the app in March 2020, securing two million registrations by 24 March, only two weeks post-launch.[83] Furthermore, UCL-Ventura designed, produced and delivered its CPAP devices to 125 UK hospitals less than a month after the project's initiation.[84] Lastly, the RECOVERY trial was one of the earliest and fastest randomised trials for COVID-19 treatment, enabling improved clinical practice early in the pandemic.[85] These examples demonstrate the common theme of rapidity among UK HEI responses impacting the COVID-19 pandemic.

5.3.6. A broad range of disciplines beyond those in REF Panel A contributed to addressing the diverse challenges COVID-19 presented

Research at UK universities also contributed expertise to creatively address the broad range of expected and unexpected consequences for people's lives the COVID-19 pandemic brought.

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80 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/ac69527c-c303-4b9f-838c-b0b0c5d2e10e?page=1

81 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/80391231-68c6-4242-8cb0-4bb2ed2ac8ab?page=1

82 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/52cf7a8d-5f6b-45bf-80b5-e4783723fd58?page=1

83 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/c897ad2d-9af3-456b-9749-73e0ce3cf626?page=1

84 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/03cf0e47-ac71-41f7-aa8a-d9dc6061d527?page=1

85 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/1c4caf3b-6c0d-432a-b8a5-a4d4279498a8?page=1

The steep rise in sudden deaths brought widespread experiences of grief, which researchers at the University of Central Lancashire (UCLan) addressed through poetry. As the pandemic hit, a UCL poet who writes about loss and founded the Poetry, Grief and Healing project in 2017 initiated online writing workshops and created digital writing resources for NHS practitioners and the public. These initiatives helped 65 individuals process their grief and become less isolated, and some reported feeling empowered by learning to put their grief into writing.[86]

One of the more unexpected outcomes experienced worldwide was the loss and change in people's sense of smell due to COVID-19. Philosophy researchers at Birkbeck, University of London, made important contributions to the UK's response to this challenge. These researchers' previous work promoted flavour perception as part of the debate about the objectivity of taste, influencing the drinks and food industry and the medical sector. This work included collaborating with psychologists and neuroscientists to understand how sensory interactions affect flavour perception. During the pandemic, the researchers contributed their expertise in designing a survey of 40,000 COVID-19 patients that showed that, on average, COVID-19 led to an 80% drop in people's ability to smell and a 69% drop in their ability to taste. These findings contributed to these symptoms' addition to the UK's official list of COVID-19 symptoms in May 2020, making it a generally accepted predictor of COVID-19 and enabling earlier identification of infection.[87]

The effective dissemination of guidelines and other vital information was essential for governments to protect the public, which was particularly challenging in multilingual societies. Research on inclusive education and multilingualism at SOAS University of London helped address this challenge in Southern Senegal, where official information was communicated in French (only understood by a minority, as ex-colonial official languages are the dominant languages in this region). In collaboration with community members, the SOAS project team created a linguistically inclusive COVID-19 health information campaign that distributed posters and brochures in up to six different languages, increasing access to life-saving information.[88]

Therefore, the COVID-19 pandemic was not solely a medical challenge but affected societies and individuals in multiple ways. Research at HEIs utilised expertise in various disciplines to respond to this multifaceted global emergency.

5.3.7. Concluding reflections

Overall, this review shows that research at UK universities made a significant and far-reaching contribution to monitoring, managing and mitigating the COVID-19 pandemic's impact. Unsurprisingly, clinical medicine and other health-related disciplines dominated HEIs' responses to addressing the pandemic. However, other fields, such as mathematical modelling, also made vital contributions to tracing the virus's spread. Research at UK universities directly influenced global healthcare practices by shaping medical

86 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/5059a81d-f89f-47d9-8934-695f347fac42?page=1

87 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/da26ca12-5f5c-4c7c-9f02-2cb017ad26cd?page=1

88 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/20248a5d-9f94-4bf4-9380-5748b09c7f2d?page=1

protocols and contributing new methods and technologies to aid patient testing and treatment. Additionally, the research informed UK and international policy measures to contain infections. The UK university sector clearly 'leant into' the crisis with a mix of agility, pace and ingenuity, saving many thousands of lives worldwide and reducing the burden of high morbidity and long COVID. As noted earlier, this deep dive provides a small window into the contribution research at universities made. Much of this work remains ongoing and falls outside the extended REF impact window. No doubt many of the impacts described above are continuing, and further research is underway to understand long COVID's impact and how best to manage and treat the virus's after-effects.

5.4. The impact of research on net zero

Net zero refers to cutting greenhouse gas emissions and balancing emissions into the atmosphere with removal. Transitioning to net zero has become a global effort, and countries worldwide have set net zero targets. In 2015, 196 countries adopted the Paris Agreement to reduce global warming, build resilience to climate change[89] and reach net zero emissions by 2050. The UK government released a strategy setting out its policies for decarbonising the UK economy and ensuring the country can meet its net zero targets by 2050.[90] This deep dive examines how research at UK universities has contributed to research around net zero based on 80 ICSs identified through keyword searches of all 6,361 ICSs (as described in Box 11).

The impact wheel in Figure 24 illustrates that although net zero-related ICSs were evident in all four Panels, the vast majority were distributed across Panels B (n=45) and C (n=28). The most common UoAs ICSs came under across these Panels were UoA 7 (Earth Systems and Environmental Sciences), with 23% of ICSs), UoA 12 (Engineering), with 21% of ICSs, and UoA 13 (Architecture, Built Environment and Planning), with 11% of ICSs.

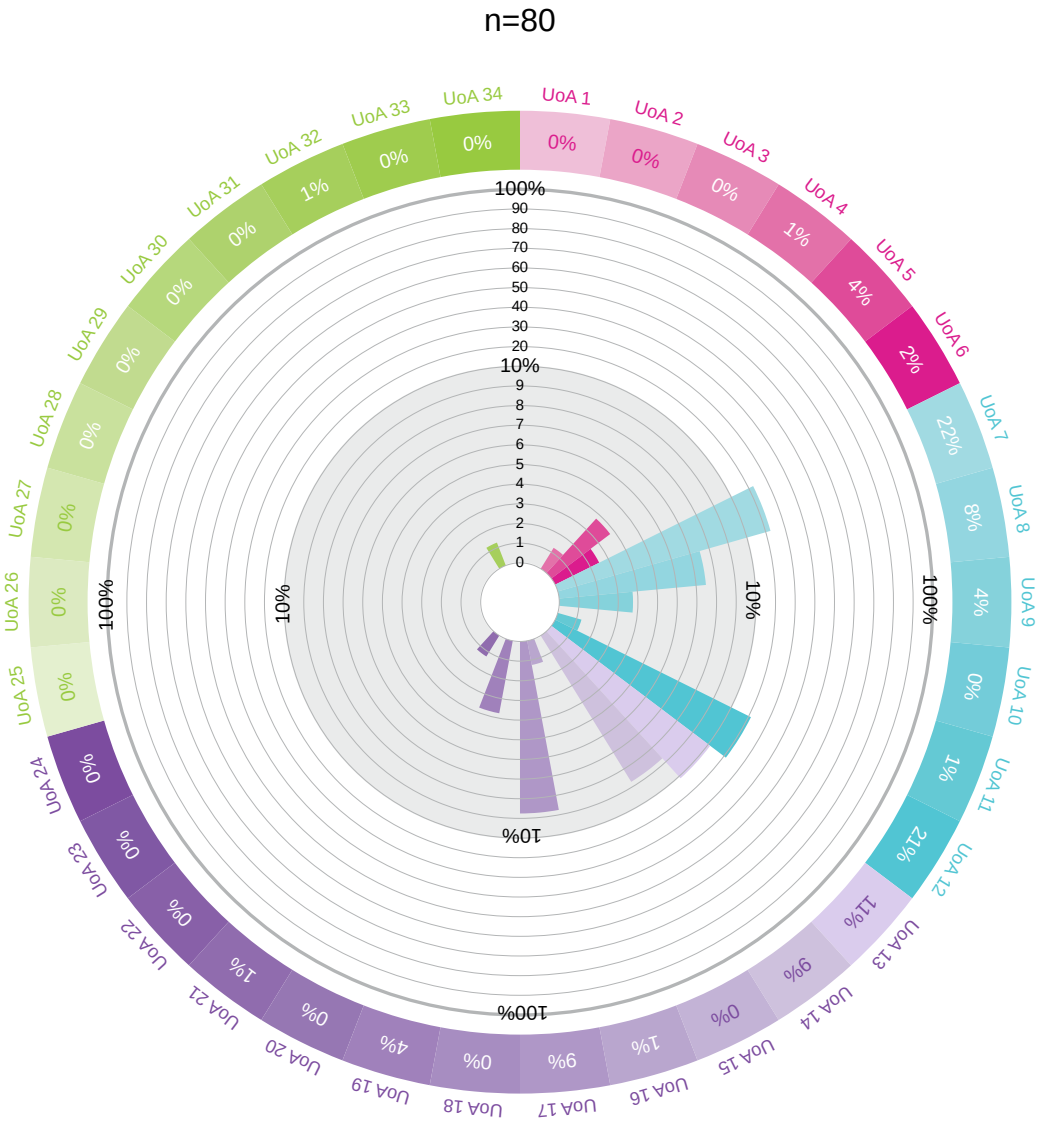
Box 11. Keyword searches of ICSs

We searched for the key terms 'net-zero' and 'net zero', determining how frequently they were mentioned in Section 4 ('Details of impact') of the ICS. This approach identified 80 ICSs that mentioned these terms one or more times. An initial review demonstrated their relevancy, identifying no false positives. Therefore, we included all 80 ICSs in the thematic analysis and deep dive.

89 UNFCC (2015).

90 UK Government (2021).

Figure 24. Impact wheel for the net zero-related deep dive



Notes: This figure shows the impact wheel for the net zero-related deep dive. The 'n' represents the number of ICSs reviewed. The four colours represent the four panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green). Different shades of the same colour represent the 34 UoAs. The impact wheel's spoke sizes reflect how frequently impact within that UoA occurred.

Table 21 highlights several features of the case studies regarding the nature of the impact and its location, underpinning research and funder, providing the percentage of ICSs within the net zero cluster tagged with these characteristics. Regarding the nature of impact, the top two topic-model topics ICSs came under were 'manufacturing and emissions' (46%) and 'energy and energy efficiency' (16%). All ICSs reported an impact in Europe (100%), although impacts occurred across all continents. Regarding the underpinning research, the top FoR codes across ICSs included 'applied economics' (25%) and 'atmospheric

sciences' (21%), with 'electrical and electronic engineering', 'mechanical engineering' and 'environmental science and management' all featuring in the top five. UKRI funded most case studies, with 78% of ICSs underpinned by UKRI funding (n=62). Of these, 43% were underpinned by EPSRC funding, 34% by NERC and 20% by Innovate UK.

Table 21. Features of the net zero-related ICSs

Nature of impact: Top three primary topics	% of cluster ICSs (n=80)	% of all ICSs (n=6,361)
Manufacturing and emissions	46%	2%
Energy and energy efficiency	16%	1%
Climate change and weather	8%	1%
Location of impact: Continent		
Europe	100%	91%
North America	31%	40%
Asia	26%	31%
Africa	18%	14%
Oceania	14%	19%
South America	6%	10%
Underpinning research: Top five fields		
Applied economics	25%	8%
Atmospheric sciences	21%	1%
Electrical and electronic engineering	20%	5%
Mechanical engineering	19%	4%
Environmental science and management	18%	2%
UKRI research funder		
All	78%	48%
Central funding (inc. RE funding, GCRF, Newton, etc.)	9%	8%
AHRC	0%	11%
BBSRC	10%	5%
EPSRC	43%	15%
ESRC	19%	16%
Innovate	20%	8%
MRC	1%	8%
NERC	34%	6%
STFC	5%	3%

5.4.1. Research at UK universities contributed to developing climate policies in the UK and internationally

Research at UK universities has contributed significantly to critical global climate change initiatives and international policy developments in four sub-thematic net zero areas: (i) informing the development of international policy agreements and wider net zero agenda setting, (ii) informing national thinking around net zero, (iii) contributing to citizen engagement with net zero, and (iv) developing decentralised climate strategies to enable localised climate action.

Informing the development of international policy agreements and wider agenda-setting around net zero

Researchers at UK universities have conducted policy research on translating global climate ambitions into tangible regulatory and policy instruments informing key international agreements and consultations. For instance, research at the University of East Anglia[91] on global carbon emission increases and climate change effects on carbon sinks helped shape a widespread understanding of the imperative of balancing global carbon budgets and achieving net zero. This research helped inform the UN Framework Convention on Climate Change (UNFCCC) consultations that led to the historic 2015 Paris Agreement. Physics researchers at the University of Oxford made another vital contribution[92] by demonstrating that climate risk is primarily determined by the total carbon dioxide emissions accumulated over time and not by emissions in a particular year or period, cementing the need for net zero carbon emissions to stop global warming. Based on this research, targets to limit warming to 2°C and 1.5°C influenced key reports, such as the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report[93] and the IPCC Special Report on 1.5°C.[94]

Research at UK universities has also made significant contributions to monitoring emissions and compliance mechanisms for key international climate agreements. Researchers at the University of Bristol[95] provided vital evidence on sub-par emissions-reporting practices and non-compliance with key international agreements. This work led to identifying and subsequently eliminating a breach in the Montreal Protocol on substances that deplete the ozone layer, creating robust standards for national inventory evaluation under the Paris Agreement, and developing a new methodological approach for measuring greenhouse gas (GHG) emissions from forestry more accurately across the EU and internationally. The Leicester Greenhouse Gas Remote Sensing Group (GGRSG) at the University of Leicester made key contributions towards accurately monitoring emissions.[96] Their research helped develop new space-based methods for GHG sensing and interpret emissions data from the European

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91 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/6c89d779-1afb-465e-8175-207bfe22f61e?page=1

92 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/aef0bff5-cc4a-4b4f-97ab-743f4f1b94f8?page=1

93 IPCC (2013).

94 IPCC (2018).

95 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/8b7de844-3de8-4afd-ae83-a5c8d339fbe0?page=1

96 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/19ffbda3-380b-4db5-b35f-8191111a8aea?page=1

Space Agency's ENVISAT SCIAMACHY instrument, the Japanese Greenhouse gases Observing SATellite (GOSAT) and The National Aeronautics and Space Administration's (NASA's) Orbiting Carbon Observatory. GGRSG research has also contributed to the UK Space Agency's recent MicroCarb mission, which will be the first dedicated European GHG mission.

Informing the UK's thinking about net zero

Alongside informing wider global developments on net zero, research at UK universities has also contributed to developing net zero-related climate policies and strategic thinking in the UK. For example, research at the University of Edinburgh[97] on GHG emission calculations improved the accuracy of emission estimates from the UK's agricultural systems, showing that soil-derived nitrous oxide emissions are lower than estimated. This finding proved instrumental in developing a more accurate understanding of agricultural emission sources and control measures, leading to a greater focus on methane emissions from livestock rather than soil-derived nitrous oxide emissions in the UK and Scottish governments' GHG mitigation support policies.

Research at UK universities has also contributed to novel approaches to strategic thinking around net zero. For instance, research at the Institute of Innovation and Public Purpose (IIPP) at University College London[98] has helped rethink the state's role as an active participant in innovation through its mission-oriented approaches to solving complex challenges like climate change. This research influenced the UK government's adoption of a mission-oriented approach to industrial policy through the industrial strategy published by the (former) Department for Business Energy and Industrial Strategy (BEIS).[99] This research also provided key insights shaping the development of the Scottish National Investment Bank and its focus on long-term, mission-oriented investments towards climate change. Another example of forward-thinking research in this area is the 'whole systems' approach developed by the University of Leeds,[100] where researchers developed a new UK carbon footprint indicator that improved material footprint measures and resource productivity. This research helped connect the need for material efficiency and decarbonisation with developing opportunities for economic growth via efficient resource use and informed the government's Resources and Waste Strategy.[101]

Contributing to greater citizen engagement with net zero

Research at UK universities has also played a role in informing key developments and debates around citizen buy-in for climate policies. For instance, research at the UCL Constitution Unit[102] on shaping the design of citizens' assemblies using attitudinal stratification facilitated the rapid growth of these mechanisms, including the creation of

97 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/10e7da10-0895-4977-97ee-1ca2030d1206?page=1

98 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/1bd0fe0a-6f1a-44e5-bfc8-9c627c81a00b?page=1

99 BEIS (2017b).

100 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/496af40e-fd57-46cb-a65e-443d3005b255?page=1

101 UK government (2018).

102 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/149f0189-62a6-40b8-bc64-85608d98f475?page=1

the UK Parliament's Climate Assembly and a similar initiative by the Scottish Government. The UK Climate Assembly's recommendations have subsequently acted as key inputs for deliberations at the 2021 United Nations Climate Change Conference (COP26) and the publication of the UK's Sixth Carbon Budget.

Researchers at the University of Lincoln[103] utilised their expertise in the science of climate change to inform the concept of citizen social science and bring experts and citizens together to co-produce climate research and policy recommendations. This research led to the establishment of the Lincoln Climate Commission and an international conference addressing human-induced climate change in collaboration with the Church of England. The 'Moana Water of Life Conference' helped inform the Church of England policy to adopt a 2030 net zero emissions target.

Research at Cardiff University[104] on public perceptions and attitudes to changes in the whole energy system provided vital insights to the UK Government, demonstrating people's strong support of renewable energy sources and a less wasteful economy, countering perceptions that people would resist wide-scale energy transformation. Their research findings led to changes in UK environmental regulations, with the government extending producer responsibility for products' end use in its Resources and Waste Strategy for England. Their research also informed the Scottish Energy Strategy[105] and its public engagement components and was incorporated into the UN's IPCC Climate Outreach Handbook[106] in 2018.

Developing decentralised climate strategies to enable localised climate action

Similarly, research at UK universities has explored decentralised climate action, especially on mechanisms enabling regional and local governments to translate and implement national and international commitments. Researchers at the University of Manchester's Tyndall Centre for Climate Change Research[107] developed a methodology to translate carbon budgets from global to local and sectoral scales, enabling UK local authorities to develop climate strategies compliant with the Paris Agreement. This research is a key component of the Setting City Area Targets and Trajectories for Emissions Reduction (SCATTER) project funded by BEIS. The project has helped shape policymaking at the Greater Manchester Combined Authority (GMCA), with the Manchester City Council and GMCA officially adopting the Tyndall-Manchester carbon budgets. This approach's success at GMCA has led to adoptions by authorities in Sheffield, Leeds and the West Midlands Combined Authority. The methodology's impact has also spread internationally, with local authorities in Sweden adopting carbon budgets based on this research.

103 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/525dfea1-80ff-44f1-a1a4-6102dd697e90?page=1

104 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/a1992cf5-833a-4619-8161-2dcbea025342?page=1

105 Demski & Pidgeon (2017).

106 Climate Outreach (2018).

107 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/49bbd69d-38d9-4b7d-9a89-13bb938ec843?page=1

Researchers at the University of Leeds[108] have supported similar initiatives, evaluating the economic benefit of city-scale climate action and building its economic case, leading to greater leadership buy-in. This research's evidence base helped secure funding for a low-carbon district heating scheme active since 2013, develop the Domestic Energy Efficiency Programme in 2015, and inform Leeds' 2019 declaration of a climate emergency.

5.4.2. Research at UK universities contributed to multidimensional insights informing UK energy transitions

Research at UK universities has contributed to key developments across the energy-transition ecosystem, from breakthrough basic research generating new fuel manufacturing methods to systems approaches on large-scale urban energy transformation. Below, we outline the sub-themes that have emerged.

Developing and informing renewable energy technologies

Research at UK universities has led to novel methods and tools for developing and designing renewable energy systems. For instance, researchers at Loughborough University[109] developed stochastic modelling methods to provide greater insights into domestic electricity use patterns, helping shed light on the economic and environmental benefits of solar Photovoltaic (PV) for householders. This research led to the development of nationwide standards on installation, performance and consumer confidence for solar PV, contributing to greater adoption of PV technologies across the UK. Similarly, multidisciplinary research at the University of Strathclyde[110] led to the development of modelling tools for planning, installing and constructing offshore wind farms, helping reduce costs and improve logistics for offshore wind energy.

Contributing to energy resilience and security

With ever-increasing reliance on renewables and alternate forms of energy to achieve net zero targets, ensuring energy systems remain stable, secure and economically viable during the transition is paramount. Research at UK universities has contributed to vital progress in this domain. A research team at Imperial College London[111] created a scenario-based modelling and optimisation framework for evaluating energy network designs, helping identify infrastructure design interventions for low-cost deep decarbonisation across electricity, gas, heat and transport energy. This research helped inform the government policy for decarbonisation via the BEIS 'Clean Growth Strategy'[112] and the Office of Gas and Electricity Market's (OFGEM's) 'Smart Systems and Flexibility Plan,'[113] alongside informing

108 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/51fd2e35-db75-408f-be28-4df59254b604?page=1

109 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/e3be1a3c-40e4-43de-95bb-7edcbf67032a?page=1

110 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/c1acddfc-8265-45ab-a63b-7874ad1c82b5?page=1

111 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/6beb41df-efd8-410b-a973-c31963f79cef?page=1

112 BEIS (2017a).

113 Ofgem (2017).

the Committee of Climate Change's 'Net zero Technical Report'.[114]

A team at the University of Reading[115] was one of the first to research demand-side flexibility in the UK energy sector, including the sectoral potential of Demand Side Response (DSR) policies. Their findings allowed industrial and commercial consumers to adapt the volume and timing of their energy consumption, creating market opportunities for energy aggregators and informing a change in national policy through the Department of Energy and Climate Change (DECC)'s decision in 2014 to include DSR participation in the capacity market. Moreover, their research on the impact of 'time of use tariffs' across demographic groups led to greater energy resilience in the residential sector.

Researchers in the University of Exeter's energy policy group[116] conducted vital policy research on the UK's 'whole energy system', looking at electricity, heating and transport holistically. Their research on the role of governance in energy system transformation – especially on the trade-offs of the capacity market system and energy system codes (multilateral agreements governing network access and market operation) – led to policy reform, including the creation of a new theory of harm around energy governance and a change in the system of industry codes to enable opportunities for green innovation. Moreover, their research contributed to BEIS creating the 'agility principle' for energy policy, specifying agile and responsive regulation incorporating digital-economy opportunities for net zero.

Supporting the UK's energy transition efforts, research at UK universities has also contributed to pathways for safe, economical and sustainable decommissioning of the oil and gas sector. Research at the University of Aberdeen has contributed in multiple ways. Research teams there have worked on several dimensions of the sector's successful decommissioning, addressing its environmental, technological, legislative and financial challenges. Research at Aberdeen led to the establishment of the National Decommissioning Centre (NDC) in 2018, which has become a key actor behind research on trialling, adopting and deploying new technology and data solutions for decommissioning projects. The Centre's work has also influenced taxation policies and government thinking about the long-term liability of decommissioning, along with improving standards and providing models for assessing the environmental impacts of these endeavours.[117, 118]

Research on alternate energy forms

Research at UK universities has also yielded promising developments in alternative fuels for energy transformation, including important research on hydrogen as a fuel source and projects focused on extracting value from bioenergy sources. Researchers at the University of South Wales (USW) have

114 Committee on Climate Change (2019).

115 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/a1fbadce-1e3f-4530-9729-d3aa93ba342b?page=1

116 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/acf019c7-b442-4f20-8072-5dd0b4a32dc5?page=1

117 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/67c1fea8-dbab-4615-8d6f-b53eee0b4c0a?page=1

118 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/a4c9f7dc-b11b-4733-a34b-71be5b084cc5?page=1

researched electrolytic hydrogen production techniques and novel techniques to recover hydrogen from steel manufacturing.[119] This research has developed cost-effective hydrogen production and recovery approaches to decarbonise the industry, transport and energy sectors and influenced hydrogen policy in both the UK and China. Research at USW also led to commercial success, with ITM Power (a UK-based energy storage and clean fuel company) deploying the first commercial polymer electrolyte membrane (PEM) electrolyser, developing a significant market share in the worldwide deployment of electrolytic hydrogen. Work at USW has also led to the establishment of a South Wales industrial cluster focused on hydrogen-based decarbonisation.

Similarly, materials chemistry research at Imperial College London[120] led to commercial success in creating Bramble Energy, behind a unique high-volume manufacturer fuel cell. Bramble Energy has attracted more funding and is collaborating on multiple projects, including power generators, LED lighting towers, passenger vehicles and medical devices, e.g. an oxygen sensor for ventilator use for COVID-19 patients.

Researchers at Aston University Energy and Bioproducts Research Institute (EBRI)[121] developed novel ways of converting biomass into sustainable energy, including creating a pyrolysis reactor, researching waste utilisation by anaerobic digestion, and using mathematical models to study reactor performance. Aston researchers also conducted techno-economic assessments to demonstrate the locations and scale at which bioenergy generation has the best performance and cost-optimisation potential. This research into bioenergy technologies and value chains led to a project supporting the development of 103 West Midlands small and medium-sized enterprises (SMEs) across industry sectors, enabling them to identify business and value opportunities and diversify into new low-carbon products and services.

Researchers at the University of Aberystwyth[122] helped address critical knowledge gaps and provide essential evidence for the UK's bioenergy policy by investigating the potential of deploying perennial biomass crops to achieve net zero targets and the environmental impacts of converting farmland to do so. This research influenced the UK government's policy on biomass cropping and land use for net zero, helping inform key Climate Change Committee (CCC) reports in this area[123,124] and contributing to CCC's sixth carbon budget. Moreover, their research and engagement with the National Farmers Union also helped de-risk industry investment in bioenergy, creating greater uptake for net zero policies.

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119 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/09a871db-2ac8-4ad4-b76d-2e5d1b272f8b?page=1

120 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/56d625e2-3fd4-4cd5-be0f-8ec23b98696a?page=1

121 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/a885dd42-243a-443b-b3aa-e2addbaebcbd?page=1

122 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/b1cceaea-cbf7-4648-9f84-a3d8509bd194?page=1

123 Committee on Climate Change (2018).

124 Committee on Climate Change (2020).

Contributing to urban energy efficiency and the housing sector

Urban energy efficiency is a major component of the UK's transition towards net zero, given steady urbanisation and the levelling up agenda. Research at UK universities has contributed meaningfully to this area through numerous multidisciplinary research projects. The Complexity Planning and Urbanism (CPU) Lab at Manchester Metropolitan University (MMU)[125] has conducted urban transformation research by developing digital tools based on Complexity Theory, identifying mechanisms of urban change and linking them to socio-technical and ecological systems. Their findings on governance and design interventions for future cities have shaped many developments, including the Manchester digital strategy and the Northern Gateway Strategic Regeneration programme. The lab also engages with international interdisciplinary networks in Japan, China and Brazil to provide vital thought leadership towards building sustainable and liveable cities.

Another example of critical research on urban transformation is the collaborative work undertaken at London South Bank University[126] to develop a forward-looking framework of models and analytical tools for government and industry to measure the broader impact of infrastructure projects at the project level, in line with the recent calls for the localisation of the Sustainable Development Goals (SDGs) in the UN Roadmap for localising SDGs. The Thames Tideway Project has incorporated this research, and the Environment Agency uses it to manage its infrastructure impact assessments.

Ensuring the housing sector moves towards net zero via efficient retrofitting of existing houses and novel technologies and standards for new, low-carbon houses is key to enabling sustainable urban transformation and energy efficiency. Research at UK universities has proved instrumental for progress in this area. For example, researchers at Cardiff University[127] developed a 'whole house' retrofit methodology by combining renewable energy supply and energy demand reduction via fabric improvements and energy efficiency technologies for deep carbon reductions in the housing sector. They also applied this whole-house systems-based approach to new buildings and developed the SOLCER house model for affordable energy-positive houses. This research led the Welsh government to invest in exemplary housing projects and retrofitting older houses.

5.4.3. Concluding reflections

It is apparent from the above analysis that multidisciplinary research at UK universities has been instrumental in informing, directing and reinventing the entire spectrum of decarbonisation and emission-reduction initiatives towards net zero at the local, national and international levels. With the ever-increasing imperative of achieving net zero in a timely and sustainable manner, the vital importance of university-based research driving innovation and impact in this domain cannot be overstated. It is also important to acknowledge the long-term impact and life cycle of research in this area; multiple studies that began years, if not decades ago, have had

125 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/defb2569-8a65-45e6-8852-b3ef6b857db1?page=1

126 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/9367cef7-ab10-4433-b996-99cc976b922a?page=1

127 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/11e7f42b-d4c4-45c2-948d-0249951f9bb3?page=1

a profound and lasting impact on current net zero and climate policies. Similarly, current research in these domains could shape future technologies and approaches. Therefore, we must recognise the likelihood of such impact falling outside the REF impact cycle.

5.5. The impact of research on Place

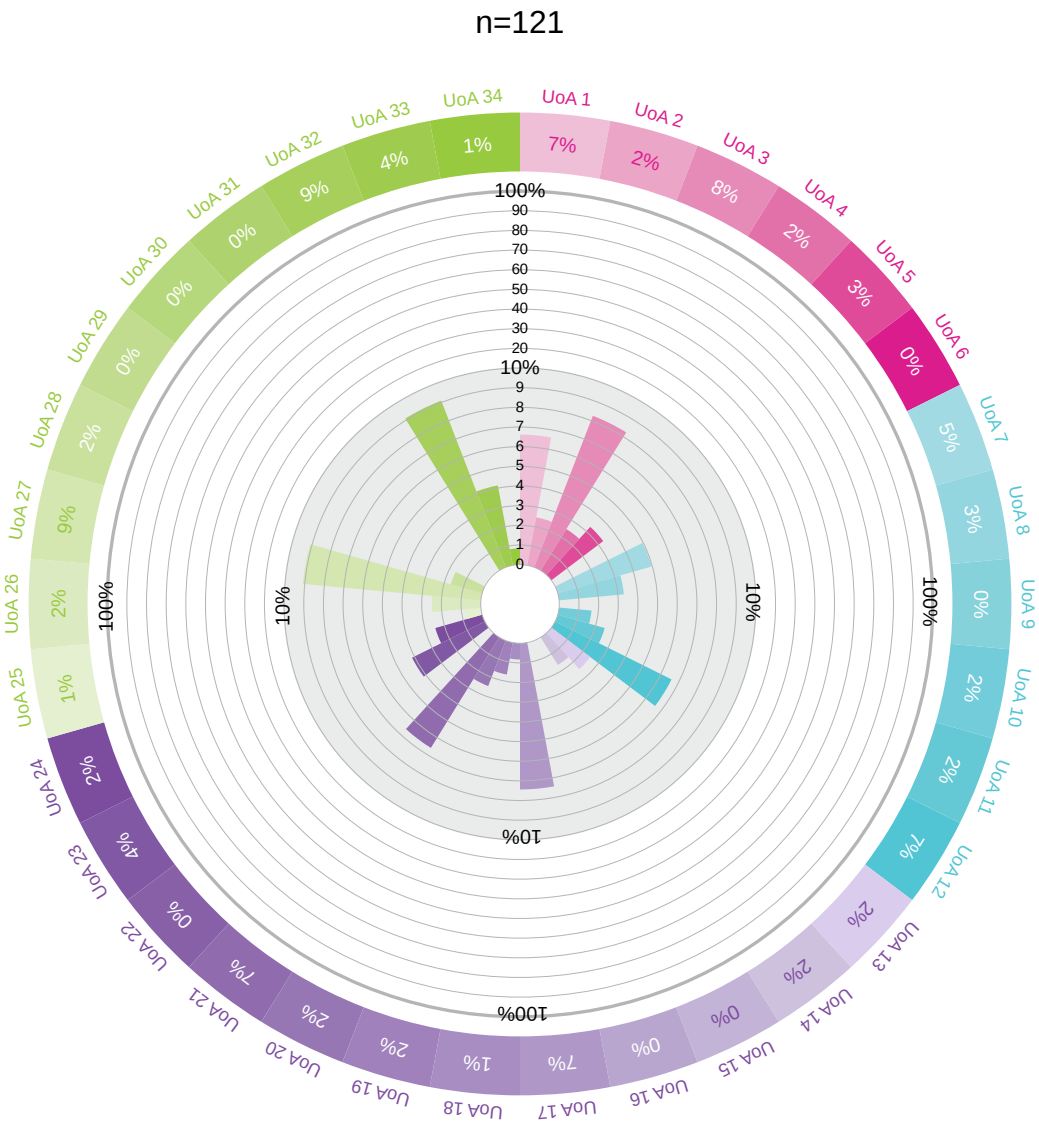
Our analysis of hyperlocal impacts (those occurring within a 25km radius of the submitting HEI) showed that research at Manchester HEIs has significantly impacted the local area. This finding is illustrated in Figure 12 and Table 22, where MMU, the University of Bolton, the Royal Northern College of Music, and the University of Salford all showed high incidences of hyperlocal impact in REF 2021. This deep dive examines the case studies submitted by all five Manchester HEIs (the University of Manchester, MMU, the University of Bolton, the University of Salford and the Royal Northern College of Music) with impacts within a 25km radius: a total of 121 ICSs.

The impact wheel in Figure 25 illustrates that ICSs from Manchester HEIs that reported impacts in Manchester were distributed relatively evenly across the four main panels, highlighting the research's cross-disciplinary nature. The UoAs with the highest number of ICSs included UoA 27 (English Language and Literature), UoA 32 (Art and Design; History, Practice and Theory) and UoA 3 (Allied Health Professions; Dentistry, Nursing and Pharmacy).

Table 22. The proportion of ICSs from Greater Manchester (GM) HEIs reporting hyperlocal impact (within 25km of the institution)

Institution name	No. of ICSs with hyperlocal impacts	Total no. of ICSs	Proportion of ICSs with hyperlocal impact (%)
Royal Northern College of Music	2	2	100%
MMU	39	49	80%
The University of Bolton	9	14	64%
University of Salford	16	30	53%
University of Manchester	55	150	37%

Figure 25. Impact wheel for the Place-related deep dive



Notes: This figure shows the impact wheel for the Place deep dive. The 'n' represents the number of ICSs reviewed in the deep dive. The four colours represent the four REF panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green). Different shades of the same colour represent the 34 UoAs. The impact wheel's spoke sizes reflect how frequently impact in that UoA occurred.

Table 23 highlights several features of ICSs regarding the nature of impact and its location, underpinning research and funder, providing the percentage of case studies within the Place cluster tagged with these characteristics.

Regarding the nature of the impact, the top topic-model topics ICSs came under were 'clinical trials' (10%) and 'creative arts and exhibitions' (7%). All case studies reported an impact in Europe (100%), although impacts occurred across all continents. Regarding the underpinning research, the top FoR codes tagged across ICSs included 'clinical sciences', 'public health and health services', 'psychology'

and 'sociology'. UKRI funded over half (58%) of the ICSs, with 27% of ICSs underpinned by ESRC funding, 18% by EPSRC funding and 17% by Innovate UK funding.

Table 23. Features of the Place-related ICSs

Nature of impact: Top three primary topics	% of cluster ICSs (n=121)	% all ICSs (n= 6,361)
Clinical trials	10%	5%
Creative arts and exhibitions	7%	3%
Professionals and practitioners	6%	5%
Location of impact: Continent		
Europe	100%	91%
North America	36%	40%
Asia	29%	31%
Africa	9%	14%
Oceania	17%	19%
South America	9%	10%
Underpinning research: Top four fields		
Clinical sciences	21%	20%
Public health and health services	19%	18%
Psychology	16%	15%
Sociology	11%	9%
UKRI research funder		
All	58%	48%
Central funding (inc. RE funding, GCRF, Newton, etc.)	11%	8%
AHRC	16%	11%
BBSRC	6%	5%
EPSRC	18%	15%
ESRC	27%	16%
Innovate	17%	8%
MRC	8%	8%
NERC	4%	6%
STFC	1%	3%

5.5.1. The multidimensional impact of research at Manchester-based universities on the city and surrounding areas

Research at Manchester universities contributed to Manchester's arts and heritage landscape and led to wider societal gains

Research conducted at Manchester universities' departments and centres dedicated to studying history, art and culture has contributed to numerous developmental initiatives in the area. These contributions range from enhancing tourism practices, preserving legacy architecture, creating greater awareness for the arts in the general populace and bolstering avenues and opportunities for new and emerging artists to prosper to contributing to critical societal conversations and issues through the medium of the arts.

For instance, researchers at the Manchester Centre for Gothic Studies (MCGS) at MMU[128] established the Haunt Manchester website to curate tourism-related digital content – a product of MCGS's mission to 'make Manchester Gothic' through a sustained programme of creative and collaborative public engagement. Through the annual Gothic Manchester Festival (2013–2019), they initiated and co-produced multiple cultural events, including a concert with BBC Philharmonic and BBC Radio 3, a public Gothic exhibition at the John Rylands Library and Gothic professional development courses at Manchester's independent 'HOME' cinema.

Another project at the MMU[129] helped revive public engagement and appreciation of the city's modern, post-war architecture. The research impacted the heritage sector through the statutory listing of post-war buildings, protecting assets by lodging them safely in archive collections, and the innovative digital preservation of the Manchester Reform Synagogue. Moreover, this was part of a broader attempt to engage Manchester residents more deeply with the cityscape by organising public talks, walking tours and exhibitions.

Research in this area has also impacted many societal and cultural issues within the region, with numerous positive outcomes. For instance, research in creative writing and nineteenth-century literature at the University of Bolton[130] enabled cultural organisations in the north of England to increase under-represented groups' participation in the arts. Chinese communities benefited through creative writing and audience-development workshops connected to the play 'From Shore to Shore', which consolidated partnerships with local educational organisations and increased understanding of migrant narratives in mainstream culture. Research-informed local heritage workshops with socially marginalised women, asylum seekers, refugees and residents in disadvantaged areas were also conducted in collaboration with community organisations like the 'Home Wonder Women' group and Bolton Big Local, with feedback pointing to an improved sense of community cohesion and wellbeing.

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128 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/4c21db69-e560-40fe-873f-bf2b5214b856?page=1

129 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/0966669b-8ef4-47f2-bb3c-64490c5a93d0?page=1

130 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/09f49471-744f-4a29-8e0a-d358df44a279?page=1

Researchers at the Centre for the Study of Sexuality and Culture (CSSC) at the University of Manchester[131] focused on research and arts activism, creating impact through initiatives like the CSSC's annual Sexuality Summer School (SSS). The SSS is a forum for scholarly conversations in sexuality studies with a curated programme of queer arts events that contribute (as curators, organisers and advisors) to a wide range of public art activities in Manchester and beyond. These endeavours have helped inform curatorial practice and programmes by public broadcasters, increased lesbian, gay, bisexual, transgender, queer or questioning, intersex, asexual and more (LGBTQ) visibility in the arts, thereby promoting LGBTQ health and well-being in Manchester through the arts.

Research in this domain has positively impacted Manchester residents' health and well-being. For instance, the Arts for Health research group at MMU[132] has generated findings that have improved care provision for mental and physical health by developing innovative arts-led and publicly engaged methodologies and creative modes of campaigning and activism. This research has helped address health inequalities by fostering greater inclusion through public engagement and advocacy, creating the conditions for marginalised groups to represent themselves and their health journeys in the mainstream. Researchers have contributed towards de-stigmatising substance use and promoting recovery and helped challenge exclusion and negative societal attitudes towards disability at the 'Sick!' festival in Manchester.

Climate

Research conducted at Manchester's universities has also contributed to transitioning to net zero and making the city and surrounding regions more climate-friendly. For instance, the European Union's Horizon 2020 RESIN (Climate Resilient Cities and Infrastructures) project[133] at the University of Manchester helped improve planning and decision-making for climate change adaptation and resilience across GM and Europe. Their research demonstrated the need to differentiate cities according to their vulnerability to extreme weather and climate change hazards, generating new datasets to identify climate change risks to GM's critical transport infrastructure. Their findings contributed to developing and implementing the Manchester Climate Change Framework (2020–2025)[134] and the Climate Change and Low Emission Strategy for Greater Manchester (2016–2020)[135] by giving adaptation and resilience strategy prominence on the local authorities' policy agendas.

Research at the University of Manchester's Tyndall Centre for Climate Change[136] identified the failure of GHG mitigation policies in the shipping and aviation sectors to align with the Paris Agreement's climate targets. The

131 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/58966841-cc89-454f-a284-e67bc0605db9?page=1

132 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/4c52cc0e-a91c-4590-a82d-ba12cc281b05?page=1

133 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/526bcc46-5aab-4399-b02f-9149b0dbf539?page=1

134 Manchester Climate Change Partnership and Manchester Climate Change Partnership Agency (2020).

135 Greater Manchester Low Carbon Hub and GMCA (2016).

136 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/b540798a-8f7b-4dae-b8da-4e30df24fd23?page=1

research characterised this failure's impact and published decarbonisation pathways that have engaged national and local policy and industry stakeholders and influenced debate at multiple scales. The Manchester Climate Change Framework has adopted aviation climate policies, shaping Manchester's climate policies and helping city authorities account for the effects of international transport on their net zero plans. For instance, the research helped inform the draft Manchester Zero Carbon Framework (2020–2038)[137] and contributed to policy options for managing emissions from Manchester Airport for the Manchester Climate Change Agency (MCCA). Moreover, their input led to the latest Manchester Climate Change Framework (2020–2025), incorporating aviation climate policies and specific emissions objectives, reducing investment and policy risks for business and local government by recognising this source of emissions in subsequent spatial and economic planning.

Industry and commerce

Research at Manchester-based universities has contributed meaningfully to commerce and industry in the area. Research has contributed to overall policies governing the development of enterprises within the area and led to multiple successful start-ups and enterprises from the multidisciplinary and cutting-edge research conducted at universities in Manchester.

For example, research at MMU Business School[138] on entrepreneurship led to the development of evidence-based frameworks around the concepts of 'strategic space' and social capital in SMEs. The 'strategic space' concept recognises the imperative for owner-managers to have the resources, capability and motivation to focus on strategic renewal and change within the organisation. At the same time, the researchers demonstrated the crucial importance of large networks, trust, reciprocity and bonding ties for entrepreneurs through the concept of 'social capital'. In partnership with Manchester's business community, this research has positively impacted local innovation and job creation. Enabled by this work, Manchester Metropolitan was chosen to deliver the Goldman Sachs-funded programme for High Growth Small Businesses, which helped many high-growth small enterprises in the North-West to unlock their businesses' economic and job creation potential by offering them specialist support and leadership engagement. Moreover, their approach of combining research-led growth expertise with scientific and industrial inputs has contributed to numerous initiatives that have had a hyper-local impact on Manchester's economy, including the Greater Manchester High Growth Network that worked with over 200 SMEs to strengthen their business strategies via research and the Manchester Fuel Cell Innovation Centre, which helps small local firms move upwards in the fuel cell industry.

Research from Manchester has also created conditions conducive to the successful creation and sustenance of multiple start-ups. For example, research at the University of Manchester's Department of Computer Science[139] led to SpiNNaker, a novel computer chip architecture with extensive impact on brain-interfaced computing. The SpiNNaker platform is globally recognised

137 Manchester Climate Change Board, Manchester Climate Change Agency, Zero Carbon Manchester (2019).

138 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d5aa7427-51f8-408a-851c-0b5d3ac263c2?page=1

139 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/945ffd0a-f60f-4036-91fd-e80a876a5fb5?page=1

and a core node in the EU Human Brains Project. In addition, the project has also had a meaningful local impact, with technologies developed based on the core research supporting and being absorbed by Manchester-based enterprises. For example, Cogniscience Ltd began at the university as a successful start-up deploying this technology. The platform has also supported new business activities for MindTrace Ltd, an independent brain computing start-up in Manchester that develops event-based Artificial Intelligence (AI) systems.

Research at the University of Salford[140] on developing novel techniques to automate real-time sound-mix production and new technologies for virtual crowd production is another illustration of cutting-edge research leading to commercial applications. This research led to the birth of the university spin-out Salsa Sound Ltd., exploiting these technologies by developing software tools to create bespoke audio mixes for broadcasters and sports clubs such as Manchester City FC and other global broadcasters.

Urban planning

Another area research at HEIs in Manchester has contributed to is urban planning, with research projects leading to crucial improvements and insights across multiple areas, from high street design and experiments on urban agriculture to creating a more elderly-friendly city.

A team at the University of Manchester[141] formulated the Urban Living Labs approach to city planning, which uses partnerships to address place-based challenges by experimenting with different kinds of sustainable infrastructure. This novel approach has helped transform sustainable infrastructure provision in Manchester by shaping £26m of infrastructure investment by Manchester City Council, which has doubled cycling rates in targeted areas and replaced 20,000km of delivery van trips with e-cargo bikes, making the city less congested and more climate-friendly.

Sociological research into the vitality and viability of high streets and town centres by the Institute of Place Management (IPM) at MMU[142] has led to significant changes in governmental policy and place management practice in Manchester and beyond. The research findings enhanced collaboration between local stakeholders by focusing on the politics, aesthetics, communal benefits and economic potential of effective urban place-making. This included the Manchester City Council, leading to a change in policy that means the City is now supportive of area-based partnership formation and has established a District Centre Subgroup to formulate effective strategies for the long-term promotion of sustainable and vibrant district centres in Manchester.

Education

Education has seen contributions from various academic disciplines and associated HEIs within Manchester, from research on developing effective pedagogies for schools to utilising alternate communication technologies within the teaching curriculum.

140 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/29e9c7e5-4261-4c65-b272-9bfc58a95962?page=1

141 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/c3828c6f-1a7e-4c8b-afe5-707407b4d18c?page=1

142 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/2fb45d55-ad87-486e-87e6-609c466c79e8?page=1

Research at the University of Manchester[143] into the recommendation and use of Augmentative and Alternative Communication (AAC) technologies has underpinned significant policy and clinical practice changes. These tools enable people to demonstrate their cognitive and linguistic capacity when natural speech is inefficient, substituting unintelligible speech. The research team conducted an inclusive Participatory Action Research (PAR) methodology, involving all stakeholder groups in developing key outcomes (including developing new resources to support professionals in health, education and social care) and including families and other key partners in the decision-making process for those who need AAC. This contributed to the GMCA launching an authority-wide Non-Specialist AAC Aids policy in 2020 to ensure equity, consistency and clarity in commissioning non-specialist AAC Aids.

Research at the University of Bolton[144] on effective school improvement techniques produced a set of 'theories of action' – a series of actions with a presumed set of outcomes that established professional protocols. These were substantiated by a high level of empirical educational research literature. The research was recognised and implemented in collaboration with the Bolton Learning Partnership and has informed the 28 schools' educational practices, impacting 3,000 teachers and over 19,000 students in Bolton. Utilising the theories of action in school practices and curriculum led to a reported increase in academic success, improved recall ability and an expanded vocabulary amongst pupils.

A team at the University of Manchester[145] analysed the interplay of language practice, needs, provisions and policy among community and statutory institutions. Findings led to the development of a new support platform for language diversity within the Manchester City Council. In 2019, Manchester became the first major city to release a report[146] on language diversity, setting in motion an ongoing consultation process for a City Language Strategy. Moreover, this research led to the setup of the Supplementary School Support Platform as part of the Multilingual Manchester project to provide curriculum enrichment sessions and teacher training delivered to hundreds of primary and secondary school pupils and teachers in Manchester.

Health

In response to workforce demands within the healthcare system, researchers at the University of Bolton[147] designed, developed and implemented the 'Bolton Model' of nurse education to help local NHS Trusts ensure a future supply of nurses. The team developed this model using PAR, creating the first Nursing-Midwifery-Council-approved programme not funded by NHS commissioning bodies. This approach has helped increase student numbers and addressed NHS staff shortages locally in Bolton and nationwide, where it has been widely adopted. The model

143 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/f024f26d-b891-4b8b-a078-f69a9a7d79b0?page=1

144 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/bb427a43-0f72-4b65-9661-ead18e8daa5f?page=1

145 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/acda3402-7f90-494c-b5eb-87a0e6b5d867?page=1

146 Manchester City Council (2019).

147 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/27ae8f8c-b400-4e2c-9aeb-71170c8a6642?page=1

features in a Health Education England report 'as good practice'. It has been instrumental in national debates on non-commissioned nursing programmes in England, changing the face of nurse education and helping position an innovation within GM on the national and international map.

Similarly, research at the University of Manchester[148] has improved primary healthcare service provision across GM and England. Researchers at the National Institute for Health and Care Research (NIHR) Collaboration for Leadership in Applied Health Research and Care (CLAHRC) evaluated two NHS schemes providing seven-day access to general practice (GP) health services across GM. The results highlighted the benefits and challenges of seven-day access, which led to the NHS in GM investing significantly in extended access provision in the region. The research was later adopted nationally and informed the Department of Health's strategies, service provision and resource allocation for primary care across England.

Illustrating pioneering healthcare research, researchers at the University of Manchester[149] developed and validated three new methods to obviate the need for inpatient investigation of chest pain, a common reason for emergency hospital admission. Their research involved over 4,000 patients and led to multiple improved diagnostic technologies adopted locally, nationally and internationally. One of these, the Troponin-only Manchester Acute Coronary Syndromes (T-MACS) decision aid, is being implemented across GM, allowing quicker, more effective diagnosis and treatment. It has been used for over 30,000 patients, reducing hospital admissions and saving approximately £2,000 per patient.

Local policymaking

Manchester research institutes have impacted and shaped the region's delivery of public services and policymaking. For instance, interdisciplinary research at MMU[150] into New Psychoactive Substances' (NPSs') detection, supply, use, trends and harm reduction has helped inform city-region police and public authority infrastructure, strategy, monitoring and operational decisions. The Drugs Early Warning System (DREWS) has informed healthcare practitioners about substances in circulation, critical incidents and emergency care protocols via its MANchester DRug Analysis and Knowledge Exchange (MANDRAKE) service that helps identify and characterise NPSs or adulterants in samples. This project was delivered in collaboration with multiple local authorities within Manchester and now serves as a national model for drug detection policy.

Research at the University of Manchester into gender and policymaking[151] has informed governance arrangements and influenced GM public policy, setting the policy agenda on the under-representation of women in GM's policymaking processes and city-region cabinet and informed the Equalities Strategy in GM pre-and post-COVID-19 and the terms

148 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/b3800cc9-01b0-4c0a-a3a5-f8157c85e533?page=1

149 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/7c78d869-8b2d-4a8d-a7dc-48fc7f589ba3?page=1

150 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/007c7fe7-a981-431a-910c-fc6b3d8c4b46?page=1

151 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/40b85ba5-5d20-4a45-8332-1598259e886f?page=1

of reference for a new Women and Girls' Equality Panel in GM by bringing together a strong evidence base in favour of greater representation of women in GM's decision making bodies.

A University of Manchester research team's work on bottom-up ways to govern towns and cities directly influenced public policy and individual organisations in GM, directly contributing to the adoption of the principle of 'co-production' as a policy across the work of the GMCA and embedded their concept of 'social value' in procurement policy in GM, in addition to helping develop a local energy market in the city region to reduce carbon emissions.

More broadly, co-production and collaboration between Manchester local authorities and HEIs has emerged as a unique theme driving impactful research within the region, explored in more detail in the section below.

5.5.2. The mechanism of impact

As seen in the preceding sections, research conducted in HEIs in Manchester has effected positive change and contributed to local social, cultural, economic, technological and political progress. Thus, it is helpful to examine the processes and factors facilitating this impact and analyse the mechanism and supporting environment that has enabled Manchester HEIs to contribute meaningfully to positive development within the region. The following sections uncover potential pathways and facilitators of this place-based research impact.

The receptive capacity of local governmental structures in Manchester: the role of demand in innovation

The dynamic interactions between academia, government and industry have long been theorised as fostering innovation, entrepreneurship and growth in a knowledge-based economy like the UK's.[152] Governance and organisational arrangements are essential as springboards to absorb and elevate research innovation. Cities and regions with independent and empowered local authorities are recognised as being uniquely positioned to drive local and hyper-local innovation.[153] In the UK, levelling up through greater regional investment and support for innovation has been at the forefront of policy, with the devolution of powers to local authorities serving as a vital enabler. Analysed through this lens, Manchester is uniquely positioned to effect local and hyper-local impact through its research institutes. Beginning with the devolution deal of 2014 between the UK government and GMCA, Manchester has steadily become a model for regional devolution, with local GM bodies building on a history of working together[154] and developing a 'Manchester model' of delivering public services bolstered by evidence-based research focused on the region's unique needs and priorities.[155] Like other devolved combined UK authorities, Manchester's local authorities (including the GMCA) have powers over transport, skills, policing, urban planning and regeneration, adult education and other

152 Etzkowitz & Leydesdorff (2000).

153 OECD (2023).

154 Centre for Public Impact (2019).

155 Greater Manchester (2019).

areas. Unlike other authorities, Manchester also has powers over health and social care commissioning, justice, and employment policy. In 2016, with the signing of the Health and Social Care Devolution MoU,[156] Manchester was given control of a £6bn health and social care budget, with GMCA and the NHS co-managing the health portfolio.[157]

This environment has empowered Manchester's local authorities to respond to the region's developmental needs and potentially act as an absorbent and receptive sounding board for the area's universities, often co-commissioning and collaborating on research projects that have led to impact in the area. This collaboration and co-creation between local authorities and HEIs in Manchester is visible in several research projects highlighted in the sections above. For instance, the high streets project[158] was a collaboration between the Institute of Place Management at MMU and Manchester City Council, leading to an active partnership enabling the running of multiple project pilots and district monitoring centres. Other urban planning research projects have also been delivered in partnership with Manchester's local bodies, including the Urban Living Lab project[159] on sustainable mobility and the Northern Roots Urban farm and Eco-park, supported by Oldham Council in Manchester.[160] This co-creation is not limited to the GMCA; various local bodies within GM have commissioned and collaborated on various university research projects. For instance, a study at the University of Manchester on elderly-friendly cities[161] was commissioned in partnership with Manchester City Council, Manchester Health and Social Care and the GM Ageing Hub, a dedicated body working on issues focused on making Manchester more inclusive for all ages. The GM Ageing Hub also acted as a receptor for other projects, including a study at the University of Manchester on well-being in an ageing workforce.[162] Devolution and localised focus on development have also enabled authorities in Manchester to commission and absorb key research on sustainability and climate change. For instance, research at the University of Manchester on the RESIN project[163] was co-produced with the GMCA and MCCA, creating a powerful pathway for incorporating the research findings into Manchester's climate strategies.

Whilst this analysis seems to illustrate the benefits of a combined local authority with powers like GMCA's, caution should be taken not to over-interpret the results. It would be useful in the future to examine other localities in the UK with different governance structures

156 The Health Foundation (2015).

157 Institute for Government (2022).

158 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/2fb45d55-ad87-486e-87e6-609c466c79e8?page=1

159 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/c3828c6f-1a7e-4c8b-afe5-707407b4d18c?page=1

160 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/55ee7bf9-9b6d-4491-a4db-0ec90012d1c8?page=1

161 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/88a8eac6-7b78-4ad7-91f9-c912b81f8e2d?page=1

162 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/37129b61-742b-446c-a9cb-bb24fd6f47be?page=1

163 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/526bcc46-5aab-4399-b02f-9149b0dbf539?page=1

to see whether there are any differences or similarities.

A multidisciplinary focus on participatory research and feeding back impact to communities and institutions within the GM area

Using and incorporating participatory research methods across multiple disciplines' research is another feature that led to impact within Manchester. While this could be reinforced by increased receptive capacity and buy-in from local authorities within Manchester, the strong focus on participatory research and feedback into communities points to an overall research culture in Manchester that places high value on decentralised approaches to conducting research worth highlighting. This principle is visible in research projects ranging from arts and culture to social policy, education and health. For instance, a study at the University of Manchester[164] on Roma migrants' lived experiences in the region used a co-production model that empowered community members to co-create and shape the research agenda and identify their own policy priorities. Another example of a research project that placed Manchester's populace at the centre of its methodological approach is a study at the University of Manchester on austerity practices,[165] which engaged citizens in an in-depth and long-term way by utilising participation and inclusion methods to inform policy. An illustrative example of participatory health research is a project at the University of Manchester[166] that used community-based screening tools to detect early-stage lung cancer, implementing a holistic community-based approach and engaging deeply with deprived and at-risk populations within Manchester to roll out the project. Another project, a study at MMU on using AAC tools[167] to aid those with speech impediments, used participatory action research to co-create the AAC website tool in close collaboration with various stakeholders, including affected patients, their families and broader support groups.

Manchester HEIs' use of such inclusive and participatory research methods has enabled their projects to identify Manchester's people's unique needs, involve them in the research and ultimately generate localised impact.

Robust research and a supportive ecosystem with strong industry-academia ties have enabled Manchester to become a testbed for innovation

As mentioned earlier, strong ties between academia and industry are crucial for an enabling and impactful R&I ecosystem. This principle is also visible in Manchester's research outputs and the industry and commerce section above. Moreover, Manchester's supportive health innovation infrastructure via academic-industry collaboration stands out. Local bodies' focused investments support Manchester's health ecosystem, enabled by the devolution deal mentioned above. These empowered local institutes, such as the Greater Manchester

164 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/6d2839b8-52d0-469e-b15d-7229c4ef0c49?page=1

165 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/e67f1a98-0937-4c15-ad40-e5029f4cedd0?page=1

166 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/e265a08b-82b6-47da-bf1c-ec242848c52d?page=1

167 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/f024f26d-b891-4b8b-a078-f69a9a7d79b0?page=1

Health and Social Care Partnership and the Manchester Biomedical Research Centre (BRC), have highly emphasised industry-academia collaboration for a thriving healthcare innovation ecosystem in Manchester.

Multiple initiatives reinforce this collaboration, including the 'Health Innovation Manchester' initiative in 2017 that combines various academic networks in the health sciences, brings them together with digital and industry expertise, and delivers projects through an accelerated innovation pipeline directly aligned with GM's transformation priorities.[168] Manchester BRC has also partnered with Health Innovation Manchester to formulate an industry advisory group to guide its commercial strategy, provide insight on optimal paths to commercialisation and provide feedback on the relevance and attractiveness of BRC research and innovation outputs. This commitment to creating real-world impact via health research's commercialisation and market penetration is also visible within higher education institutes in Manchester, with the University of Manchester Innovation Factory driving the commercialisation of the University of Manchester's innovations and intellectual property, of which health innovation is a key focus. Supported by the local authorities, these strong collaborative ties between Manchester's HEIs and its health industry are an enabling factor driving positive health outcomes for Manchester's people.

5.5.3. Concluding reflections

It is evident from the research Manchester's HEIs submitted in this REF cycle that HEIs in the area have conducted research generating wide-ranging, profound and localised impact on Manchester's economy, culture, governance practices and its people's broader health and well-being. This section also sought to analyse the mechanisms behind this place-based impact in Manchester, and an integrated local authority empowered by devolution combined with a collaborative and participative research culture and dynamic industry-academia linkages emerge as initial candidates. The factors and forces driving this localised impact warrant greater examination, with potential learnings for levelling up via research and innovation.

168 Health Innovation Manchester (2021).

Chapter 6

Conclusions

Bringing together this evidence, we can draw several conclusions regarding the ICSs and what they can tell us about the impact of research at UK HEIs.

Research at UK HEIs has had a significant and diverse impact on society and the economy

A key observation from reviewing a sample of these ICSs is that research at UK HEIs has significantly impacted society and the economy in the UK and globally. Our deep dives identified illustrative examples ranging from the critical contributions to tracking COVID-19's emergence and developing and testing treatments to developing renewable technologies towards net zero goals. These impacts were diverse; we identified 79 unique impact 'topics' spanning 'cancer diagnostics and therapy' and 'intelligence and cyber security' to 'pollution and air quality' and 'language and linguistics'.

Impact pathways are complex, diverse and unique

Research impact depended on various disciplines, and all four REF panels (A–D) contributed to most impact topics. This principle was also evident when examining the underpinning research disciplines, with 53% of ICSs based on publications from two or more FoRs. Mapping these different routes showed there is no single pathway to impact. Instead, the fields contributing to ICSs within each UoA showed significant diversity, and ICSs from each UoA contributed to multivarious impact topics. Since impact is often a bespoke activity with diverse pathways, developing a balanced and comprehensive set of impact metrics that capture this range of activities would be very challenging.

Impact is global, national and local

Research at UK HEIs has had global impacts, with almost every country benefitting from the research. When we examined impact flows between UK regions, we found that most research impact was 'exported' from the home region to other UK areas. The biggest 'exporter' was the Southeast of England, which distributed 69% of its impact to other areas. This finding is particularly beneficial to the discussion on 'levelling up', where many metrics typically used to explore R&I focus on input measures (e.g. location of research investment). This impact analysis shows that examining which institutions receive the money gives a partial picture of the role R&I plays across UK regions. Although impact can occur where money is invested, only a few institutions' majority impact was 'hyperlocal'. Exploring this through a deep dive into the Manchester region surfaced broader structural factors that may have enabled this hyperlocal impact. Further research would be beneficial to understand how impact occurs across locations and the relationship between HEIs and their locality.

ICSs offer information for analysing research impact characteristics

Analysing the ICSs provided useful information on the broader characteristics of research impact. For example, while the average time lag from the start of research to the end of impact across the set of ICSs was ten years, research in Panels A and B took an average of three years longer than in C and D. However, there were also limitations to the analysis we could conduct. For example, ICSs provided many useful examples of the ROI of research with mentions of currency or 'return on investment' in the impact section of 2,146 ICSs.

However, the various ways this was expressed made it difficult to aggregate the results systematically and meaningfully. Standardising some aspects of ICSs might be worthwhile to facilitate analysis, building on previous work on standardisation in ICSs.[169]

Research benefits many different groups

We identified evidence of 59 different beneficiary types across ICSs, and there are likely many more. The top five beneficiary groups identified were quite broad, comprising 'governments', 'communities', 'policymakers', 'practitioners' and the 'public'. However, we also identified more specific beneficiary groups, such as 'nurses' and 'farmers', highlighting the range of groups addressed within the ICSs. The main Panels also contributed to almost all these beneficiary groups, further emphasising the disciplinary spread of impact. Investigating the impacts on policy in particular, we linked ICSs to policy documents through common citations. This analysis identified 305 ICSs linked to UK government sources, with particularly strong links to ICSs from Panels A and C.

Interdisciplinarity and collaboration levels differed across the ICS set

As highlighted previously, it is clear that research impacts draw on insights from multiple FoRs. However, when we explored the ICS set to understand which parts of the

169 Parks et al. (2018).

portfolio were more and less interdisciplinary or collaborative by analysing the underpinning research's characteristics, we found differences in the concentration of IDR between topics, with topics associated with societal challenges likelier to have higher IDR levels and topics in clinical medicine likely to have lower IDR levels. This was reflected at the UoA level to some extent. For example, UoA 5 (biological sciences) and UoA 32 (art and design: history, practice and theory) had high levels of IDR research, whereas UoA 1 (clinical medicine) and UoA 16 (economics and econometrics) had lower levels. While this analysis can reveal relative differences in IDR concentrations across the REF 2021 ICS portfolio, no other reference benchmark is available. A more comprehensive analysis that benchmarks research underpinning the impact to that submitted as outputs to REF and, more generally, to the UK and global background would provide greater insight.

ICS are underpinned by highly cited research

Most underpinning research performed better than the global average CNCI of '1.0', with the highest citation counts associated with research from Panel A. The percentage of HCPs was well above the global average of 1% and significantly higher than this across all Panels.

There is significant consistency between REF 2021 and REF 2014

Analysis of the ICSs from REF 2021 showed significant consistency with the ICSs from REF 2014. At a broad-brush level, our findings are largely similar to those in 2014, showing that impact is multidisciplinary and occurs through numerous unique pathways. The global impact of research at UK HEIs was also consistent with 2014, with a comparably rich and diverse impact portfolio. There were some differences in the 2014 analyses, largely stemming from the approach taken. For example, as we would expect, the topic model is different, which should not be interpreted to reflect a decline or increase in specific impact types – and as such, like-for-like detailed comparison is not appropriate. However, the high-level picture that impact is a complex, bespoke activity remains.

We also examined how rule changes for 2021 changed the nature of ICSs, generally finding that HEIs did not significantly utilise them. Very few HEIs took the opportunity to submit ICSs focusing on impacts on students and teaching, and there appears to have been a lack of clarity around continued case studies.

It is interesting to observe the remarkable consistency between the two datasets after two such exercises, reinforcing the strength of these conclusions.

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Annex A. **UKRI-specific analysis**

Box 12. Key findings

- **UKRI funding significantly contributed to the research underpinning the REF ICSs.** UKRI funding underpinned 46% of the 6,361 ICSs submitted to REF 2021. Correspondingly, many observations of the broader ICS dataset also held for those receiving UKRI support. As in the broader ICS set, UKRI-supported ICSs were diverse and multidisciplinary, comprising a wide range of impact pathways.
- UKRI-funded ICSs benefited as broad a range of groups, consistent with the larger ICS set, with the same three groups occurring in the top three (governments, communities and policymakers). However, other groups featured higher up. For example, 'industry' and 'public' were higher up the UKRI list of beneficiaries than in the larger ICS dataset.
- **UKRI-funded research contributed to addressing policy priorities such as COVID-19, net zero and Place,** with many key contributions funded partly by UKRI.
- **Research funded by multiple UKRI councils was more likely to be interdisciplinary and collaborative.** Comparing the case studies supported by multiple UKRI councils showed that the IDR metric increased as the number of councils supporting the ICSs increased. We also found that as the number of councils supporting the case studies increased, the average number of DOIs with domestic, international and multilateral collaboration increased.
- **Research funded by multiple UKRI councils also typically had higher citation and local impact levels.** On average, UKRI-funded ICSs had higher citation levels than the world average. However, this increased as the number of UKRI councils supporting the research increased and was significantly higher for ICSs supported by three or more UKRI Councils.
- **ICSs supported by multiple UKRI research councils generated diverse impacts, including those around environmental sustainability, energy and applied technology.** Regarding impact topics related to ICSs supported by three or more UKRI councils, key topics included 'environmental management', 'environmental sustainability', 'energy' and 'food policy and applied technology'.

This annex sets out the analysis focusing specifically on ICSs where UKRI funded or partly funded the underpinning research. The analysis focuses on three key aspects: (i) the research impact's nature and beneficiaries (the impact types identified, pathways to impact, beneficiaries of impact and diversity of the underpinning research), (ii) the role of UKRI funding (how UKRI support leverages industry funding and the role of UKRI capability in supporting impact) and (iii) details of the impact arising from UKRI support.

A.1. The nature and beneficiaries of research impact

Based on the metadata provided with each ICS, we identified ICSs whose underpinning


Photo by Magda Vrabetz on Unsplash

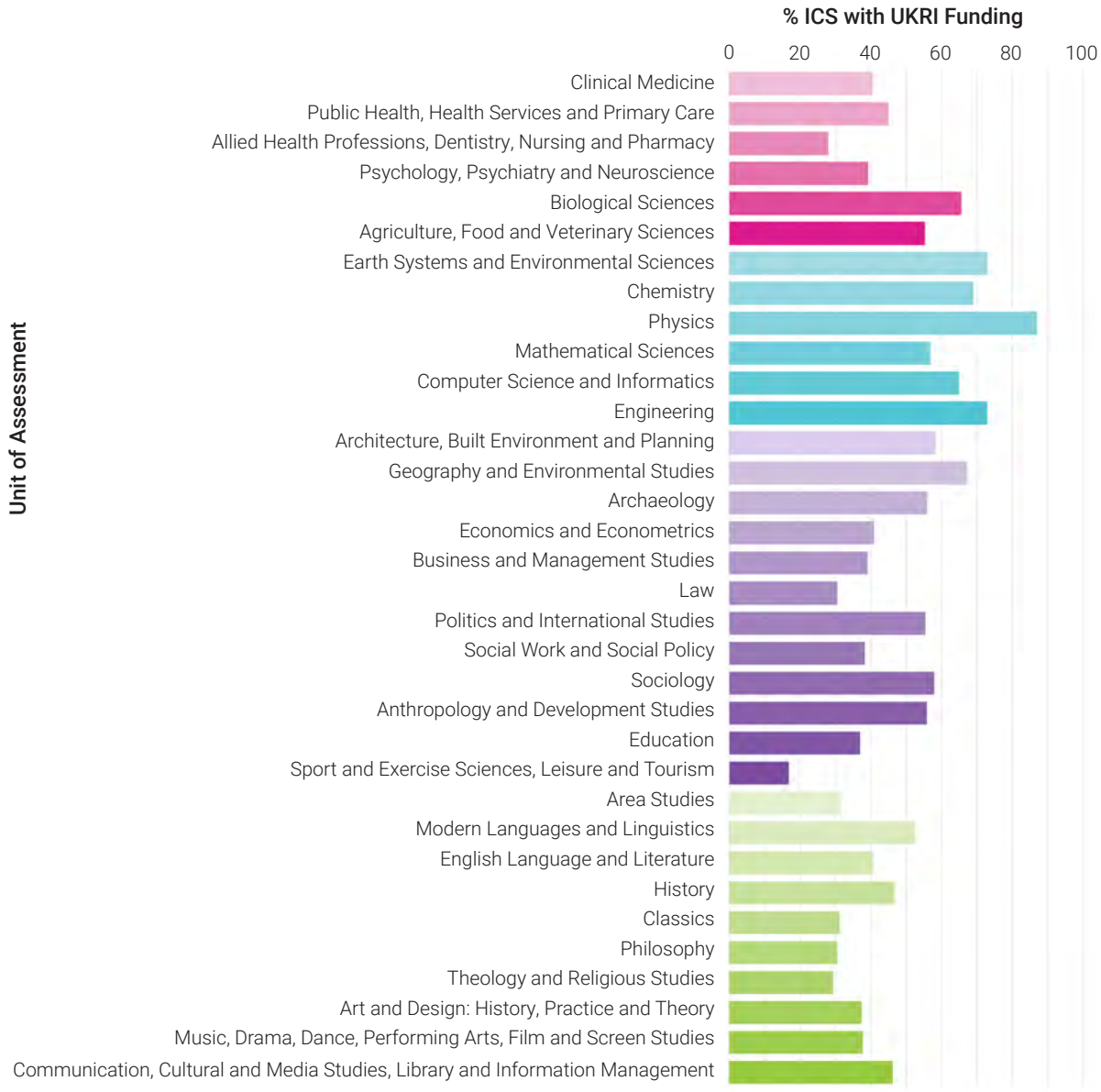
research was supported by UKRI. Of the 6,361 ICSs, 3,032 (46%) were underpinned by UKRI funding.[170] By Panel, this breaks down as follows:

- Panel A: 42% of ICSs had UKRI support
- Panel B: 71% of ICSs had UKRI support
- Panel C: 43% of ICSs had UKRI support
- Panel D: 40% of ICSs had UKRI support

Figure 26 shows the proportion of ICSs in each UoA that received UKRI support. This evidence largely reflects the overall Panel-level data above, with particularly high proportions of Panel B ICSs receiving UKRI support compared to other Panels. However, we also identified some significant variations by UoA, even within panels. For example, in Panel C, 67% of ICSs from UoA 14 (Geography and Environmental Studies) received UKRI support compared to only 17% of ICSs in UoA 24 (Sport and Exercise Sciences; Leisure and Tourism). Similarly, in Panel A, only 28% of ICSs in UoA 3 (Allied Health Professions, Dentistry, Nursing and Pharmacy) had UKRI support compared to 66% of ICSs in UoA 5 (Biological Sciences).

170 Tier 1 UKRI support is where there is a strong link indicating that UKRI funding underpinned these impacts. Matched to at least one of (i) grant reference in funding metadata, (ii) funder name in funding metadata or (iii) funder or subsidiary (e.g. institute, facility) name in the ICS text.

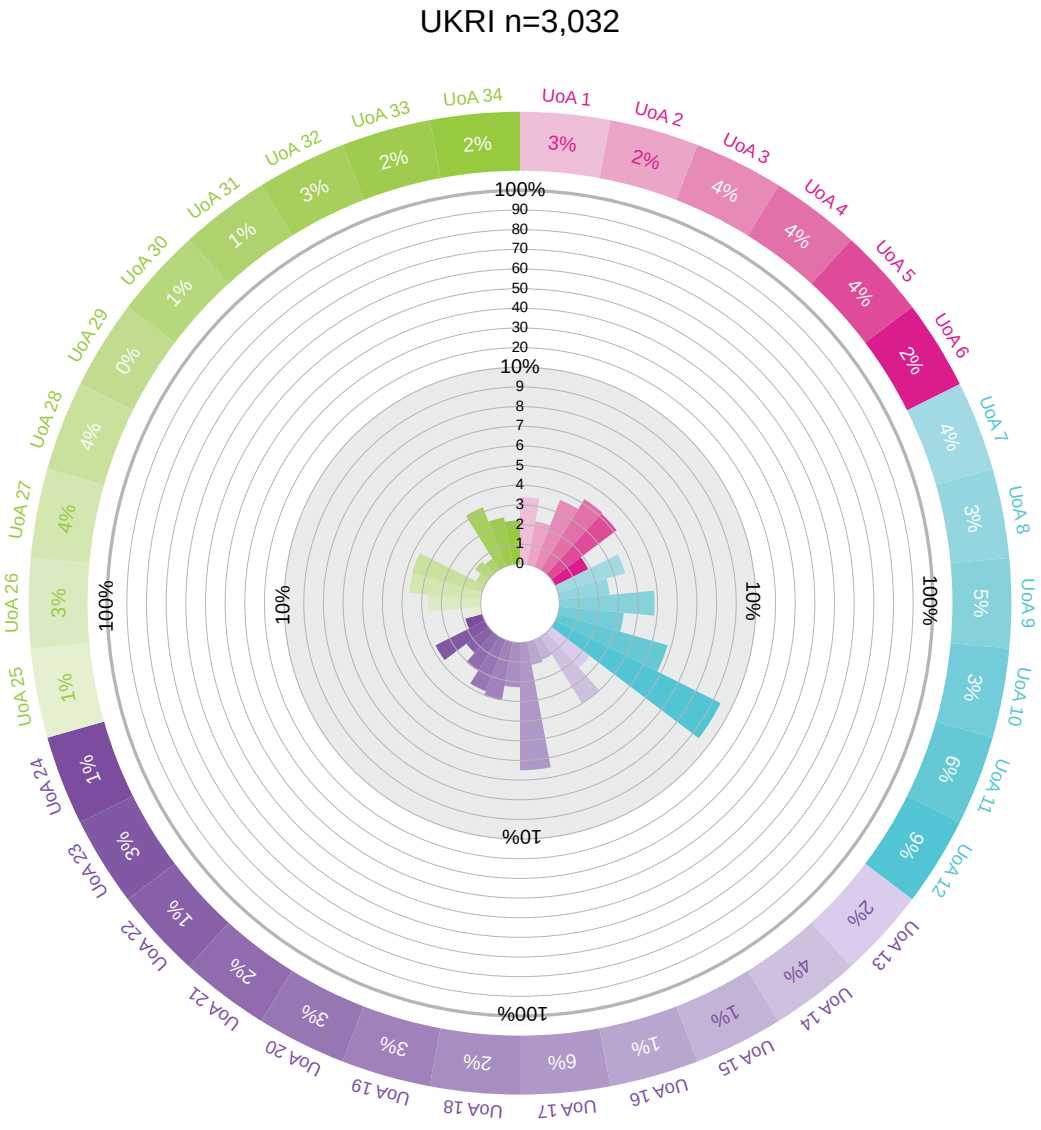
Figure 26. The proportion of ICSs from each UoA that received UKRI support



Notes: This figure shows the proportion of ICSs from each UoA that received UKRI support (n=6,361). The four colours represent the four panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green). Different shades of the same colour represent the 34 UoAs.

We also examined how UKRI-supported ICSs were distributed across UoAs, as shown in Figure 27. This further emphasises the distribution across UoAs, with UoA 12 (Engineering) and UoA 17 (Business and Management Studies) constituting a relatively high proportion of UKRI-supported ICSs (9% and 6%, respectively). However, this is partly a function of the higher ICS submissions in some UoAs.

Figure 27. The distribution of UKRI-supported ICSs across UoAs

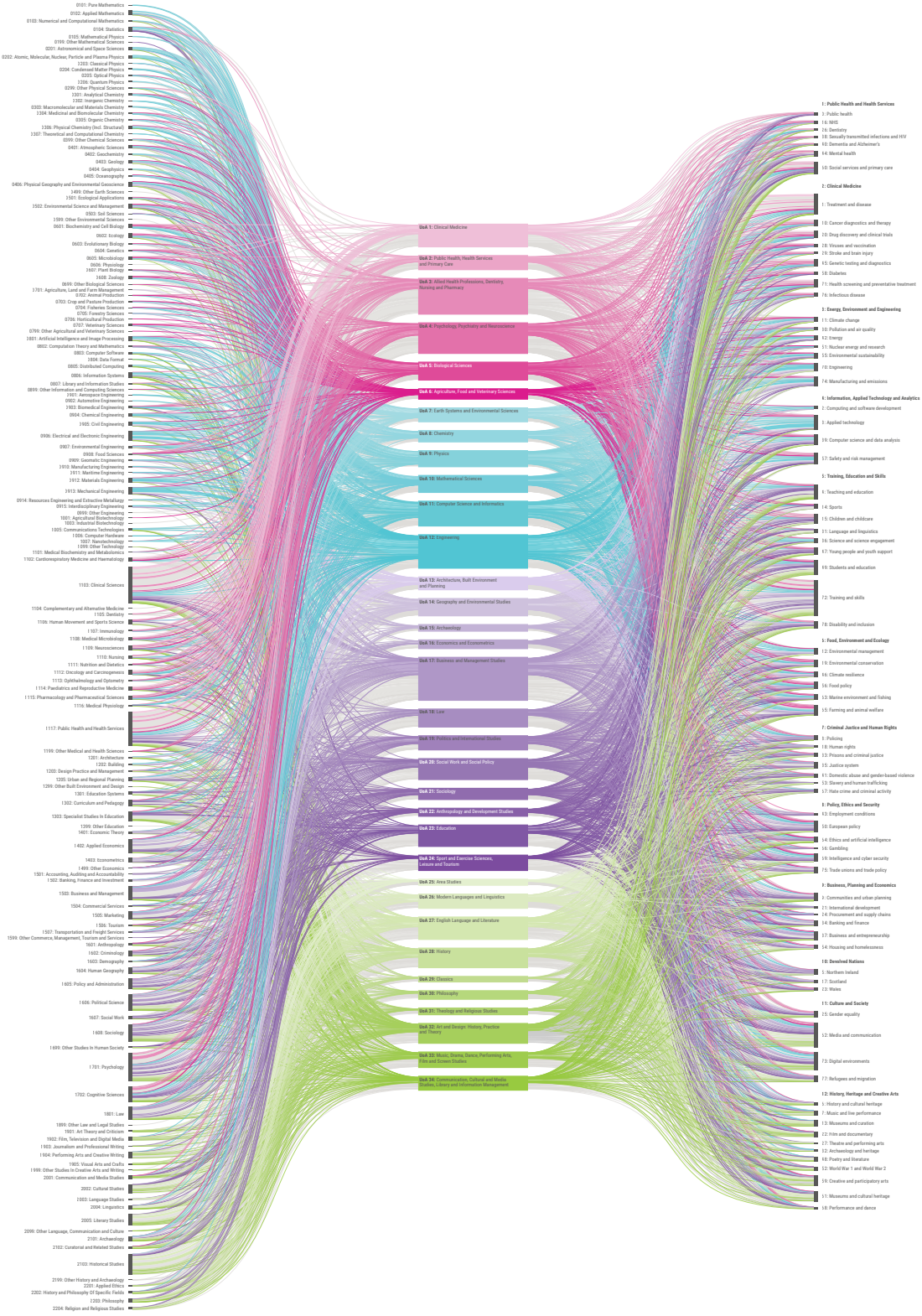


Notes: This figure shows the proportion of UKRI-supported case studies within each UoA (n=3,032). The four colours represent the four panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green). Different shades of the same colour represent the 34 UoAs. The impact wheel's spoke sizes indicate how frequently each UoA was represented in the UKRI-funded ICSs.

Using the broader population of ICSs, we mapped the UKRI-supported case studies against topics to analyse the contributions made to these topics by different Panels, UoAs and FoRs based on the publications underpinning the impact. As in the broader analysis, the alluvial diagram presented in Figure 28 and simplified in Figure 29 shows similarly diverse pathways to impact, with various contributions from multiple FoRs to each Panel. In turn, UKRI-supported case studies from each Panel contributed across

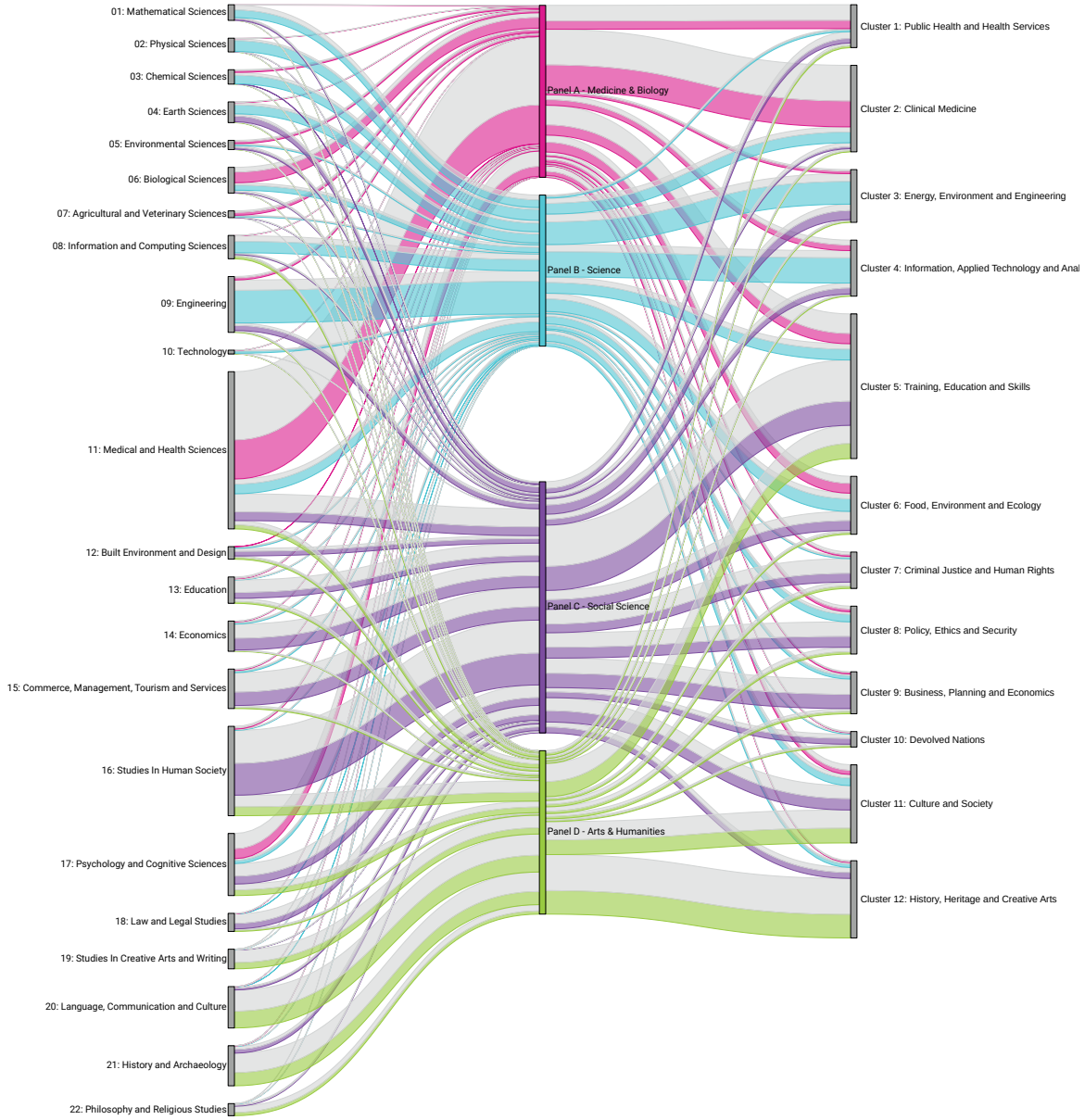
multifarious topic clusters. Some Panels had more ICSs involving UKRI funding than others. In Panel B, for example, a high proportion of grey (total ICSs) was funded by UKRI (blue). In contrast, UKRI-funded case studies represented a smaller proportion of grey (less than 50%) for Panels A, C and D. Similarly, the right-hand side of the figure shows that some impact clusters contained numerous UKRI-funded case studies and others less so. An example is Cluster 3 (Energy, Environment and Engineering), which had a significant number of ICSs supported by UKRI funding. In contrast, Cluster 2 (Clinical Medicine) had a smaller proportion (around 50%), indicating that a higher diversity of other funders supported research in some areas. Figure 30 summarises the relationship between topics and UoAs in a bubble plot, showing the distribution of ICSs across impact topics and UoAs and demonstrating a relationship between the impact type (represented by the impact topic) and the UoA.

Figure 28. Alluvial diagram illustrating impact pathways for UKRI-supported research



Notes: This alluvial diagram shows the pathways to impact for UKRI-supported ICS (in colour) against the full set of ICSs (in grey). As before, this links the underpinning research's FoRs with the four REF panels –represented by the four colours: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green) – and the 12 impact clusters.

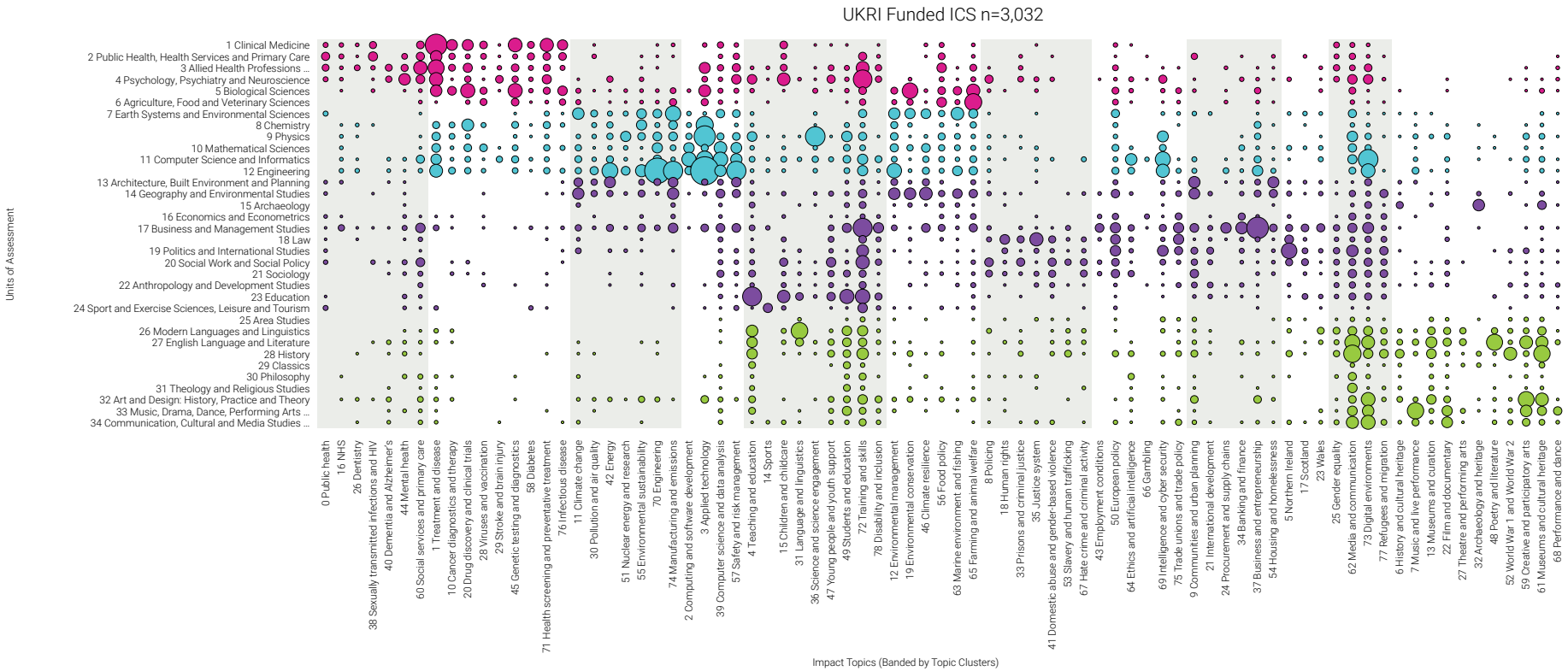
Figure 29. Simplified alluvial diagram showing impact pathways for UKRI-supported research[171]



Notes: This figure shows a simplified alluvial diagram of the pathways to impact for UKRI-supported ICSs (in colour) against the full set of ICSs (in grey). As before, this links the underpinning research's FoRs with the four REF panels – represented by the four colours: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green) – and the 12 impact clusters.

171 The wider population of pathways for all ICSs is shown in grey. The alluvial links the FoRs for the underpinning research (left) with the four REF panels (middle) and the 12 impact clusters (right).

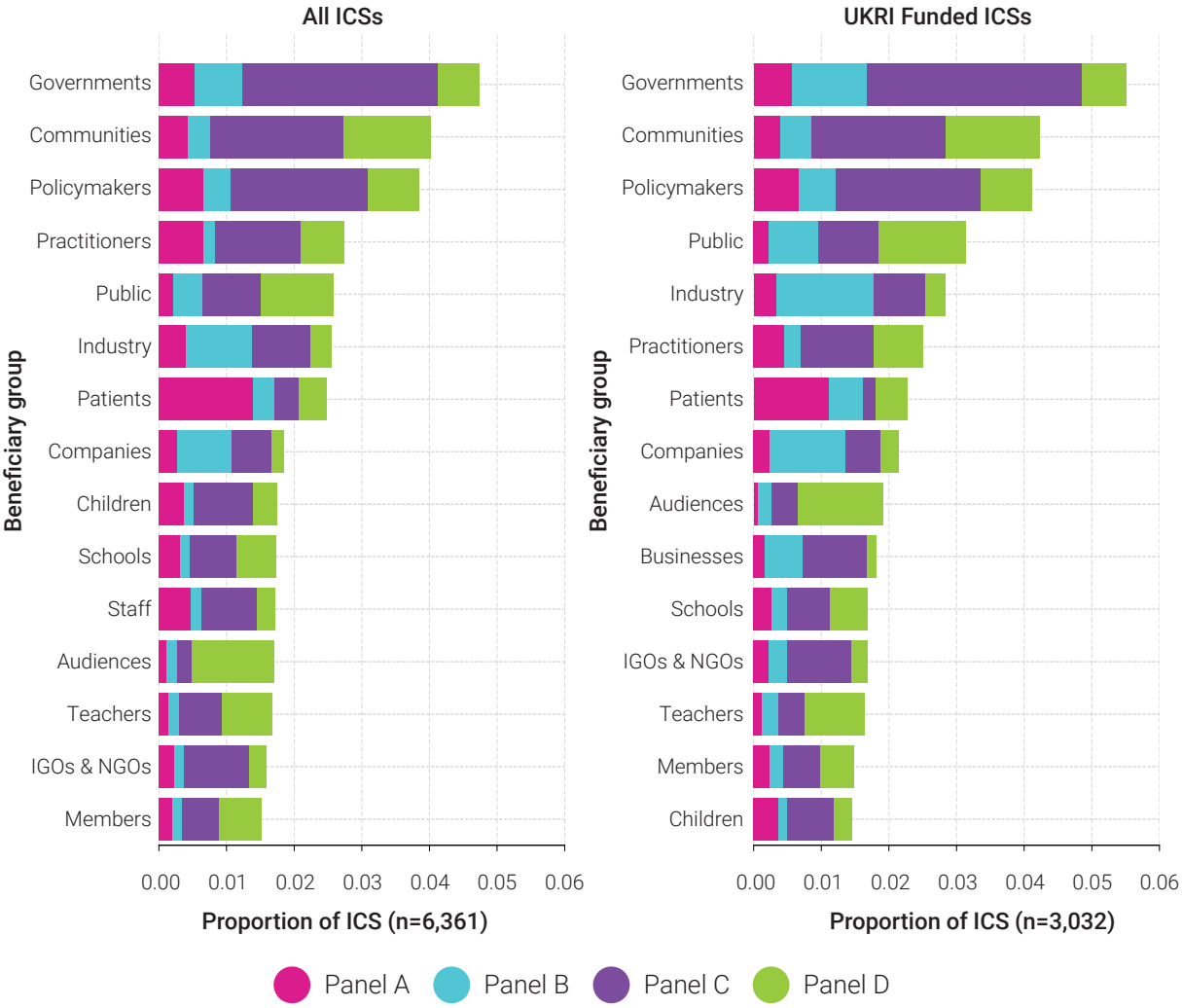
Figure 30. Bubble plot linking topics to UoAs in UKRI-funded ICSs



Notes: This figure shows a bubble plot mapping the 79 impact topics (x-axis) against the 34 UoAs (y-axis). Each bubble's size indicates the number of ICSs assigned to that topic and found within that UoA. As before, the four colours represent the four panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green).

We analysed the text in the impact section of the ICSs to identify information about the research impacts' beneficiaries. As before, we used a keyword-in-context (KWIC) approach to generate nouns (or noun phrases) appearing near the words 'stakeholder', 'beneficiary' or 'user' in Section 4 of the ICSs to identify potential research beneficiaries. This search yielded 59 different beneficiary types. Figure 31 shows the results of this analysis for the top 12 beneficiary types for UKRI-funded ICSs (see Annex D for the complete list). The top three beneficiary groups identified align with those in the broader ICS set: 'governments', 'communities' and 'policymakers'. However, the two groups which followed this 'public' and 'industry' were placed slightly higher up on the UKRI list when compared to the wider ICS group. The ICS set showed contributions to almost all beneficiary groups across all Panels, further emphasising the diverse impact pathways. As before, the Panels contributed differently to each beneficiary group. ICSs in Panel D contributed significantly to 'audiences', whereas ICSs in Panel A contributed more to 'patients'.

Figure 31. Beneficiaries of research impact by Panel for all ICSs (left) and UKRI-funded ICSs (right)

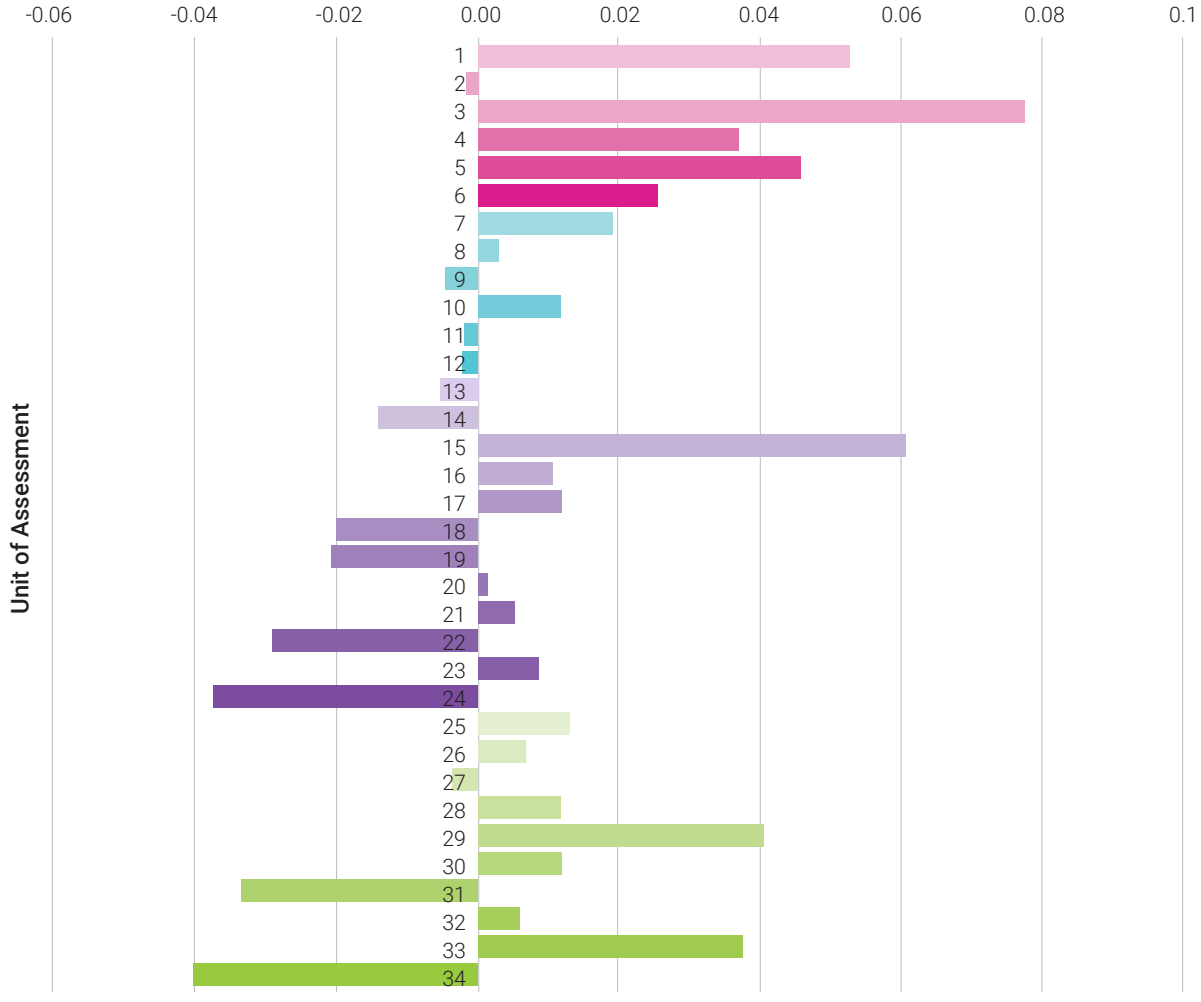


A.2. Research underpinning the impact

We used the methodology described in the main report (Section 3.1.1) to measure the disciplinarity of the ICSs' underpinning research, profiling the UKRI-funded component against the global dataset. We calculated the inter and multidisciplinary metric (RS-IDR) based on the underpinning research's cited references, with the result expressed as a Panel-normalised percentile. A value of '0' denotes research entirely within one field, while '1' represents research based on the broadest and most novel combinations of research disciplines.

Figure 32 plots the relative difference in the mean RS-IDR for each UoA. Except for UoA 2 (Public Health, Health Services and Primary Care), Panel A ICSs supported by UKRI funding had relatively higher rates of interdisciplinary research, as much as 0.08 percentile points in UoA 3 (Allied Health Professions, Dentistry, Nursing and Pharmacy). In contrast, Panel B ICSs (which had a relatively high proportion of UKRI funding) exhibited similar levels of interdisciplinarity whether they were UKRI-funded or not. Some UoAs in Panel C show slightly lower rates of IDR – e.g. UoAs 18, 19, 22 and 24 – but the decrease is marginal (less than -0.04 percentile points).

Figure 32. Percentile (RS_IDR) advantage for UKRI-funded ICSs by UoA



We used this metric of disciplinarity to investigate the relative proportions of UKRI-funded research in various RS-IDR percentile buckets. In Figure 33, the pink line shows the mean percentile (RS-IDR) for UKRI-funded research from monodisciplinary (left) to highly interdisciplinary (right) ICSs. The purple line represents the overall expected proportion of UKRI-funded research (48%), shown for comparison. The figure demonstrates that ICSs with the highest RS-IDR values were more likely to be funded by UKRI.

To explore this association further, we plotted the mean percentile (RS-IDR) for various ICSs by the number of UKRI funding streams (primarily research councils) in Figure 34. The purple line shows the mean percentile (RS-IDR) for ICSs that received no UKRI funding (left) through to those that received funding from six UKRI councils (right). The orange line represents the total ICS count in each bucket (right y-axis). The result confirms expectations that the underpinning research for ICSs reporting multiple UKRI funders is more likely to be interdisciplinary. Without similar data to compare other funding streams (e.g. from the European Union, charities or industry), we cannot determine whether UKRI is unique in supporting highly interdisciplinary research or if other funding sources are also responsible.

Figure 33. Percentage of ICSs with UKRI funding according to mean percentile (RS-IDR)

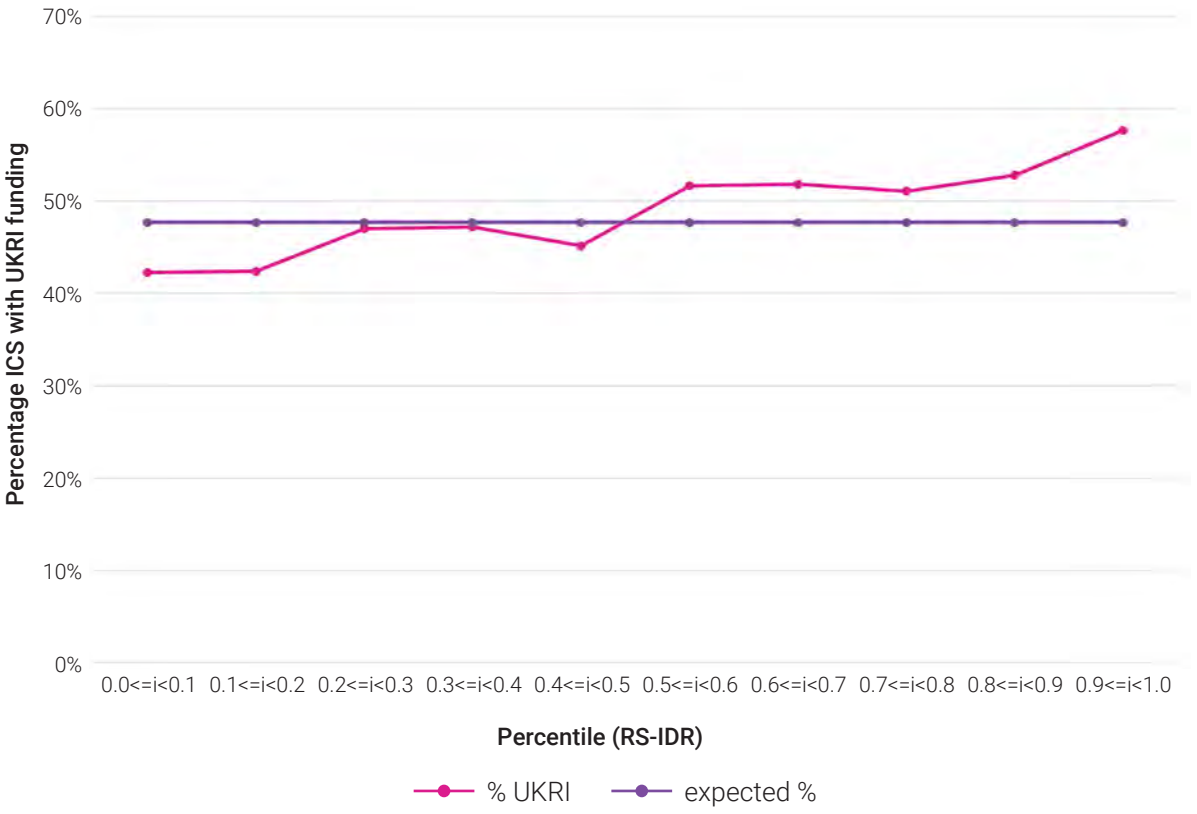
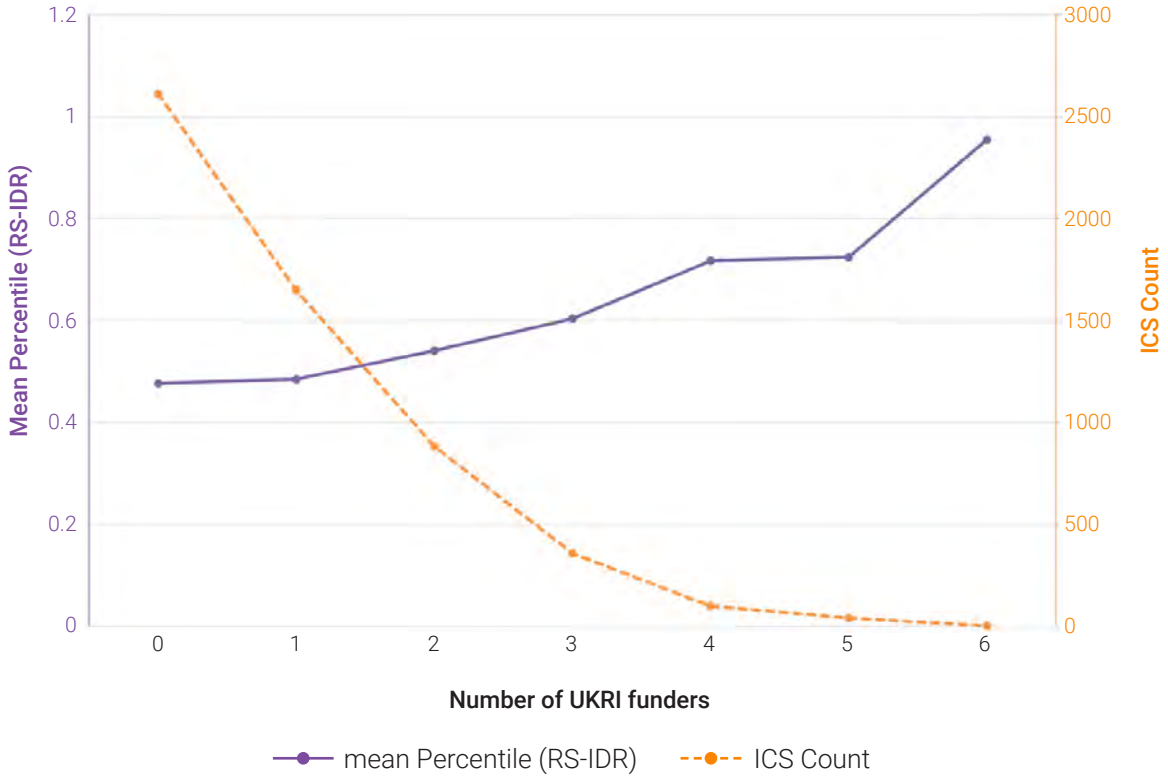


Figure 34. Percentile (RS-IDR) by UKRI funder count

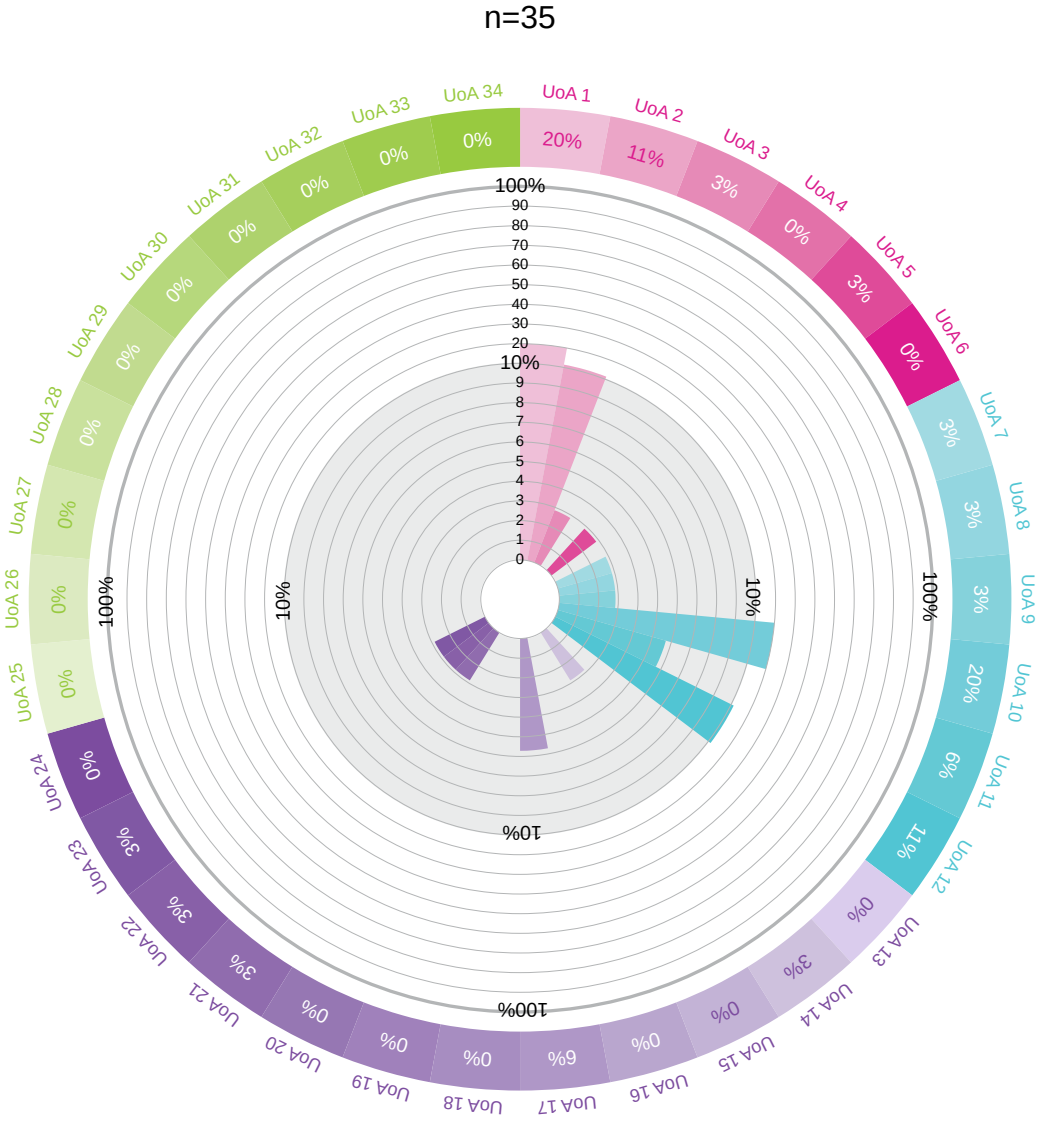


A.3. Government policy and strategy

A.3.1. The impact of UKRI-supported research on COVID-19

As part of this study, we undertook a deep dive into the impact of research on COVID-19. This deep dive showed that research at UK universities made a significant and far-reaching contribution to monitoring, managing and mitigating the COVID-19 pandemic's impact. Various disciplines contributed towards these impacts, including clinical medicine, health-related disciplines and mathematical modelling. Research outputs directly influenced global healthcare practices, providing tools and technologies to support patient testing and treatment and policy measures to help contain infection. Research in the UK university sector helped mitigate the crisis through agility, pace and ingenuity, saving many thousands of lives worldwide and reducing disease burden, morbidity and long-COVID associated with COVID-19. We described the full analysis in Section 5.3. Of the 66 ICSs reviewed for the full deep dive, 53% (n=35) were underpinned by UKRI funding, distributed across Panels A, B and C. The impact wheel below shows the distribution of COVID-19-related ICSs across Panels and UoAs. Table 24 provides information on the nature and composition of the ICSs included in the deep dive.

Figure 35. Impact wheel for the COVID-19-related deep dive into the UKRI-funded ICS subset
Notes: The 'n' represents the number of ICSs reviewed. The four colours represent the four panels: Panel A (pink),



Panel B (blue), Panel C (purple) and Panel D (green). Different shades of the same colour represent the 34 UoAs. The impact wheel's spoke sizes indicate how frequently impact within that UoA occurred.

Table 24. Features of the COVID-19-related UKRI-funded ICSs

Nature of impact: Top three primary topics	% of cluster ICSs (n=35)	% of all ICSs (n=6,361)
Viruses and vaccination	23%	1%
Clinical trials	14%	5%
Patient care	11%	2%
Location of impact: Continent		
Europe	97%	91%
North America	51%	40%
Asia	40%	31%
Africa	20%	14%
Oceania	29%	19%
South America	9%	10%
Underpinning research: Top three fields		
Public health and health services	71%	18%
Clinical sciences	60%	20%
Medical microbiology	29%	2%
UKRI research funder		
Central funding (inc. RE funding, GCRF, Newton etc.)	29%	8%
AHRC	0%	11%
BBSRC	31%	5%
EPSRC	60%	15%
ESRC	26%	16%
Innovate	20%	8%
MRC	66%	8%
NERC	11%	6%
STFC	11%	3%

Here, we discuss the primary themes emerging from the deep dive, referencing UKRI examples where relevant. While UKRI-funded case studies contributed to all themes mentioned in the main deep dive, the three themes outlined below were most prominent.

UK university research informed global clinical guidelines and practice related to treating COVID-19, saving lives and easing symptoms among patients worldwide

Our deep dive revealed that research at UK universities informed global clinical guidelines and practices for treating COVID-19,

contributing to saving lives and easing symptoms worldwide. Our review of the UKRI subset demonstrated that UKRI partly funded some of the most significant contributions to clinical guidelines and practice. This includes the RECOVERY trial, which, as described in the main deep dive, changed global clinical guidelines and practices for dexamethasone use, saving an estimated 650,000 lives in 2020 and preventing harm and waste from using medications that it demonstrated to be ineffective.[172] UKRI also partially funded the work on the Oxford-AstraZeneca COVID-19 vaccine, developed at remarkable speed and approved to supply 2.6 million vaccine doses worldwide, half of which went to low- or middle-income countries.[173] UKRI funding also supported work on the earlier mentioned UCL-Ventura CPAP breathing aids, which helped COVID-19 patients in 125 UK hospitals and 20 other countries.[174]

Research at Aston University led to another UKRI-funded contribution not yet mentioned, facilitating the development of a novel personal protective equipment (PPE) device for ear, nose and throat (ENT) medicine. This device enabled clinicians to safely conduct nasendoscopy, a procedure used to diagnose throat cancers and rehabilitate stroke patients, during COVID-19 by making it possible for the patient to wear a surgical mask, reducing the risk of contamination for patients and staff. By the end of 2020, 5,000 devices had been supplied free of charge to the NHS, and international sales had begun with 14 interested countries.[175]

Developing productive policy interventions required extensive and accurate data, to which research at UK universities contributed tools and methods related to diagnostics, contact tracing and other surveillance

It is evident from the main deep dive that research at UK universities made vital contributions to diagnostics, contact tracing, surveillance techniques and acquisition of other forms of data essential to inform COVID-19 policy responses in the UK and internationally. Reviewing the UKRI-funded ICS subset demonstrated that UKRI funding supported this aim, e.g. by contributing to the work on contract tracing, briefly mentioned in the main deep dive. Researchers at the University of Oxford provided epidemiological evidence to NHSX that informed the development of contact tracing apps. This evidence helped establish these tools' requirements, benchmarks, parameters and principles internationally. The NHS COVID-19 Contact Tracing App is estimated to have prevented 600,000 cases of COVID-19 between September and December 2020 in the UK by sending 1.7 million exposure notifications.[176] Research at Bangor University made another important UKRI-supported contribution in which researchers collaborated with the government to develop viral waste-water surveillance approaches to track SARS-CoV-2 in UK cities.

172 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/1c4caf3b-6c0d-432a-b8a5-a4d4279498a8?page=1

173 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/52cf7a8d-5f6b-45bf-80b5-e4783723fd58?page=1

174 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/03cf0e47-ac71-41f7-aa8a-d9dc6061d527?page=1

175 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/999f71c5-e22d-48d9-ac5a-af0102e8446a?page=1

176 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d3d20ce5-b625-4da5-9e0e-8e4bf87ef238?page=1

By building on earlier methods for quantifying and sequencing human pathogenic viruses in water and shellfish, these approaches enabled whole-community monitoring of COVID-19 and a warning system protecting national infrastructure from COVID-19 outbreaks. Furthermore, it supported decisions on where to target mass testing and evaluations of COVID-19 mitigation measures.[177]

UKRI-funded aerosol science research at the University of Bristol also contributed significantly to the UK's evidence base on COVID-19 transmission. A study team of physical scientists and clinicians developed a strategy for measuring the concentration and particle size distributions of aerosols generated during respiratory and medical procedures. Their work contributed to clinical practice standards worldwide and informed the re-opening of the UK performing arts sector.[178]

Modelling played a vital role in the research impacting COVID-19, enabling better monitoring of the pandemic's rapid and unpredictable developments

The main deep dive revealed that many UK scientific contributions to COVID-19 involved modelling supported by UKRI funding. Examples extend beyond the ICSs already mentioned in the deep dive. For example, a suite of models developed at Queen's University Belfast helped the UK government's emergency planning. These models applied statistical data analytics to model disease prevalence and spread in the UK population, informing local and national alert levels.[179]

Other contributions came from research at Lancaster University, where epidemic modelling helped understand the pandemic potential of the SARS-CoV-2 outbreak in China in January 2020. This research provided early evidence to the UK Government's Scientific Advisory Group on Emergencies (SAGE) and directly informed disease control policies in the UK and internationally, as well as the UK Government's COVIDTracer planning tool. In the UK, it also informed policies relating to household isolation, school re-opening, hospital transmission control and hotspot detection.[180]

Mathematical modelling at Swansea University also informed multiple health policies in Wales via the 'Swansea Model', which facilitated early and accurate forecasting for planning hospital capacity, predicting ambulance service call demand and other national interventions. For example, the model provided evidence for the October 'Firebreak' lockdown in Wales estimated to have saved 1,100 fewer deaths and 5,000 fewer hospital admissions.[181]

A.3.2. The impact of UKRI-supported research on net zero

We undertook a deep dive into the impact of research on net zero, which showed that research at UK universities was instrumental in informing, directing and reinventing the entire spectrum of decarbonisation and emission

177 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d54c7e46-dee1-4228-8382-38f25f4e5b90?page=1

178 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/c5cb45da-3c59-45f0-812c-98df2e9fd742?page=1

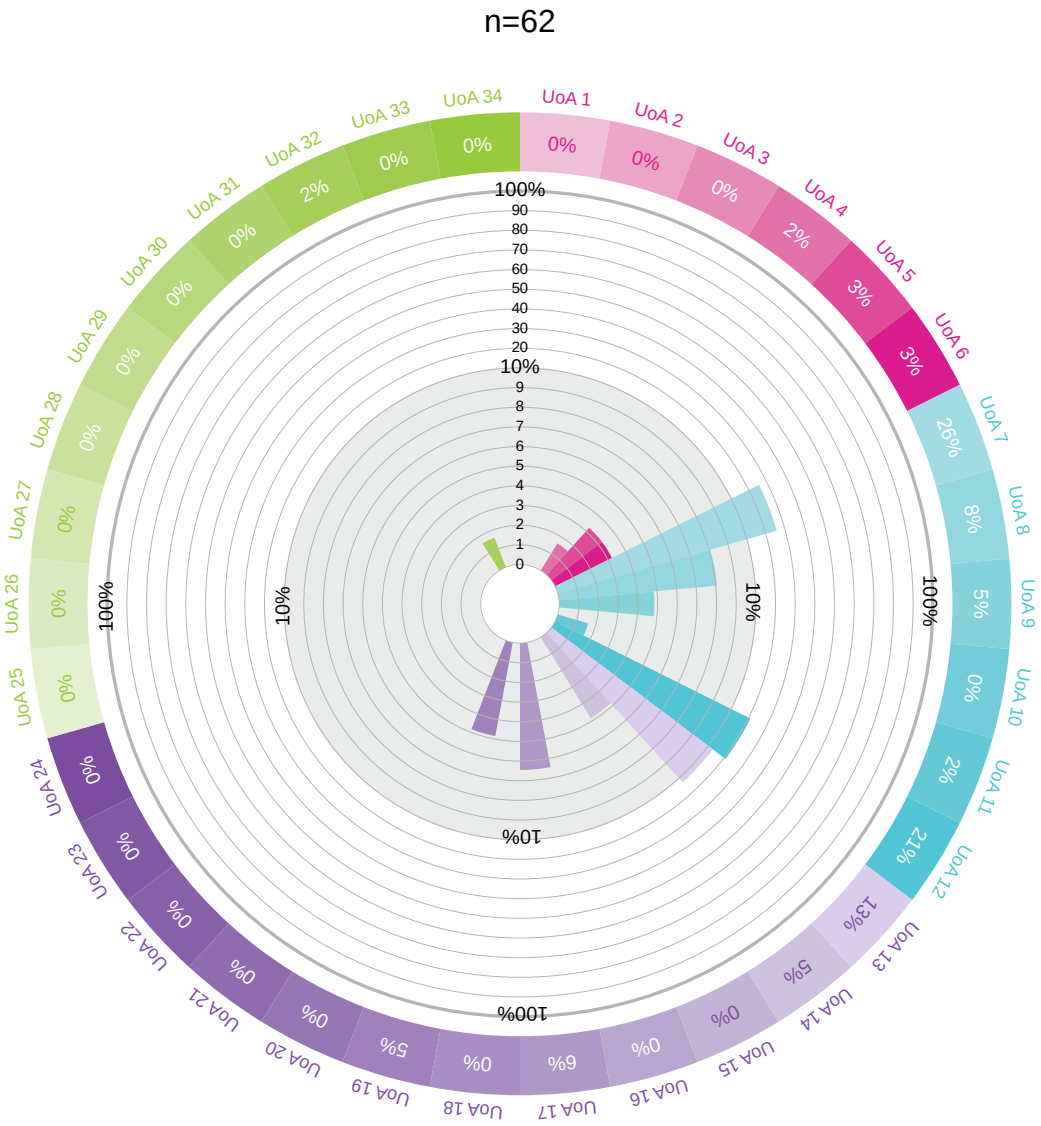
179 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/17332d6d-ea04-47f2-83d0-e4c3512d61ac?page=1

180 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/fc4c6f63-5ed6-490b-96c5-855c6697be3a?page=1

181 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/a059b0ba-02c6-4d12-aa0c-de00e59d6d5a?page=1

reduction initiatives towards net zero. Section 5.4 provides the full analysis. Of the 80 ICSs we reviewed, 78% (n=62) were supported by UKRI funding and distributed across Panels A, B, C and D. However, only one ICS featured in Panel D. The impact wheel below illustrates how the net zero-related ICSs were distributed across the Panels and UoAs. Table 25 details the nature and composition of the ICSs included in the deep dive.

Figure 36. Impact wheel for the net zero-related deep dive into the UKRI-supported ICS subset



Notes: The 'n' represents the number of ICSs included. The four colours represent the four panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green). Different shades of the same colour represent the 34 UoAs. The impact wheel's spoke sizes indicate how frequently impact within that UoA occurred.

Table 25. Features of the net zero-related UKRI-supported ICSs

Nature of impact: Top three primary topics	% of cluster ICSs (n=62)	% of all ICSs (n=6,361)
Manufacturing and emissions	50%	2%
Energy and energy efficiency	16%	1%
Climate change and weather	6%	1%
Location of impact: Continent		
Europe	100%	91%
North America	32%	40%
Asia	31%	31%
Africa	5%	14%
Oceania	18%	19%
South America	15%	10%
Underpinning research: Top three fields		
Applied economics	23%	8%
Atmospheric sciences	23%	1%
Electrical and electronic engineering	21%	5%
UKRI funder of research		
Central funding (inc. RE funding, GCRF, Newton etc.)	11%	8%
AHRC	0%	11%
BBSRC	13%	5%
EPSRC	55%	15%
ESRC	24%	16%
Innovate	26%	8%
MRC	2%	8%
NERC	44%	6%
STFC	6%	3%

In the main deep dive, we highlighted themes and sub-themes emerging from research at UK universities on net zero, showing that UKRI-funded research impacted most thematic areas. The following analysis showcases a snapshot of the impact generated through UKRI-supported research relative to some of these themes.

Informing the development of international net zero policy agreements and agenda-setting

Research funded by UKRI contributed to developing pivotal international policy protocols and agreements supporting net zero ambitions, bolstering the UK as a scientific leader in this arena. Contributions include

key ICSs highlighted in section 5.4, including the research conducted at the University of Bristol[182] on sub-par emission-reporting practices for international climate agreements and work at the University of Leicester's[183] Greenhouse Gas Remote Sensing Group on space-based methods to monitor greenhouse emissions accurately.

UKRI-funded research has made numerous other related contributions. For instance, research at the London School of Economics and Political Science's Grantham Research Institute (GRI)[184] actively supported adopting and implementing the historic Paris Agreement at national and international levels. A notable contribution of GRI research was the development of the Climate Change Laws of the World (CCLW),[185] an open-access database providing detailed information about climate change laws and executive acts in 196 countries and climate court cases in 35 countries. This database has been used as a helpful resource to analyse and identify the conditions for climate policy success in different socioeconomic and political contexts internationally. Moreover, GRI research has also contributed towards making the economic case for climate finance and sustainable infrastructure, especially in the context of the Paris Agreement. GRI's statistical analysis demonstrated that climate action in the UK and Europe has increased innovation rather than negatively impacting firm profitability, competitiveness and jobs, bolstering the case for broader climate action and informing development banks' increased climate-financing flow, particularly in infrastructure.

Research at the University of Exeter[186] has helped inform net zero policy nationally and internationally. Long-term climate research at Exeter has led to the development and testing of early warning methods for climate tipping points and quantified how the risks of reaching them alter economic analyses of climate change. Their work assessed how the dynamic interactions between tipping points increase these risks and affect the urgency of tackling climate change. This research has contributed to vital evidence underpinning the internationally accepted climate goal of limiting global warming to below 2°C. Various international reports recognise this goal, including the key 2018 Intergovernmental Panel on Climate Change (IPCC) Special Report on 'Global Warming of 1.5°C',[187] to which research team members contributed.

Another example of UKRI-funded research contributing to global climate developments was research at the University of Edinburgh[188] on quantifying anthropogenic effects on past, present and future climates and extreme weather events. The researchers' estimates of climate sensitivity (how much greenhouse

182 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/8b7de844-3de8-4afd-ae83-a5c8d339fbe0?page=1

183 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/19ffbda3-380b-4db5-b35f-8191111a8aea?page=1

184 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/08536f22-e906-40a0-a468-7aa8d5a32fe0?page=1

185 LSE Grantham Research Institute (2023).

186 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/219c2e40-1262-4004-a367-be9c41cf29f1?page=1

187 IPCC (2018).

188 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/b3d82d38-2b54-4bb2-8b88-86c1746f193a?page=1

gas emissions warm the climate) and the human contribution to recent warming were essential to IPCC's reports, including the 2014 IPCC 5th Assessment Report[189] and the 2018 Special Report on Global Warning. Research at the university on determining the human contribution to climate change, including changes in extreme events, also influenced the 2016 report of the US National Academies on the attribution of extreme weather events, which subsequently influenced service provision on event attribution and national climate change policies in the UK and worldwide.

Contributing to greater citizen engagement with net zero

UKRI-funded research has shed light on new and innovative ways to engage citizens and the wider public with net zero ambitions, helping promote greater acceptance of climate change and sustainability initiatives in the public sphere. For example, research into experiential learning at Southampton Business School[190] found that positive solution-based news stories are more effective than catastrophic or cautionary tales at inspiring ethical and sustainable behaviour and mindsets among citizens. This research has impacted the news sector, raising public awareness of the adverse effect of the dominance of negative news and supporting the design of high-profile initiatives by leading media organisations (including the BBC and the Guardian) that have engaged several million people in a more constructive, solutions-focused approach to journalism on climate change and net zero. The research has informed a broader 'constructive journalism' training in the UK and Europe. The research team's work has also helped shape the design of projects that encourage writers to generate positive visions of what a sustainable society might look like in response to the climate crisis. Examples include the 'Green Stories' writing competition, launched by the research team to encourage climate action through environmental storytelling.

Another example of significant research in this area is work at the University of Westminster[191] on designing and implementing citizens' assemblies locally and nationally in the UK. This research helped outline the distinctive design characteristics of citizen assemblies or 'Deliberative mini-publics', distinguishing this institutional form from other approaches to participatory governance and highlighting critical design choices for success. Moreover, this research helped inform and shape other citizen climate initiatives' content, including the 'Wellbeing of Future Generations Bill' and the' Today For Tomorrow' campaign. As the previous net zero section (5.4) highlighted, UKRI-funded research conducted at University College London's Constitution Unit[192] also made important contributions to designing citizen assemblies for climate and sustainability initiatives.

UKRI-funded research has also helped towards greater public engagement with net zero by generating key insights on public attitudes to sustainability initiatives, influencing these initiatives' design to achieve greater public uptake. For instance, Strathclyde's

189 IPCC (2014).

190 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/1a9feb2a-4f7a-4466-88a7-1595afd8414d?page=1

191 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/5abdc68c-d0e0-4632-b945-89d1c70ca97f?page=1

192 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/1bd0fe0a-6f1a-44e5-bfc8-9c627c81a00b?page=1

Centre for Energy Policy (CEP) research[193] on understanding, quantifying and building consensus around the broader economic impacts of industry, household and policy actions has shaped policy development to support low carbon transition to mid-century net zero carbon targets through direct engagement with Scottish, UK and international public policy stakeholders. This impact includes using CEP's research by the (former) UK Government Department for BEIS to support a 2018 policy strategy on carbon capture, usage and storage for industrial decarbonisation and inform the UK Chancellor's July 2020 decision to allocate public spending to support residential energy efficiency.

Developing and informing renewable and alternate energy technologies

Another critical area that has benefitted from UKRI-funded research is the development of renewable and alternate energy options and technologies for fulfilling the UK's net zero ambitions, including research enabling the technical progression of renewable and alternate technologies. It also includes research on optimal policy and implementation pathways for those technologies. We outline a few illustrative examples below.

Multidisciplinary research at Oxford Brookes University's Sustainable Vehicle Engineering Centre (SVEC)[194] helped address the economic, technical, social and environmental aspects of electric vehicles and personal mobility. SVEC has achieved commercial and policy impact through collaborations with the industry, local government and public-private partnerships. This impact includes commercial gain for automotive manufacturer BMW, who used SVEC's research to inform the technical development of their electric cars and benefitted from guidance on building wider acceptance of electric vehicles in their global markets. Moreover, SVEC research has influenced and informed UK transport policy on electric vehicle adoption via vehicle trials and influenced policy on powered light vehicles through collaboration with the Low Carbon Vehicle Partnership.

UKRI-funded research has also led to developments in solar PVNote technology. For instance, Sheffield Solar, a research group at the University of Sheffield, conducted research on PV systems[195] that has underpinned the development of pivotal milestones in the UK's solar PV journey. Sheffield researchers made vital progress for UK's solar sector via contributions to various research initiatives focused on PV technologies, including the £1.3m Engineering and Physical Sciences Research Council (EPSRC) funded 'Solar Energy in Future Societies' and the £1.1m EPSRC-funded 'Whole System Impacts and Socio-Technical Integration of Wide Scale PV'. This impact includes the development of PV Live, the national-level solar photovoltaic (PV) electricity monitoring service that progressed due to Sheffield Solar's research. PV Live has positively impacted the UK's energy forecasting and grid-balancing abilities, expanded a user base of energy service companies and emerged as a key source for public data relating to PV electricity generation in Great Britain.

193 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/b3ff85f2-44ca-4261-8dbd-2d42d6ef4741?page=1

194 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/0f1cbefa-ab37-4d46-aa32-b494373db75f?page=1

195 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/704fd078-c4db-4ee2-824b-35b8ce2ee1f9?page=1

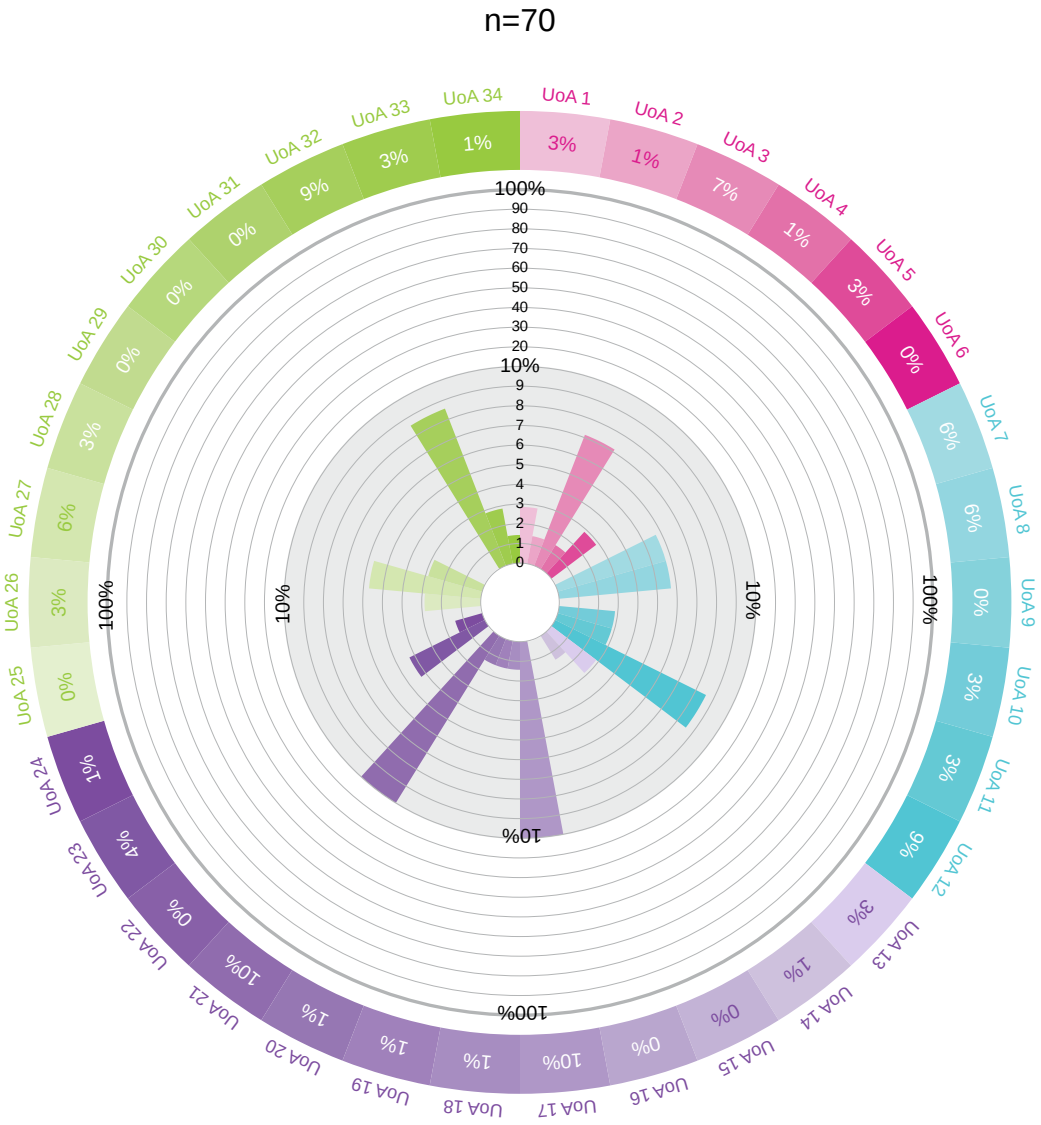
UKRI-funded research at UK universities has also contributed to developments in advanced fuel-cell materials. For example, research at the University of St Andrews[196] helped industry and policymakers solve the technical and economic challenges impeding hydrogen's use as a fuel for public transport in Scotland. This contribution helped inform policies like the Scottish Government Hydrogen Assessment, which marks a policy change towards adopting green hydrogen as an integral solution for decarbonising public transport. Their research also helped inform Aberdeen City Council's initiative to assemble a fleet of hydrogen-powered buses that significantly reduced CO^2 and NO_x emissions. Moreover, the research team leads the Hydrogen Accelerator (with £300,000 per year in funding), which provides expert advice and support to transport initiatives across Scotland.

A.3.3. The impact of UKRI-supported research on Place

As part of this study, we undertook a deep dive into the impact of research on Place. This deep dive specifically examined hyperlocal impacts (occurring within 25km of an institution) in Manchester. The results showed that research at Manchester HEIs had significant impacts within the GM area, including in arts and culture, climate, industry, health, urban planning and education. These impacts were supported by an integrated local authority empowered by devolution, a collaborative and participative research culture and a dynamic relationship between industry and academia. Section 5.5 details the full analysis. Of the 121 ICSs reviewed in the full deep dive, 58% (n=70) were underpinned by UKRI funding, distributed across Panels A, B, C and D. The impact wheel below illustrates how the net zero-related ICSs were distributed across the Panels and UoAs. Table 26 details the nature and composition of ICSs in the deep dive.

196 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/72a1c873-3199-4425-bb16-54a753a8f2fc?page=1

Figure 37. Impact wheel for the deep dive into Place-related ICSs in the UKRI-supported ICS subset



Notes: The 'n' represents the number of ICSs reviewed. The four colours represent the four panels: Panel A (pink), Panel B (blue), Panel C (purple) and Panel D (green). Different shades of the same colour represent the 34 UoAs. The impact wheel's spoke sizes reflect how frequently impact within that UoA occurred.

Table 26. Features of the Place-related ICSs in the UKRI-funded subset

Nature of impact: Top three primary topics	% of cluster ICSs (n=70)	% of all ICSs (n=6,361)
Professionals and practitioners	9%	5%
Clinical trials	7%	5%
Manufacturing and emissions	7%	2%
Location of impact: Continent		
Europe	100%	91%
North America	31%	40%
Asia	29%	31%
Africa	6%	14%
Oceania	16%	19%
South America	4%	10%
Underpinning research: Top three fields		
Psychology	19%	15%
Clinical sciences	16%	20%
Public health and health services	16%	18%
UKRI research funder		
Central funding (inc. RE funding, GCRF, Newton etc.)	19%	8%
AHRC	27%	11%
BBSRC	10%	5%
EPSRC	31%	15%
ESRC	47%	16%
Innovate	30%	8%
MRC	14%	8%
NERC	7%	6%
STFC	1%	3%

As discussed in the main deep dive, research from various Manchester-based HEIs had some 'hyper-local' impacts on the area's social, economic and political developments. UKRI-funded research at universities in and around Manchester has also had wide-ranging impacts on the region and its population's progress and well-being. The analysis below illustrates the impact generated through UKRI-funded research on health, climate and local policymaking.

Health

UKRI-funded research at Manchester HEIs has contributed to multiple positive outcomes regarding residents' health and well-being in the area and beyond. An example is the design and implementation of the 'Bolton model' for nurse education pioneered by researchers at the University of Bolton, as highlighted in section 5.5.

Other important contributions by UKRI-funded research in this domain include immunotherapy research at the University of Manchester[197] at the forefront of cancer treatment. Researchers at the University of Manchester contributed to developing a branch of immune oncology known as Adoptive Cell Therapy (ACT), which uses a patient's T-cell lymphocytes as a 'living drug' to induce an anti-cancer response. Over a long and sustained research cycle, these researchers saw this therapy through molecular and pre-clinical research. The NHS has also delivered it as a standard-of-care treatment. The work was further bolstered by ACT products' development and commercialisation, including creating the spinout company Immetacyte (now Instil Bio). This research has deeply impacted the cancer treatment landscape in Manchester and beyond, implemented via the Innovate Manchester Advanced Therapy Centre Hub (iMATCH), one of three National Advanced Therapy Treatment Centres (ATTCs). iMATCH has generated impact by integrating and collaborating with commercial, clinical and academic partners to scale up and deliver ACT in Manchester and beyond.

Recent pandemic-related experiences have emphasised the importance of multidisciplinary research in tackling health emergencies. UKRI-funded mathematics research at the University of Manchester[198] is a prime example. The researchers' expertise in modelling and analysing epidemics – particularly transmission in enclosed communities – had a regional and national impact throughout the COVID-19 pandemic, delivered through direct collaboration with national and regional bodies and to the Government via the SAGE and Public Health England (PHE). The work's key hyper-local contributions included informing hospital resource planning in the North West, which permitted elective non-COVID life-threatening work to continue to save lives.

UKRI-funded health research in Manchester has also helped increase public awareness and educational engagement with pressing health issues. For instance, researchers at MMU[199] combined traditional microbiology quantitative analyses with social science techniques to curate a structured approach to public engagement and education on surface hygiene, fomites and human behaviour in disease transmission to promote participation in effective infection control. Researchers also played a vital role in the £1.2m Manchester Beacon for Public Engagement initiative funded by the Resuscitation Council UK, the Wellcome Trust, HEFCW, SFC and the Higher Education Funding Council for England (HEFCE). The project's findings and methods contributed to emergent local and national discourse to change culture and develop and disseminate best practices in public engagement under the aegis of the National Coordinating Centre for Public Engagement (NCCPE).

Climate

UKRI-funded research has contributed to multi-faceted developments towards net zero goals and climate-resilient practices in Manchester and its surrounding areas. For instance, researchers at the University of Manchester's Tyndall Centre for Climate

197 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/7cf998ce-1250-4c0f-af39-05e62d0358da?page=1

198 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d03d2b76-004f-4472-9821-a00927a75ac5?page=1

199 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/3dbd8e22-c56c-44df-ab83-58a446956b55?page=1

Change Research[200] developed a methodology for translating carbon budgets from global to local and sectoral scales. Their work enabled local, national and international authorities to develop climate change strategies and policies compliant with the Paris Agreement, shifting focus from long-term 2050 targets towards prioritising immediate action to cut emissions in local authorities' climate change plans.

UKRI-funded research at the University of Salford[201] in low-carbon housing has enabled impactful emission-reduction practices in Manchester and beyond. Salford's Energy House Laboratories (EHL) team focused on the performance of homes driven by technological interventions and supporting policy and regulation, developing the Salford Energy House to further these aims. This novel facility is a Victorian house in a climate-controlled chamber that allows research traditionally undertaken in the field to be rapidly conducted in replicable and repeatable controlled conditions, allowing unique experiments and supporting innovators to quickly bring new products to market. Researchers at Salford have also made key contributions to climate initiatives in collaboration with the GMCA, including the Green Deal Communities project funded by the Department of Energy and Climate Change to install 1,432 retrofit measures in 1,302 households across GM.

UKRI-funded research has also helped promote local engagement and citizen participation in climate adaptation strategies. For example, Multi-Story Water (MSW) was a community-facing, practice-as-research project to develop understanding and engagement between local communities and responsible agencies in flood-prone areas of Yorkshire's Aire Valley. Led by the University of Manchester,[202] the project used site-responsive creative methods to stimulate community dialogue and capacity building. Notable impacts for communities and stakeholders in Yorkshire include informing the creation of a housing estate residents' group that has gone on to secure riverside landscape improvements, a stakeholder network that informed communication strategies in the water sector and contributions to innovative public communications strategies highlighting major flood alleviation and river-improvement schemes.

Local policymaking

UKRI-funded research conducted at universities in Manchester has helped inform and shape local policymaking across multiple domains. For instance, MMU researchers at the Manchester Centre for Youth Studies (MCYS)[203] collaborated with the Greater Manchester Youth Justice University Partnership (GMYJUP) to co-create a novel framework for Participatory Youth Practice (PYP). This framework was one of the first of its kind to be created in tandem with justice-involved young people based on their lived experiences. PYP and its foundational principles of involving young people in decision making that directly affects them helped shape various youth engagement and criminal justice policies and

200 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/49bbd69d-38d9-4b7d-9a89-13bb938ec843?page=1

201 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/6ef01b49-a7b6-4173-a049-637b8e19fcae?page=1

202 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/d12bc73c-8b41-4072-9dc3-bdd9a8aed6cb?page=1

203 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/fb8dee8a-26bb-4e8f-8f9a-1407a61bc38f?page=1

initiatives in GM, nationally and internationally. In Manchester, PYP training has been delivered to over 250 Greater Manchester Youth Justice Service professionals, helping inform the region's youth engagement practices through rigorous social science research conducted at MCYS. It has also been recognised in Australia, where it has been adopted by the University of New South Wales in Sydney.

A.4. The role of UKRI and its funding streams

A.4.1. UKRI's role in the funding landscape

Of the 6,361 ICSs examined, we identified 3,032 underpinned by UKRI support. These ICSs were spread across UKRI's research councils and central UKRI funding, such as GCRF and Newton (Table 27). All councils supported a proportion of the ICSs, although the most significant contributions were from EPSRC, ESRC and AHRC.

Our review of UKRI Research Councils' co-funding across ICSs showed that Panels A and B had a median of two funders per ICS compared to one for Panels C and D (Figure 38). The number of funders varied across UoAs (Figure 39). For some, such as UoA 6 (Agriculture, Food and Veterinary Sciences), the number of funders was spread more evenly. For others, such as UoA 27 (English Language and Literature), many ICSs only had one funder.

Table 27. UKRI-supported ICSs by funding source

UKRI funding source	No. of ICSs underpinned by UKRI funding	% of total ICSs (n=6,361)
Central funding	486	8%
AHRC	698	11%
BBSRC	318	5%
EPSRC	973	15%
ESRC	1,038	16%
Innovate	529	8%
MRC	509	8%
NERC	354	6%
STFC	197	3%

Figure 38. Number of UKRI research councils per ICS by Panel

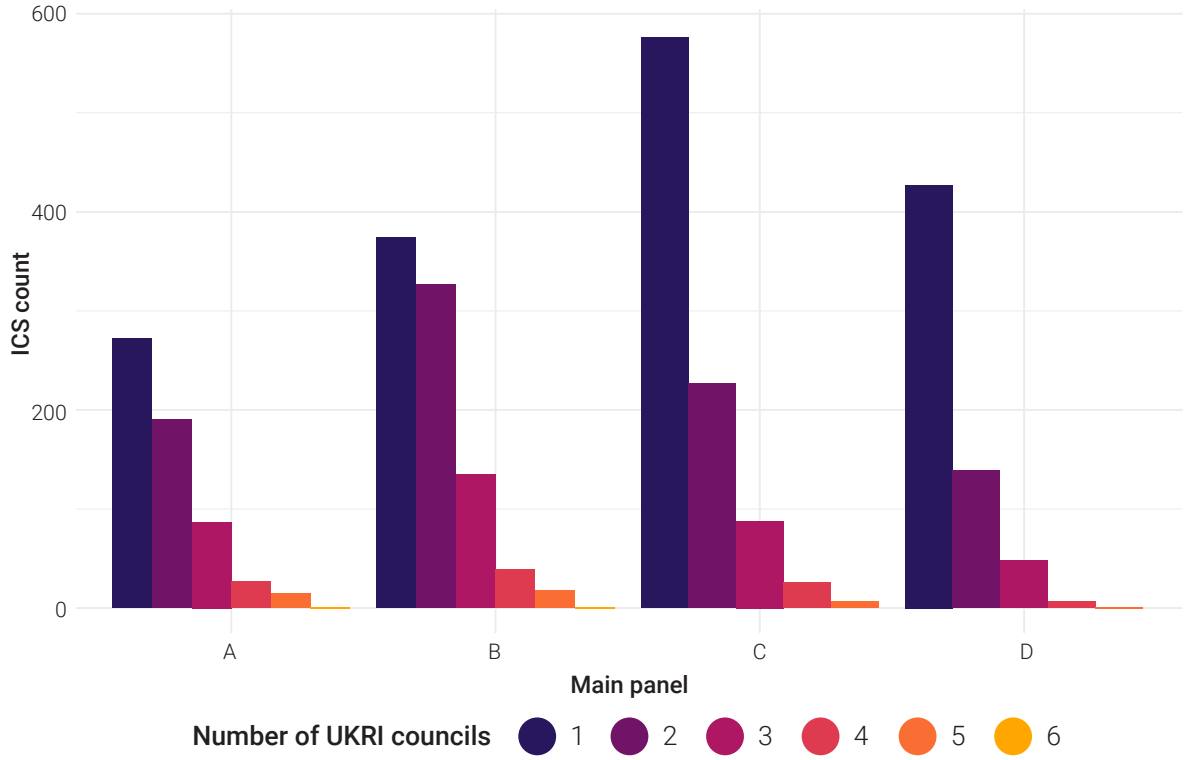
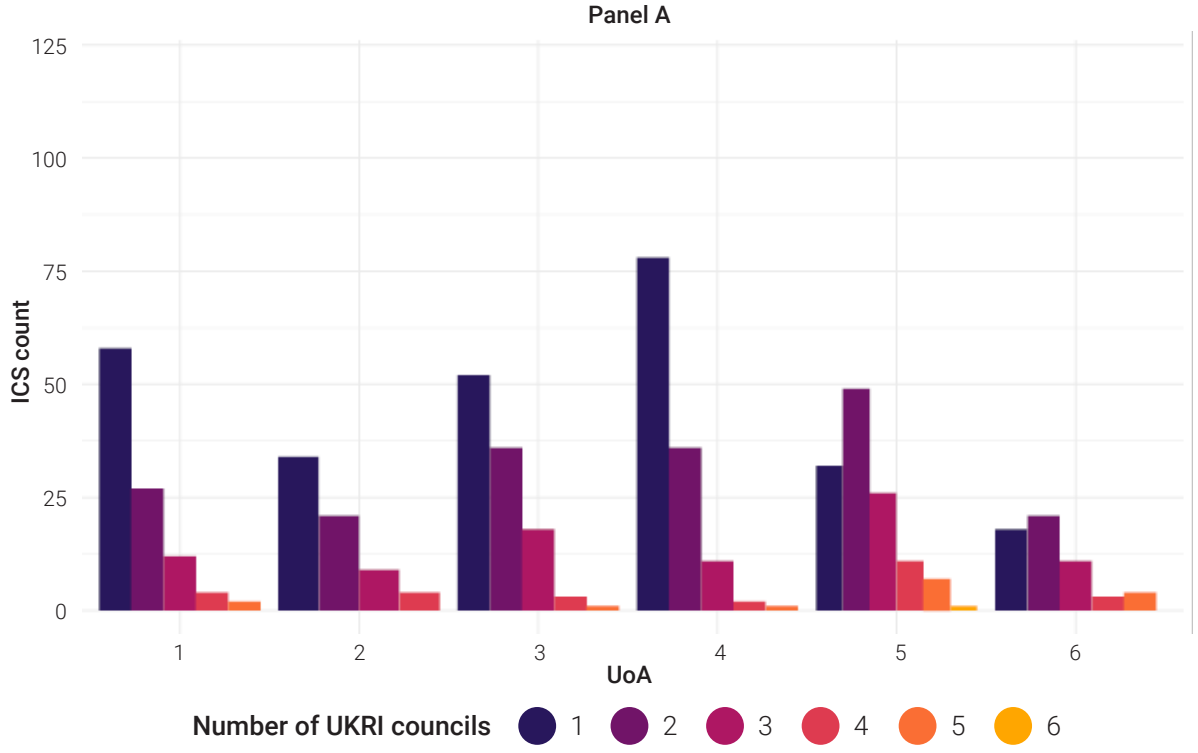
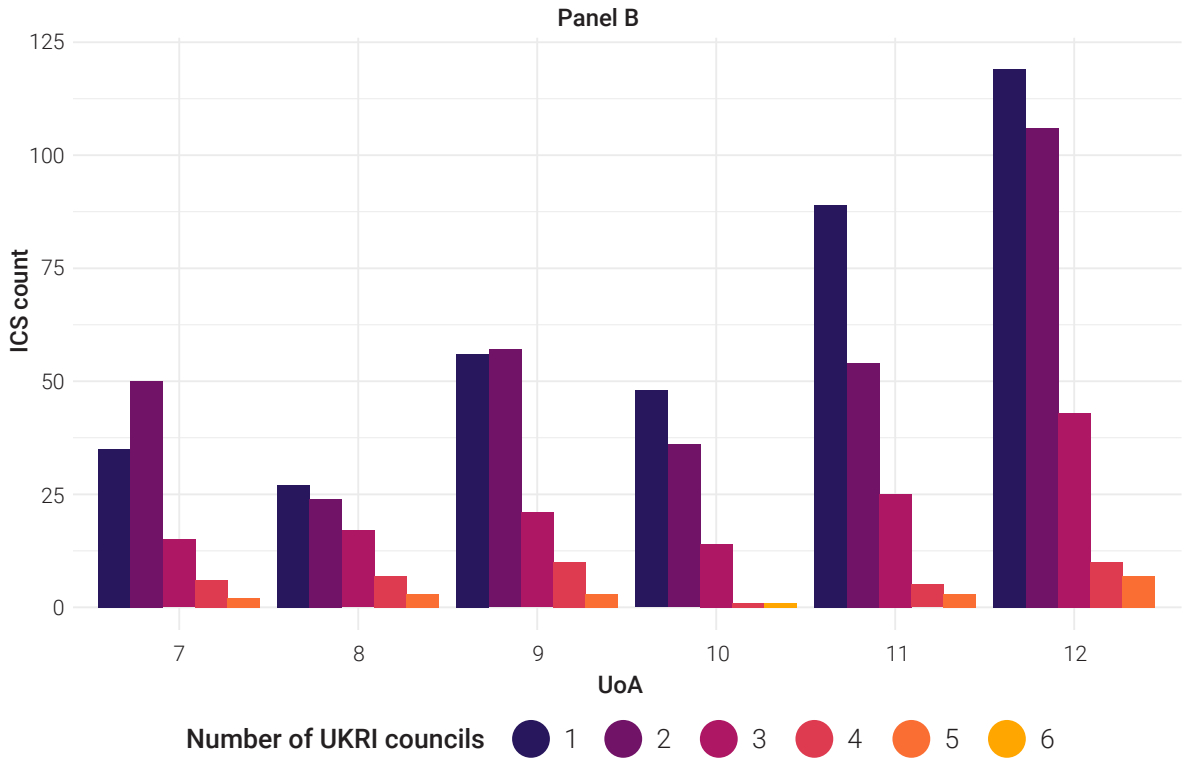
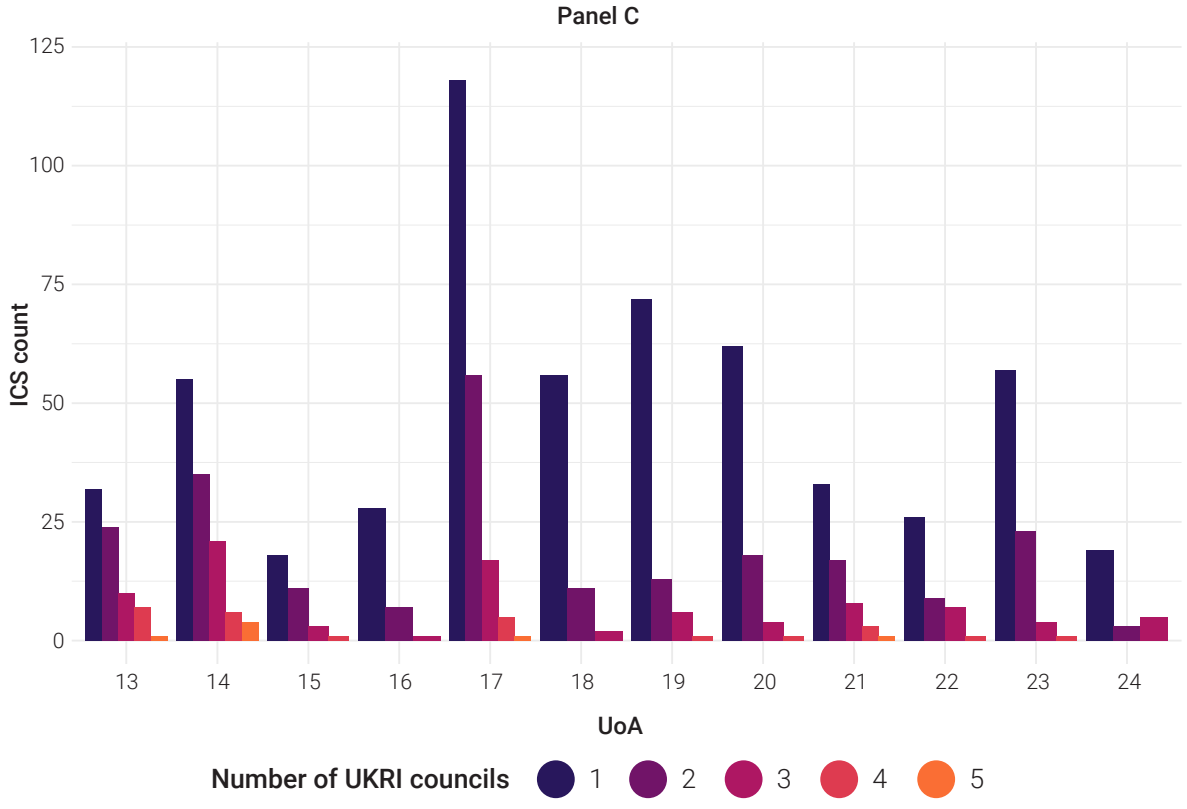
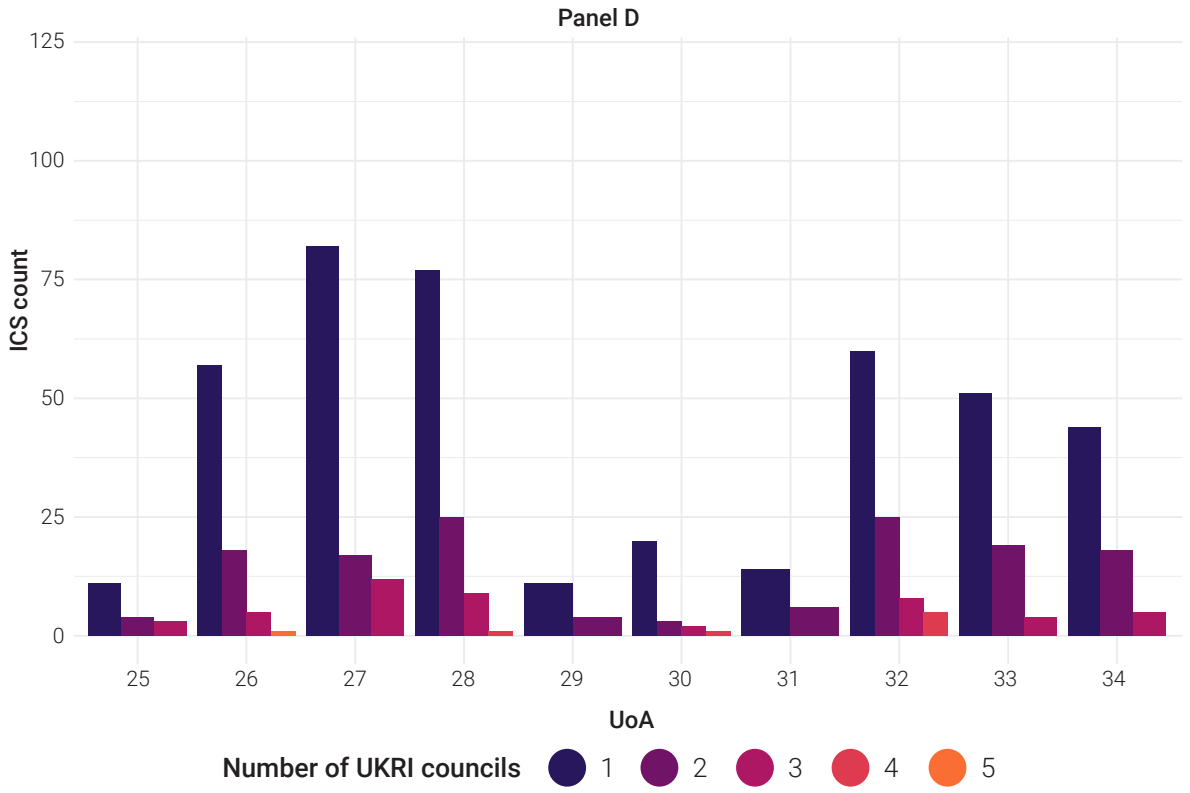


Figure 39. Number of UKRI research councils per ICS by UoA and Panel




Panel B
125
100
75
50
25
0
ICS count
7
8
9
10
11
12
UoA
Number of UKRI councils
1
2
3
4
5
6


Panel C
125
100
75
50
25
0
ICS count
13
14
15
16
17
18
19
20
21
22
23
24
UoA
Number of UKRI councils
1
2
3
4
5



A.4.2. The contribution of other funders

Within the contextual data, UKRI-supported ICSs acknowledge a wide range of funders supporting the research. Of the 3,032 UKRI-supported ICSs, 95% acknowledged funders. Looking at ICSs supported by funders other than UKRI, 17% acknowledged EU funding and 58% acknowledged other funder types.

Funders frequently mentioned across the ICSs' contextual data included broad references to the European Commission and specific funding bodies such as the European Research Council. Aside from UKRI and the European Commission, most other acknowledged funders were UK-based. These included charities and trusts (e.g. Wellcome Trust, the Leverhulme Trust and Cancer Research UK), government departments and executive agencies (e.g. the Department of Health[204]) and research funding organisations (e.g. the NIHR). The top 12 are listed in Table 28.

Table 28. Most commonly listed funders

Funder
European Commission
NIHR
Leverhulme Trust
Wellcome Trust
British Academy
DEFRA
Royal Society
European Research Council
British Council
Department of Health
Scottish Government
Cancer Research UK

204 Now 'Department of Health and Social Care'.

We identified several industry funders from the contextual data, although fewer ICSs specifically acknowledged industry funding. Examples of key industry funders identified in the UKRI-supported case studies include GlaxoSmithKline, Pfizer and EDF (Box 13).

Box 13. The top ten commonly mentioned industry funders identified within the UKRI-supported ICSs

Pfizer
GlaxoSmithKline
EDF
AstraZeneca
Google
BAE Systems
Boehringer Ingelheim
Rolls Royce
Siemens
Airbus

A.4.3. The role of cross-UKRI funding

This deep dive examines how UKRI councils supported research impact, studying the 500 ICSs underpinned by UKRI funding and supported by three or more UKRI councils (Table 29).[205]

Table 29. Number of ICSs funded by UKRI councils

Number of UKRI Councils	ICS count
0	3,329
1	1,649
2	883
≥3[206]	500

ICSs supported by multiple UKRI research councils tended to involve more interdisciplinary research

As described in 3.1.1, we used the subject categories referenced by each ICS's underpinning research articles to calculate interdisciplinarity using the Rao-Sterling metric. The metric defines interdisciplinarity using three aspects: variety (the number of different subjects), balance (the skew towards certain subjects), and disparity (how unusual the combination of subjects is). It produces values ranging from '0' (least interdisciplinary) to '1.0' (most interdisciplinary). Comparing the ICSs supported by multiple UKRI councils showed that the IDR metric increased as the number of councils supporting the ICSs increased (Table 30). While it is challenging to determine from the ICSs alone why multiple funding councils led to higher levels of interdisciplinarity, it does indicate that cross-council funding tended to support interdisciplinary research.

Table 30. Interdisciplinarity by number of UKRI councils

Number of UKRI Councils	Mean IDR Metric
0	0.441913
1	0.470061
2	0.530547
≥3	0.630537

Case studies supported by multiple UKRI research councils tended to involve higher levels of collaboration

As underpinning research publications record authors' affiliations, we could measure aspects of collaboration. This section focuses on

205 Tier 1 UKRI support is where there is a strong link indicating that UKRI funding underpinned these impacts, matched to at least one of (i) grant reference in funding metadata, (ii) funder name in funding metadata or (iii) funder or subsidiary (e.g. institute or facility) name in the ICS text.

206 We group ICSs supported by three or more research councils together in a single cluster throughout this section.

Table 31. Collaboration modes by number of UKRI councils

No. of UKRI Councils	Mean DOIs with collab mode 'None'	Mean DOIs with collab mode 'Domestic'	Mean DOIs with collab mode 'International'	Mean DOIs with collab mode 'Multilateral'
0	0.675	1.128	1.003	0.186
1	0.848	1.271	1.063	0.184
2	1	1.519	1.409	0.182
≥3	0.914	1.622	1.678	0.242

Source: Data from Web of Science, provided by Clarivate

collaboration mode, classified according to whether research was conducted solely at the submitting institution ('none'), with domestic collaborators ('domestic'), with international collaborators ('international'), or with a large number of international collaborators from at least five different countries ('multilateral'). A comparison of the ICSs supported by multiple UKRI councils showed that the average number of DOIs with domestic, international and multilateral collaboration increased as the number of councils supporting ICSs increased (Table 31).

ICSs supported by multiple UKRI research councils tended to have higher bibliometric impact

We matched DOIs identified in the ICSs to records in Web of Science, allowing the calculation of bibliometric impact. We calculated citation impact as defined by Clarivate using the Category Normalised Citation Impact (CNCI). Across all groups, the underpinning research performed better than the global average CNCI of 1.0, with the highest citation impact associated with ICSs funded by three or more UKRI councils.

Table 32. Mean CNCI by number of UKRI councils

No. of UKRI Councils	Mean CNCI
0	3.165
1	3.594
2	3.946
≥3	5.439

Source: Data from Web of Science, provided by Clarivate

Case studies supported by multiple UKRI research councils tended to have higher local impact levels

Our examination of the proportion of ICSs reporting local impact (Section 2.1.3) showed that the proportion of case studies with hyperlocal impact increased as the number of UKRI councils increased.

Table 33. Proportion ICSs with hyperlocal impact by number of UKRI councils

No. of UKRI Councils	% with hyperlocal impact
0	28.387
1	32.505
2	33.409
≥3	35

Table 34. Impact topics supported by multiple UKRI councils

Cluster	Topic	Topic label	Total ICS count	No. funded by ≥3 UKRI councils	% Funded by ≥3 UKRI councils
4	3	Applied technology	489	103	21.063
6	12	Environmental management	208	43	20.673
3	55	Environmental sustainability	168	32	19.048
3	42	Energy	162	29	17.901
6	56	Food policy	224	40	17.857
2	20	Drug discovery and clinical trials	236	41	17.373
6	65	Farming and animal welfare	344	58	16.860
2	45	Genetic testing and diagnostics	226	37	16.372
3	51	Nuclear energy and research	71	11	15.493

ICSs supported by multiple UKRI research councils generated diverse impacts, including those around applied technology, environmental sustainability and energy

We examined the impact topics related to ICSs supported by three or more UKRI councils. Table 34 below describes the top impact topics relative to the percentage of associated ICSs funded by multiple councils.

This section discusses the ICS impacts across these topics in more detail, grouped by overarching impact clusters: environmental sustainability, energy, nuclear energy and research (within Cluster 3); applied technology (Cluster 4); food policy, farming, and animal welfare (Cluster 6).

Environmental sustainability and energy

Environmental sustainability

UKRI-funded research contributed to impact across several areas of environmental sustainability, including sustainable production and management and guidance to policymakers and government.

Research funded by UKRI made several contributions to sustainable production and management, both in the UK and abroad. Researchers at Cranfield University helped develop and commercialise a novel technology to remove ethylene in fresh produce packaging, contributing to reduced food waste.[207] Research at the University of Leeds led to a spin-out company that developed a range of

207 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/5276D593-549C-4FF2-BD3B-B05B7291D7A1?page=1

patented techniques allowing the extraction of high-value ingredients from food waste to support the production of skin and hair-care products.[208] Looking at global impact, research undertaken at the University of Cambridge on charcoal production in northern Uganda significantly impacted the establishment of local environmental monitoring mechanisms and the drafting of new legislation.[209] Another example of global impact came from research at the University of Sussex, which led to changes in urban waste management policy and practice in India and influenced Indian national waste management legislation.[210]

Research also led to changes around guidance and informing policy. Researchers at the University of Plymouth integrated psychological research on marine pollution into science advice, introducing knowledge around risk perception, risk communication and behaviour into UK policy. The evidence on the effectiveness of marine litter schemes enabled local governments and charities to increase participation and led to new marine litter schemes abroad.[211] Research at the University of Leeds developed an approach to assessing infrastructure value used by national and local policymakers,[212] and research at the University of Exeter's Land, Environment, Economics & Policy (LEEP) Institute led to shifts in UK policy, including by informing the creation of the UK Government's 25 Year Environmental Plan.[213]

Energy

UKRI-funded research also impacted the energy landscape, including energy mapping systems, solar-powered technologies and energy infrastructure.

Researchers at Oxford Brookes University developed DECoRuM®, an award-winning Geographic Information System (GIS) domestic energy mapping software. By combining spatial mapping with a data-driven approach, this software can rapidly and accurately identify appropriate dwellings for area-based energy upgrades at a neighbourhood or city scale, leading to emission reductions.[214] ICSs within this topic have also had a global impact. Research at the University of Edinburgh on solar energy technologies in South Asia and Sub-Saharan Africa changed how renewable energy organisations engage with global energy access challenges, leading to developments increasing access to clean energy in India and new standards for sustainable design in the off-grid solar industry.[215] Another global example is research led by De Montfort University, which

208 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/A76F4EC0-CF2B-4518-99DC-99CED90B4A6C?page=1

209 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/5010D71F-CF70-4BA6-89EB-955F7172D05F?page=1

210 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/14E3C79F-A97A-447F-8CA1-1AD1DC581E29?page=1

211 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/4AAB2E22-D4CA-47E4-BF3C-B2D6553DD82B?page=1

212 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/B4DE58F3-2B44-44B8-AB05-6D5F0D620178?page=1

213 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/FE3FAFDA-61B9-49DB-A585-C6723DA23B8A?page=1

214 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/2AEFE25B-98C5-4366-BEE5-64D9F559EAC5?page=1

215 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/2770CFEC-E783-41B3-9460-79C5984A35B3?page=1

established solar-powered mini-grids in rural India to enable electricity supply and led to 5,000 previously non-electrified households gaining electricity access.[216]

UKRI-funded research has also helped reduce carbon emissions through energy infrastructure. Research conducted at Aston University led to significant reductions in carbon emissions and energy costs via a spin-out company that developed and commercialised cloud-based AI software tools to allow building operators to predict, optimise and control their buildings' energy profiles, reducing carbon emissions and costs and improving user comfort.[217] Another example of impact is research at Swansea University developing the concept of 'buildings as power stations'. This concept goes beyond buildings as self-sufficient, integrating them into the local and national energy infrastructure to enable net contribution. This research led to the construction and operation of energy-positive buildings.[218]

Nuclear energy

UKRI-funded research has also led to advancements in nuclear energy that tended to focus on safety and environmental considerations. For example, research at the University of Bristol strengthened safety considerations using novel methodologies to map and characterise environmental radioactivity, including nuclear waste disposal.[219] Depth profiling research at the University of Lancaster improved the decommissioning process for nuclear fuel storage,[220] and research at the University of Bristol provided insights underpinning safety assessments of advanced gas-cooled reactors that helped keep them operational.[221]

216 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/49BE7AE6-1C65-4404-9099-FC3D576651DF?page=1

217 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/A0CBCDC9-AD35-4CD8-9B4D-CFC55ABB65D5?page=1

218 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/BF1C3A5A-FC72-4360-A123-1413E666A72C?page=1

219 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/09304124-1BA5-40BC-87E6-2ED72BAA2BCE?page=1

220 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/6E84D037-4900-4657-A4FE-44269CA7FDA5?page=1

221 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/793D28FC-ED52-4B4B-A150-8C65A85C882A?page=1

Applied technology

UKRI-funded research contributed to progress across several applied technology areas, including instrumentation in clinical settings, law enforcement and arts and design.

Clinical settings

Multiple impact examples exist within clinical and healthcare settings. For example, research at the University of Oxford enabled developing and commercialising a unique fluorescence microscope for single-molecule imaging that was cheaper and easier to use than similar microscopes, supporting rapid diagnostic tests.[222] Another example is research on DNA imaging at UCL that improved the performance of atomic force microscopic instruments and probes.[223],[224] Work at the University of Nottingham enabled the development of improved instrumentation for measuring human brain function through magnetic fields,[225] and research at the University of Kent enabled the development of bio-safe virus mimics, enabling the rapid growth of virus reference standards, clinical diagnostic tests and antibody screening.[226]

Law enforcement

UKRI-funded research has also led to improvements within law enforcement. For example, research led by Nottingham Trent University generated patented X-ray diffraction techniques to identify explosives and other threats, such as illicit drugs or contraband items, in luggage and cargo.[227] Research at the University of Bath increased navigation systems' resilience to criminal activity that can jam the signals, enabling the detection and location of deliberate jamming in real time and facilitating a rapid and efficient law-enforcement response.[228]

222 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/C30022B1-3EEA-43E4-9963-EAEC0815A93F?page=1

223 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/C30022B1-3EEA-43E4-9963-EAEC0815A93F?page=1

224 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/0E71F442-3234-4EAA-B41D-9907CEFD4B9C?page=1

225 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/13BECDF3-A76B-4A88-B7D1-3CB64C55DDCD?page=1

226 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/8935AFC9-B829-452F-8EF5-DFA878C25FF9?page=1

227 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/ED04E014-E8F5-4F5E-9690-9FEF5C39F8CB?page=1

228 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/FDBACF86-287B-46DE-A0D2-37C80271052B?page=1

Art and design

UKRI-funded research has supported the development of applied technologies relevant to art and design. Examples include research at the University of the West of England on colour, inks and print processes, which has enabled technical innovation and the production of new materials, including print technologies' improved performance.[229]

Food policy, farming and animal welfare

UKRI-funded research contributed to impacts within food policy (e.g. health and food security) and farming (e.g. crop disease, sustainability and resilience).

Food policy

UKRI-funded research has significantly contributed to health, food security and supply chains. Research at the University of Reading demonstrated how replacing dietary saturated fat with unsaturated fat reduced cardiovascular disease risk factors, changing public advice from the Scientific Advisory Committee on Nutrition.[230] The ICSs also demonstrated UKRI-funded research's impact on obesity. Researchers at the University of Bristol developed a toolkit quantifying the extent to which foods are expected to stave off hunger and deliver fullness, which several food manufacturers have adopted.[231] ICSs have also impacted childhood obesity, with WHO national and regional stakeholders adopting recommendations from research at Durham University to take a 'whole systems approach' to tackle this issue.[232] Lastly, there have been impacts on diet more broadly. These include an accurate and user-friendly online food diary, 'Intake 24', developed at Newcastle University and used to monitor diet,[233] and research at Ulster University into the impacts and potential benefits of folic acid on women of reproductive age.[234]

229 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/C2AC5925-0210-4F73-B495-4B7724713FEE?page=1

230 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/EEFA0A3D-4BA8-4419-8C28-836E06B41EED?page=1

231 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/FA238DE3-2BC0-4216-95FF-45BF9F6F365A?page=1

232 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/58E184F3-1770-47FE-A62A-3F5B19DB602B?page=1

233 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/E1627C2A-EFB3-42DE-A612-2997740EFACA?page=1

234 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/7C39B507-038A-4B6B-9C3F-FE5AB446B3C2?page=1

Food security and supply chains

UKRI-funded research has also impacted food security and supply chains. Researchers at the University of Lincoln adopted AI and deep learning to enable safer and more efficient food chains in energy management and food labelling during production.[235] Research on complex systems at the University of Leeds influenced the UK's approach to net zero land use.[236]

Farming and animal welfare

UKRI-funded research has had various impacts on farming, including crop disease, environmental sustainability and resilience in farming systems. Research at the University of Hertfordshire into diseases affecting oilseed rape, barley and strawberry crops (among others) shaped control strategies in the UK and China by enabling better disease management.[237] Regarding sustainability, research at Swansea University helped find safe alternatives to traditional chemical pesticides,[238] and research at the University of Lincoln led to the adoption and development of robotics and autonomous systems to support agriculture's sustainable intensification.[239] There have also been several impacts around climate resilience, including research at the University of Sussex to improve forecast information informing early-warning systems for drought in Sub-Saharan Africa[240] and the advancement of environmentally-friendly technologies at Royal Holloway and Bedford New College to refine the quality, storability and resilience of crop seeds, supporting increased food security.[241]

Concluding reflections

In this section, we explored the role of UKRI funding by examining ICSs funded by multiple UKRI councils. We note that this is an indirect method to review UKRI's capability, and examining ICSs alone can only tell us about the impacts achieved or the underpinning research. It is hard to explicitly define the UKRI's independent role from these data alone. However, the analysis yielded several interesting results. ICSs funded by three or more UKRI councils tended to have more interdisciplinary underpinning research, higher bibliometric impact and more domestic and international collaboration. Reviewing the case studies and the impact topics they linked to showed that certain impact areas are highly represented within ICSs, ranging from impacts in applied technology (such as clinical instrumentation), environmental sustainability and energy to food policy and farming. Although we cannot determine the mechanistic links explaining why UKRI councils led to high-performing research and impact across certain ICS areas, this deep dive highlights the UKRI's important role in the research ecosystem.

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235 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/6399AF09-1465-4629-BD02-F46B90077DC6?page=1

236 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/ABFA6565-BB4C-4209-A3EA-8975FB623BCF?page=1

237 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/386BBEEB-5A3E-4B3C-9605-CBBD64E3AE3E?page=1

238 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/546753E7-06AB-42DF-8DF9-469ECE3E050D?page=1

239 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/73BE8E7C-907E-4E5B-8A8B-953B4D394C1B?page=1

240 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/8E1018A6-68F5-4AEE-89E7-D43F057FF570?page=1

241 See REF 2021 Impact Case Study database. (2023a). As of 4 October 2023: https://results2021.ref.ac.uk/impact/A51FC91D-41FF-4299-8BB9-E815F14AEA60?page=1

A.4.4. Impact arising from UKRI support

Significant research breakthroughs

Identifying and characterising significant research 'breakthroughs' is a complex and subjective process. The phrase typically refers to research that has engendered novel discoveries, created new fields of enquiry or otherwise innovated how research is conducted and utilised. Some definitions of 'breakthrough' focus on basic research only, while others consider novel applications of established research, as currently evident with the widespread use of machine learning.

In this analysis, we deployed two complementary methods to identify breakthrough research to provide insights into its relationship to impact. The first is bibliometric, measuring the number of HCPs (those in the top 1% of the citation count) associated with ICSs. The second is based on natural language, using text processing to identify any research-based use of the term 'breakthrough' in Sections 1, 2 or 4 of the ICSs. The second approach is effectively a proxy for the ICS authors' self-reported significant breakthroughs. We collected data across the full ICS research portfolio and cross-referenced it to identify ICSs underpinned by UKRI funding.

Of the 6,361 ICSs reviewed, 1,286 (20%) referenced at least one HCP in their underlying research section, with 730 of these supported by UKRI (57%). Since the overall rate of UKRI support across all ICSs was 48%, the UKRI appears to support a larger proportion of the research than expected.

Regarding self-reported breakthroughs, we identified 306 sentences across 220 unique ICSs. Table 35 shows their distribution by panel, with the left three columns showing the number of ICSs that had UKRI support, those that were not associated with UKRI (other), and the percentage explicitly mentioning breakthrough research. For comparison, the right three columns show the same statistics based on ICSs with one or more HCPs. Although the volume of ICSs was lower for those mentioning 'breakthrough' research than HCP, UKRI supported more ICSs than expected, in terms of those mentioning 'breakthrough' research and those referencing HCPs, in panel B. Figures for both measures were substantially lower in Panel D. Table 36 presents the same data aggregated by UoA.

Table 35. Summary of 'breakthrough' research by Panel

	Mentioned breakthrough research			≥1 HCPs		
	With UKRI support	Other	% With UKRI support	With UKRI support	Other	% With UKRI support
A	32	34	48	273	295	48
B	97	28	78	217	75	74
C	9	14	39	192	140	58
D	4	2	67	48	46	51

Source: Data from Web of Science, provided by Clarivate

Table 36. Summary of 'breakthrough' research by UoA

		Mentioned breakthrough research			≥1 HCPs		
UoA number	UoA name	With UKRI support	Other	% With UKRI support	With UKRI support	Other	% With UKRI support
1	Clinical Medicine	4	10	29	75	101	43
2	Public Health, Health Services and Primary Care	0	2	0	37	40	48
3	Allied Health Professions, Dentistry, Nursing and Pharmacy	10	8	56	24	63	28
4	Psychology, Psychiatry and Neuroscience	2	6	25	54	54	50
5	Biological Sciences	13	7	65	64	21	75
6	Agriculture, Food and Veterinary Sciences	3	1	75	19	16	54
7	Earth Systems and Environmental Sciences	4	1	80	38	12	76
8	Chemistry	11	3	79	25	11	69
9	Physics	26	5	84	62	9	87
10	Mathematical Sciences	8	4	67	20	15	57
11	Computer Science and Informatics	13	6	68	28	18	61
12	Engineering	35	9	80	44	10	81
13	Architecture, Built Environment and Planning	2	0	100	15	5	75
14	Geography and Environmental Studies	4	2	67	38	11	78
15	Archaeology	0	1	0	11	5	69
17	Business and Management Studies	2	3	40	29	30	49
18	Law	0	2	0	8	11	42
19	Politics and International Studies	0	1	0	14	10	58
20	Social Work and Social Policy	0	1	0	16	15	52
21	Sociology	0	1	0	23	12	66
22	Anthropology and Development Studies	0	1	0	7	3	70
24	Sport and Exercise Sciences, Leisure and Tourism	1	2	33	9	19	32
26	Modern Languages and Linguistics	1	1	50	5	6	45
28	History	0	1	0	17	8	68
33	Music, Drama, Dance, Performing Arts, Film and Screen Studies	2	0	100	4	3	57
34	Communication, Cultural and Media Studies, Library and Information Management	1	0	100	4	8	33

Source: Data from Web of Science, provided by Clarivate

Table 37 presents the same data aggregated by Impact Cluster. The results suggest that UKRI provided more than the expected level of support in multiple clusters, especially Cluster 3 (Energy and Environment), Cluster 4 (Information and Applied Technology) and Cluster 6 (Food, Environment and Ecology).

Particular UK regions/places

To examine the impact arising from the ICSs funded by UKRI in particular regions or clusters, we calculated the amount of UKRI-funded ICSs across UK regions. Table 38 below includes the top 20 NUTS 3 regions for UKRI ICSs. Table 39 shows data for NUTS 1 regions. The results show that many regions containing high numbers of UKRI ICSs were concentrated around cities, including Manchester, Bristol, Edinburgh, Birmingham, and Glasgow. Comparing these numbers against the total number of ICSs within that region shows that approximately 50% of ICSs within any region were funded by UKRI. However, there is some variance in the top 20, with Southampton having the highest proportion of UKRI ICS and Sheffield and Nottingham having lower levels.

Table 37. Summary of 'breakthrough' research by Impact Cluster

		Mentioned breakthrough research			≥1 HCPs		
Cluster	Cluster label	With UKRI support	Other	% With UKRI support	With UKRI support	Other	% With UKRI support
1	Public Health and Health Services	2	1	67	45	40	53
2	Clinical Medicine	27	29	48	162	201	45
3	Energy and Environment	23	11	68	82	33	71
4	Information and Applied Technology	29	10	74	69	23	75
5	Training, Education and Skills	14	7	67	87	75	54
6	Food, Environment and Ecology	21	4	84	110	46	71
7	Criminal Justice and Human Rights	0	2	0	21	25	46
8	Policy, Ethics and Security	9	3	75	41	28	59
9	Business, Planning and Economics	4	4	50	23	19	55
10	Devolved Nations	0	1	0	5	1	83
11	Culture and Society	8	3	73	56	43	57
12	History, Heritage and Creative Arts	5	3	63	29	22	57

Source: Data from Web of Science, provided by Clarivate

Table 38. The top 20 UKRI ICS counts by NUTS 3 region

NUTS 1 region	NUTS 2 region	NUTS 3 region	ICS count	ICS count, Panel A	ICS count, Panel B	ICS count, Panel C	ICS count, Panel D	UKRI-funded ICS count	UKRI-funded ICS count, Panel A	UKRI-funded ICS count, Panel B	UKRI-funded ICS count, Panel C	UKRI-funded ICS count, Panel D	% of UKRI-funded ICSs
North West (England)	Greater Manchester	Manchester	314	60	53	89	112	176	23	44	49	60	56
South East (England)	Berkshire, Buckinghamshire and Oxfordshire	Oxfordshire	218	45	47	42	84	110	24	37	18	31	51
South West (England)	Gloucestershire, Wiltshire and Bristol/Bath area	Bristol, City of	176	30	32	42	72	108	18	24	25	41	61
Scotland	Eastern Scotland	Edinburgh, City of	175	25	27	49	74	101	12	24	26	39	58
West Midlands (England)	West Midlands	Birmingham	178	28	26	54	70	100	9	25	30	36	56
Scotland	West Central Scotland	Glasgow City	163	27	24	51	61	87	8	22	24	33	53
South West (England)	Devon	Devon CC	127	31	12	40	44	83	19	9	27	28	65
East of England	East Anglia	Cambridgeshire CC	173	40	30	35	68	80	19	25	13	23	46
Yorkshire and the Humber	West Yorkshire	Leeds	157	25	30	45	57	79	7	27	23	22	50
North East (England)	Northumberland and Tyne and Wear	Tyneside	155	44	26	32	53	78	15	19	22	22	50
North West (England)	Merseyside	Liverpool	152	24	27	42	59	78	11	21	21	25	51
Wales	East Wales	Cardiff and Vale of Glamorgan	130	21	28	45	36	65	4	14	30	17	50

NUTS 1 region	NUTS 2 region	NUTS 3 region	ICS count	ICS count, Panel A	ICS count, Panel B	ICS count, Panel C	ICS count, Panel D	UKRI-funded ICS count	UKRI-funded ICS count, Panel A	UKRI-funded ICS count, Panel B	UKRI-funded ICS count, Panel C	UKRI-funded ICS count, Panel D	% of UKRI-funded ICSs
West Midlands (England)	Shropshire and Staffordshire	Staffordshire CC	116	21	17	43	35	58	9	10	20	19	50
East Midlands (England)	Leicestershire, Rutland and Northamptonshire	Leicestershire CC and Rutland	112	21	20	38	33	56	8	15	17	16	50
Yorkshire and the Humber	North Yorkshire	York	104	20	17	27	40	55	8	14	15	18	53
North East (England)	Tees Valley and Durham	Durham CC	96	8	24	32	32	52	3	18	18	13	54
Yorkshire and the Humber	South Yorkshire	Sheffield	109	20	15	34	40	49	3	13	17	16	45
East Midlands (England)	Derbyshire and Nottinghamshire	Nottingham	98	23	15	21	39	44	4	11	10	19	45
South East (England)	Hampshire and Isle of Wight	Southampton	72	19	20	14	19	44	10	15	8	11	61
Northern Ireland	Northern Ireland	Belfast	74	7	8	23	36	43	1	7	15	20	58

Table 39. The top 20 UKRI ICS counts by NUTS 1 region

NUTS 1 ID	NUTS 1 region	ICS count	ICS count, Panel A	ICS count, Panel B	ICS count, Panel C	ICS count, Panel D	UKRI-funded ICS count	UKRI-funded ICS count, Panel A	UKRI-funded ICS count, Panel B	UKRI-funded ICS count, Panel C	UKRI-funded ICS count, Panel D	% UKRI-funded ICSs
UKN	Northern Ireland	94	13	13	27	41	53	2	11	17	23	56
UKK	South West (England)	503	88	77	140	198	279	43	59	78	99	55
UKM	Scotland	502	93	84	141	184	267	40	67	71	89	53
UKL	Wales	258	40	64	78	76	135	17	37	45	36	52
UKD	North West (England)	732	157	134	213	228	381	60	109	103	109	52
UKH	East of England	382	74	61	111	136	198	35	47	56	60	52
UKG	West Midlands (England)	432	80	69	130	153	223	30	53	64	76	52
UKC	North East (England)	304	57	54	87	106	152	18	39	51	44	50
UKJ	South East (England)	644	128	116	170	230	322	59	94	70	99	50
UKE	Yorkshire and the Humber	487	86	79	142	180	238	28	66	66	78	49.
UKI	London	1222	168	148	370	536	585	64	112	173	236	48
UKF	East Midlands (England)	293	54	50	92	97	128	13	32	37	46	44

A.5. Conclusions

UKRI funding makes a significant contribution to the research underpinning the REF ICS

UKRI funding underpinned 46% of the 6,361 UCSs submitted to REF 2021. Correspondingly, many of our observations for the wider ICS dataset also held for those receiving UKRI support. As for the broader case study set, UKRI-supported ICSs were diverse and multidisciplinary, comprising numerous impact pathways. The UKRI-funded ICSs drew on diverse disciplines and contributed across a wide range of impact topics via multiple UoAs. However, we also identified key findings specific to the UKRI-funded case subset.

While UKRI supported ICSs across all Panels, Panel B had a significant number of UKRI-supported ICSs

Overall, 71% of ICSs in Panel B received UKRI support, compared to 40–43% of ICSs in the other Panels. While primarily reflected at the UoA level, there were some nuances in the proportion of ICSs that received UKRI support, ranging from 16.8% for UoA 24 (Sport and Exercise Sciences, Leisure and Tourism) to 87% for UoA9 (Physics).

UKRI-funded ICSs benefited multiple groups

The top three beneficiary groups identified match those for the broader ICS set, comprising 'governments', 'communities' and 'policymakers'. However, the following two groups were 'industry' and 'public', which moved higher up this list than in the wider ICS group, where they placed fifth and seventh respectively. As for the broader ICS set, there were contributions to almost all beneficiary groups from all Panels, further emphasising the impact pathways' diverse nature.

The research underpinning the UKRI-funded ICSs in Panel A was more interdisciplinary than in the broader ICS set

Except for UoA 2 (Public Health, Health Services and Primary Care), Panel A ICSs that received

UKRI funding had relatively higher rates of interdisciplinary research than the broader ICS set. This pattern did not hold for the other Panels, where the level of interdisciplinarity for UKRI-funded ICSs resembled the broader set, with variation between UoAs.

UKRI research contributed to addressing policy priorities such as COVID-19, net zero and Place

Research at UK universities informed global clinical guidelines and practices for treating COVID-19 via modelling, monitoring, contract tracing and diagnostics. Many of these contributions were partly funded by UKRI, including the RECOVERY trial and the work relating to the Oxford-AstraZeneca COVID-19 vaccine, work informing the NHS COVID-19 contact tracing app, and several modelling studies informing policy decisions, including local and national alert levels. UKRI-funded research also contributed to a range of key actions towards net zero, including work actively supporting the implementation of the Paris Agreement, mechanisms to support greater public engagement, and technologies enabling the implementation of renewable and alternative energy sources, such as PV-Live, the national-level solar PV electricity monitoring service. Regarding Place, our results showed that UKRI-funded research supported hyperlocal impacts in the Manchester region, particularly in health, climate and local policymaking.

Research funded by multiple UKRI councils was more likely to be interdisciplinary and collaborative

Examining ICSs supported by multiple UKRI councils showed that the IDR metric increased as the number of councils supporting the case studies increased. Moreover, as the number of councils supporting the ICSs increased, the average number of DOIs with domestic, international and multilateral collaboration also increased.

Research with multiple UKRI funders tended to have higher citation and local impact levels

On average, UKRI-funded ICSs had higher citation levels than the world average. However, this increased as the number of UKRI councils supporting the research rose and was significantly higher for ICSs supported by three or more UKRI Councils. The proportion of ICSs reporting local impact also increased as the number of UKRI councils increased.

Case studies supported by multiple UKRI research councils reported a diverse range of impacts, including environmental sustainability, energy and applied technology

Key topics among impact topics related to ICSs supported by three or more UKRI councils included ‘environmental management’, ‘environmental sustainability’, ‘energy’, ‘food policy’ and ‘applied technology’. A more detailed exploration of these impacts revealed a diversity of examples. In sustainability, UKRI-funded research contributed towards several impact areas, including sustainable production and management, pollution and guidance to policymakers and government. UKRI-funded research also impacted the energy landscape, including developing solar-powered technologies, emission reduction and energy infrastructure. Regarding impacts on food policy and practice, UKRI-funded research made significant contributions across health, food security and supply chains. Applied technologies show applications across health, law enforcement and art and design.

Annex B. **Research questions**

B.1. Research questions

The questions in the Invitation to Tender (ITT) are outlined in Table 40 and Table 41 below and correspond to the FRAP (Future Research Assessment Programme) and UKRI components respectively.

Table 40. List of research questions for the FRAP component

Question number	Research question
1	What types of impact outcomes have been submitted to the REF? How does this vary by discipline/user type (beneficiary)/institution
2	What are the pathways by which different types of impact outcomes have been realised? How does this vary by discipline/user type (beneficiary)/institution
3	To what extent are 'negative' findings included in the ICS, or are only 'positive' stories submitted? Are 'learning' type impacts reported?
4	What time lags exist between underpinning research and impact outcome exampled in the ICS? How does this vary between types of impact, users and disciplines?
5	To what extent does the conclusion from the REF 2014 analysis, that it is not possible to estimate the overall return on investment, still stand?
6	According to the ICS, what types of research users benefit from HE research, and to what extent?
7	What are the characteristics of the underpinning research outputs on which ICS are based (in terms of methodologies, approaches or research topics)? Do these vary by type of impact?
8	What is the role of inter and multidisciplinary research in leading to impact?
9	Can we learn anything about how research collaboration affects impact?
10	How does the impact described in the REF case studies relate to the government's economic/industry strategies and those of the other devolved administrations?
11	Can we learn anything about the connections between the social and economic impact of research and related citation data?
12	What are the effects of changes brought in since REF 2014, including allowing the submission of continued case studies and the impacts on teaching within the institution?
13	Can we identify how HEIs contribute to government policy priorities in the UK and devolved administrations, for example COVID-19, net zero, increasing productivity and the UK's global influence, through a series of deep dives into impact?
14	What comparisons can be drawn with REF 2014 ICSs and their evaluation? Have any standards changed since it was first introduced? For example, are units utilising standardised impact measures and has the language or narrative altered?
15	Where continued case studies from REF 2014 are evidenced, what is the volume and distribution of these across disciplines and impact types?

Question number	Research question
16	What do the case studies tell us about the role of funding that is less likely to have been referenced in the case studies (e.g. underpinning and earlier investments or block-grant funding such as QR or REG)? Is there a way to identify this funding, e.g. tracking through the referenced papers?

Table 41. List of research questions, UKRI component

Question number	Research question
17a	For case studies that reference UKRI support, what types of impact outcomes have been submitted to the REF? How does this vary by discipline/ user type (beneficiary)/ institution?
17b	For case studies that reference UKRI support, what are the pathways by which different types of impact outcomes have been realised? How does this vary by discipline/user type (beneficiary)/ institution?
17c	For case studies that reference UKRI support, what types of research users benefit, from what sectors, and to what extent?
17d	For case studies that reference UKRI support, what is the role of inter and multidisciplinary research in leading to impact?
17e	What do the case studies tell us about UKRI's role in the R&I funding landscape? For case studies that reference UKRI support, what is the role of other funders and partners in the pathways to impact?
17f	What do the case studies tell us about how UKRI support leverages/unlocks industry funding and how this relates to impact?
17g	What do the case studies tell us about the role of UKRI capability in supporting impact? Including UKRI infrastructure, facilities, and datasets; and UKRI research institutes.
17h	What do the case studies tell us about the role of and interplay between different parts of UKRI and different UKRI funding streams in supporting the delivery of impact?
18a	What do the case studies tell us about the impact arising from UKRI support? In particular, we are interested in identifying strong case studies/examples, including: (a) Significant research breakthroughs and how they relate to impact.
18b	What do the case studies tell us about the impact arising from UKRI support? In particular, we are interested in identifying strong case studies/examples, including (b) Particular UK regions/places – cluster impacts.
18c	What do the case studies tell us about the impact arising from UKRI support? In particular. we are interested in identifying strong case studies/examples, including (c) Impacts underpinned by UKRI infrastructure, networks, facilities and datasets.
18d	What do the case studies tell us about the impact arising from UKRI support? In particular, we are interested in identifying strong case studies/examples, including (d) Impacts underpinned by the capability/outputs of UKRI research institutes, catapults and campuses.
18e	What do the case studies tell us about the impact arising from UKRI support? In particular, we are interested in identifying strong case studies/examples, including (e) Impacts related to government policy priorities in the UK, for example, COVID-19, net zero, increasing productivity and the UK's global influence.

Figure 40. Questions from the ITT mapped onto the report structure

Questions from ITT

1. What types of impact outcomes have been submitted to the REF? How does this vary by discipline/user type (beneficiary)/institution
2. What are the pathways by which different types of impact outcomes have been realised? How does this vary by discipline/user type (beneficiary)/institution
3. To what extent are 'negative' findings included in the ICS, or are only 'positive' stories submitted? Are 'learning' type impacts reported?
4. What time lags exist between underpinning research and impact outcome exampled in the ICS? How does this vary between types of impact, users and disciplines?
5. To what extent does the conclusion from the REF 2014 analysis, that it is not possible to estimate the overall return on investment, still stand?
6. According to the ICS, what types of research users benefit from HE research, and to what extent?
7. What are the characteristics of the underpinning research outputs on which ICS are based (in terms of methodologies, approaches or research topics)? Do these vary by type of impact?
8. What is the role of inter and multidisciplinary research in leading to impact?
9. Can we learn anything about how research collaboration affects impact?
10. How does the impact described in the REF case studies relate to the government's economic/industry strategies and those of the other devolved administrations?
11. Can we learn anything about the connections between the social and economic impact of research and related citation data?
12. What are the effects of changes brought in since REF 2014, including allowing the submission of continued case studies and the impacts on teaching within the institution?
13. Can we identify how HEIs contribute to government policy priorities in the UK and devolved administrations, for example COVID-19, net zero, increasing productivity and the UK's global influence, through a series of deep dives into impact?
14. What comparisons can be drawn with REF 2014 ICSs and their evaluation? Have any standards changed since it was first introduced? For example, are units utilising standardised impact measures and has the language or narrative altered?
15. Where continued case studies from REF 2014 are evidenced, what is the volume and distribution of these across disciplines and impact types?
16. What do the case studies tell us about the role of funding that is less likely to have been referenced in the case studies (e.g. underpinning and earlier investments or block-grant funding such as QR or REG)? Is there a way to identify this funding, e.g. tracking through the referenced papers?

Report structure

Chapter 1
Introduction

Chapter 2
Nature and beneficiaries of research impact

Chapter 3
Research underpinning the research

Chapter 4
Change and continuity from REF **2024**

Chapter 5
Government policy and strategy

Chapter 6
Conclusions

Annex A
UKRI-specific analysis

Annex B
Research questions

Annex C
Methods

Annex C. **Units of Assessment**

Main Panel	UoA	
A	1	Clinical Medicine
	2	Public Health, Health Services and Primary Care
	3	Allied Health Professions, Dentistry, Nursing and Pharmacy
	4	Psychology, Psychiatry and Neuroscience
	5	Biological Sciences
	6	Agriculture, Food and Veterinary Sciences
	7	Earth Systems and Environmental Sciences
	8	Chemistry
B	9	Physics
	10	Mathematical Sciences
	11	Computer Science and Informatics
	12	Engineering
	13	Architecture, Built Environment and Planning
	14	Geography and Environmental Studies
	15	Archaeology
	16	Economics and Econometrics
	17	Business and Management Studies
C	18	Law
	19	Politics and International Studies
	20	Social Work and Social Policy
	21	Sociology
	22	Anthropology and Development Studies
	23	Education
	24	Sport and Exercise Sciences, Leisure and Tourism
D	25	Area Studies
	26	Modern Languages and Linguistics
	27	English Language and Literature
	28	History
	29	Classics
	30	Philosophy
	31	Theology and Religious Studies
	32	Art and Design: History, Practice and Theory
	33	Music, Drama, Dance, Performing Arts, Film and Screen Studies
	34	Communication, Cultural and Media Studies, Library and Information Management

Annex D. **Additional figures and tables**

Table 42. The 79 impact topics with top terms

Topic	Topic name	ICS count: primary assigned topic (P)	ICS count: all assigned topics (N)	Top terms within the topic
0	Public health	24	104	health | public health | physical activity | physical | activity | phe | guidelines | guidance | obesity | tobacco
1	Treatment and disease	317	665	patients | treatment | clinical | patient | trial | guidelines | therapy | nice | trials | disease
2	Computing and software development	25	104	software | code | model | users | modelling | tools | design | tool | models | systems
3	Applied technology	154	489	technology | company | products | product | ltd | market | sales | commercial | manufacturing | technologies
4	Teaching and education	201	493	teachers | schools | education | teacher | school | teaching | pupils | curriculum | learning | primary
5	Northern Ireland	47	184	ireland | brexit | committee | irish | northern | northern ireland | political | report | electoral | government
6	History and cultural heritage	27	105	heritage | cultural | cultural heritage | history | sites | historic | tourism | heritage sites | world heritage | unesco
7	Music and live performance	126	188	music | musicians | musical | sound | opera | composers | concert | classical | performances | jazz
8	Policing	69	146	police | policing | crime | officers | forces | forensic | police forces | victims | police officers | criminal
9	Communities and urban planning	55	263	local | community | city | urban | communities | planning | council | cities | social | authorities
10	Cancer diagnostics and therapy	96	192	cancer | breast | prostate | breast cancer | prostate cancer | patients | radiotherapy | cancer patients | treatment | cancers
11	Climate change	46	164	climate | climate change | change | adaptation | ipcc | weather | climate action | action | warming | paris
12	Environmental management	106	208	water | water quality | drinking water | drinking | water companies | groundwater | quality | management | water resources | waters

Topic	Topic name	ICS count: primary assigned topic (P)	ICS count: all assigned topics (N)	Top terms within the topic
13	Museums and curation	43	236	exhibition | visitors | exhibitions | history | visitor | catalogue | gallery | library | curator | museum
14	Sports	83	156	sport | athletes | coaches | sports | football | players | rugby | coach | coaching | elite
15	Children and childcare	70	305	children | child | childrens | parents | families | school | schools | family | early years | early
16	NHS	14	98	nhs | patient | hospital | care | trust | healthcare | england | health | trusts | services
17	Scotland	12	88	scottish | scotland | scottish government | government | scotlands | scottish parliament | scottish governments | parliament | edinburgh | glasgow
18	Human rights	29	92	rights | human rights | human | un | torture | legal | accountability | indigenous | violations | protection
19	Environmental conservation	109	222	conservation | species | biodiversity | wildlife | forest | iucn | endangered | management | wild | protected
20	Drug discovery and clinical trials	67	236	drug | drugs | pharmaceutical | clinical | drug discovery | discovery | trials | clinical trials | compounds | phase
21	International development	9	64	un | african | africa | countries | conflict | south | global | peace | humanitarian | dfid
22	Film and documentary	92	213	film | films | cinema | festival | film festival | screenings | filmmakers | documentary | bfi | festivals
23	Wales	18	101	welsh | wales | welsh government | cardiff | government | welsh language | welsh governments | across wales | cymru | swansea
24	Procurement and supply chains	16	55	procurement | supply | chain | supply chain | toolkit | suppliers | chains | supply chains | ktp | public procurement
25	Gender equality	45	204	women | gender | womens | female | equality | diversity | girls | pregnancy | gender equality | menopause
26	Dentistry	35	62	dental | oral health | oral | fluoride | dentists | toothpaste | caries | health | tooth | intervention
27	Theatre and performing arts	24	59	theatre | shakespeare | performance | play | audiences | audience | creative | performances | production | drama
28	Viruses and vaccination	53	104	vaccine | vaccination | influenza | vaccines | hpv | immunisation | jcvi | ebola | disease | meningitis

Topic	Topic name	ICS count: primary assigned topic (P)	ICS count: all assigned topics (N)	Top terms within the topic
29	Stroke and brain injury	36	65	stroke | rehabilitation | stroke patients | stroke survivors | patients | survivors | mt | stroke care | clinical | stroke services
30	Pollution and air quality	42	95	air | air quality | pollution | air pollution | quality | clean air | clean | emissions | defra | environmental
31	Language and linguistics	55	139	language | languages | gaelic | english | english language | teachers | translation | speakers | linguistic | speech
32	Archaeology and heritage	36	84	archaeology | archaeological | site | volunteers | stonehenge | heritage | visitors | roman | ancient | excavations
33	Prisons and criminal justice	61	114	prison | prisoners | prisons | justice | hmp | probation | criminal | criminal justice | hmpps | prisoner
34	Banking and finance	78	178	bank | financial | banks | monetary | monetary policy | banking | bank england | risk | finance | stability
35	Justice system	75	245	law | legal | court | justice | bill | courts | judicial | supreme | reform | criminal
36	Science and science engagement	43	142	science | physics | stem | quantum | engagement | students | astronomy | scientific | public engagement | school
37	Business and entrepreneurship	107	298	business | smes | growth | innovation | businesses | enterprise | sme | investment | productivity | entrepreneurship
38	Sexually transmitted infections and HIV	34	65	hiv | prep | msm | hiv testing | prevention | sexual | testing | guidelines | health | hiv prevention
39	Computer science and data analysis	77	336	data | ons | statistics | information | statistical | monitoring | analysis | analytics | open | app
40	Dementia and Alzheimer's	32	70	dementia | people dementia | carers | care | living dementia | dementia care | living | people living dementia | people living | alzheimers
41	Domestic abuse and gender-based violence	51	114	abuse | domestic | domestic abuse | violence | sexual | victims | domestic violence | child | sex | survivors
42	Energy	75	162	energy | electricity | renewable | carbon | smart | wind | solar | grid | power | buildings
43	Employment conditions	25	65	wage | living wage | minimum wage | minimum | labour | pay | living | workers | employers | wages

Topic	Topic name	ICS count: primary assigned topic (P)	ICS count: all assigned topics (N)	Top terms within the topic
44	Mental health	68	186	mental | mental health | health | wellbeing | service | services | perinatal | suicide | psychosis | mental health services
45	Genetic testing and diagnostics	52	226	genetic | testing | diagnosis | test | sequencing | tests | diagnostic | genetic testing | gene | disease
46	Climate resilience	57	168	flood | risk | flood risk | flooding | coastal | ea | insurance | risk management | management | resilience
47	Young people and youth support	81	240	young | young people | youth | youth justice | young peoples | children young | justice | children young people | peoples | social
48	Poetry and literature	74	175	poetry | writing | writers | literary | poets | creative | literature | poems | book | festival
49	Students and education	152	502	students | student | university | education | teaching | universities | higher education | learning | higher | course
50	European policy	109	385	eu | european | commission | european commission | european parliament | member states | ec | europe | directive | regulation
51	Nuclear energy and research	45	71	nuclear | radioactive | edf | sellafield | nuclear power | power | radiation | decommissioning | radioactive waste | graphite
52	World War 1 and World War 2	60	158	war | world war | first world war | first world | history | centenary | holocaust | military | commemoration | world
53	Slavery and human trafficking	31	56	slavery | modern slavery | modern | trafficking | human trafficking | victims | survivors | anti_ slavery | labour | stolen
54	Housing and homelessness	44	129	housing | homes | social housing | homelessness | social | residents | affordable | government | tenants | affordable housing
55	Environmental sustainability	55	168	waste | environmental | plastic | recycling | waste management | plastics | materials | environment | plant | sustainable
56	Food policy	93	224	food | dietary | food insecurity | nutrition | insecurity | sugar | food systems | foods | fsa | food policy
57	Safety and risk management	130	357	safety | fire | risk | road | road safety | suicide | rail | transport | prevention | hydrogen
58	Diabetes	43	93	diabetes | type diabetes | glucose | insulin | type | blood glucose | blood | patients | diabetic | monogenic

Topic	Topic name	ICS count: primary assigned topic (P)	ICS count: all assigned topics (N)	Top terms within the topic
59	Creative and participatory arts	160	406	art | artists | arts | gallery | cultural | artist | creative | contemporary | tate | contemporary art
60	Social services and primary care	108	394	care | palliative | palliative care | care homes | social care | homes | care home | social | services | home
61	Museums and cultural heritage	162	388	museum | museums | collections | objects | visitors | history | collection | curators | artefacts | curator
62	Media and communication	258	883	media | bbc | radio | history | news | book | times | article | series | audience
63	Marine environment and fishing	81	177	marine | fisheries | fishing | fish | sea | coastal | mpa | ocean | management | environmental
64	Ethics and artificial intelligence	69	180	ai | ethics | ethical | standards | code | governance | intelligence | artificial | artificial intelligence | robot
65	Farming and animal welfare	167	344	farmers | insurance | animal | welfare | agricultural | veterinary | farming | dairy | farm | crop
66	Gambling	14	32	gambling | betting | gaming | problem gambling | harm | responsible gambling | online gambling | gambling commission | gamblers | tax
67	Hate crime and criminal activity	47	122	hate | crime | hate crime | islamophobia | hate speech | speech | victims | source | chs | definition
68	Performance and dance	31	88	dance | dancers | ballet | arts | dance artists | artists | creative | contemporary dance | parkinsons | dance uk
69	Intelligence and cyber security	106	272	security | cyber | cyber security | cybersecurity | iot | defence | intelligence | ncsc | airbus | government
70	Engineering	109	264	engine | aircraft | fuel | rolls_royce | engines | design | trent | aviation | airbus | xwb
71	Health screening and preventative treatment	76	250	screening | hpv | screening programme | cervical | fit | cancer screening | bowel | test | cancer | lung
72	Training and skills	338	1,185	training | staff | professional | course | practitioners | skills | participants | professionals | trained | organisations
73	Digital environments	244	619	digital | online | digital skills | technology | skills | app | media | internet | storytelling | platform
74	Manufacturing and emissions	129	303	emissions | carbon | gas | zero | ghg | net zero | oil | greenhouse | net | ipcc
75	Trade unions and trade policy	74	208	trade | trade policy | union | trade union | labour | international trade | wto | unions | brexit | trade agreements

Topic	Topic name	ICS count: primary assigned topic (P)	ICS count: all assigned topics (N)	Top terms within the topic
76	Infectious disease	46	131	malaria | elimination | control | resistance | vector | insecticide | vector control | nets | malaria elimination | tb
77	Refugees and migration	116	218	migration | refugee | refugees | migrants | immigration | migrant | asylum | integration | home | home office
78	Disability and inclusion	93	235	disability | disabled | autism | disabled people | disabilities | learning | learning disabilities | employment | people learning | autistic

Table 43. The top 20 most frequently referenced journals

Source	Pub. Count	Earliest Pub. Year	Latest Pub. Year
LANCET	313	2000	2021
PLOS ONE	283	2008	2021
NEW ENGLAND JOURNAL OF MEDICINE	193	2000	2021
BMJ OPEN	172	2012	2021
BMJ-BRITISH MEDICAL JOURNAL	142	2001	2021
NATURE	141	2001	2020
SCIENTIFIC REPORTS	124	2013	2020
SCIENCE	111	2000	2021
NATURE COMMUNICATIONS	106	2011	2021
COCHRANE DATABASE OF SYSTEMATIC REVIEWS	82	2006	2020
PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA	81	2002	2020
SCIENCE OF THE TOTAL ENVIRONMENT	69	2004	2021
ENVIRONMENTAL SCIENCE & TECHNOLOGY	61	2005	2020
PHYSICAL REVIEW LETTERS	59	2006	2020
BMC PUBLIC HEALTH	58	2006	2020
PLOS MEDICINE	56	2005	2020
MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY	54	2000	2021
LANCET INFECTIOUS DISEASES	51	2010	2021
SOCIAL SCIENCE & MEDICINE	50	2004	2019
FRONTIERS IN PSYCHOLOGY	49	2011	2020

Source: Data from Web of Science, provided by Clarivate

Figure 41. Research impact beneficiaries by Panel

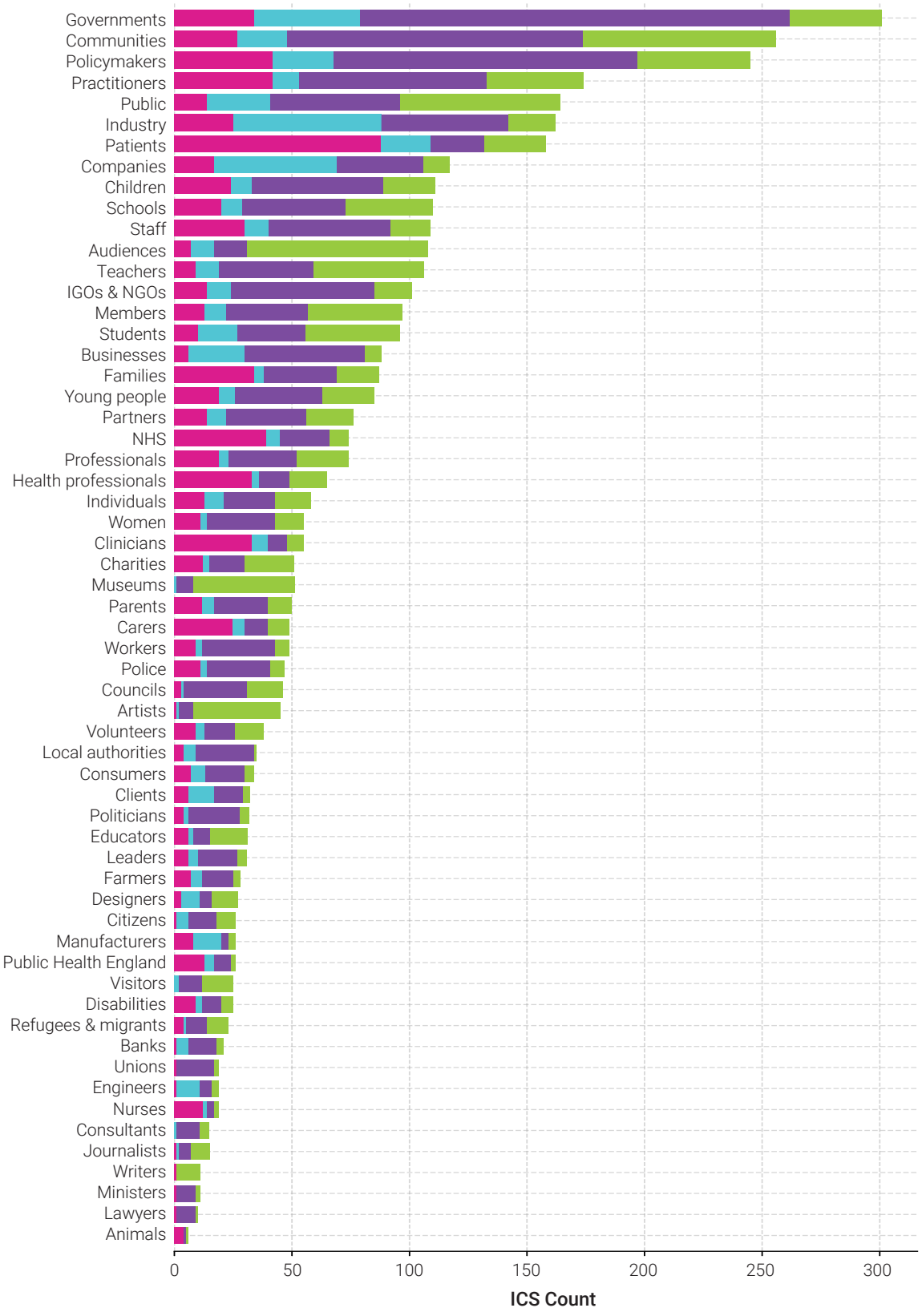

Figure 42. Research impact beneficiaries for UKRI-supported ICSs by Panel

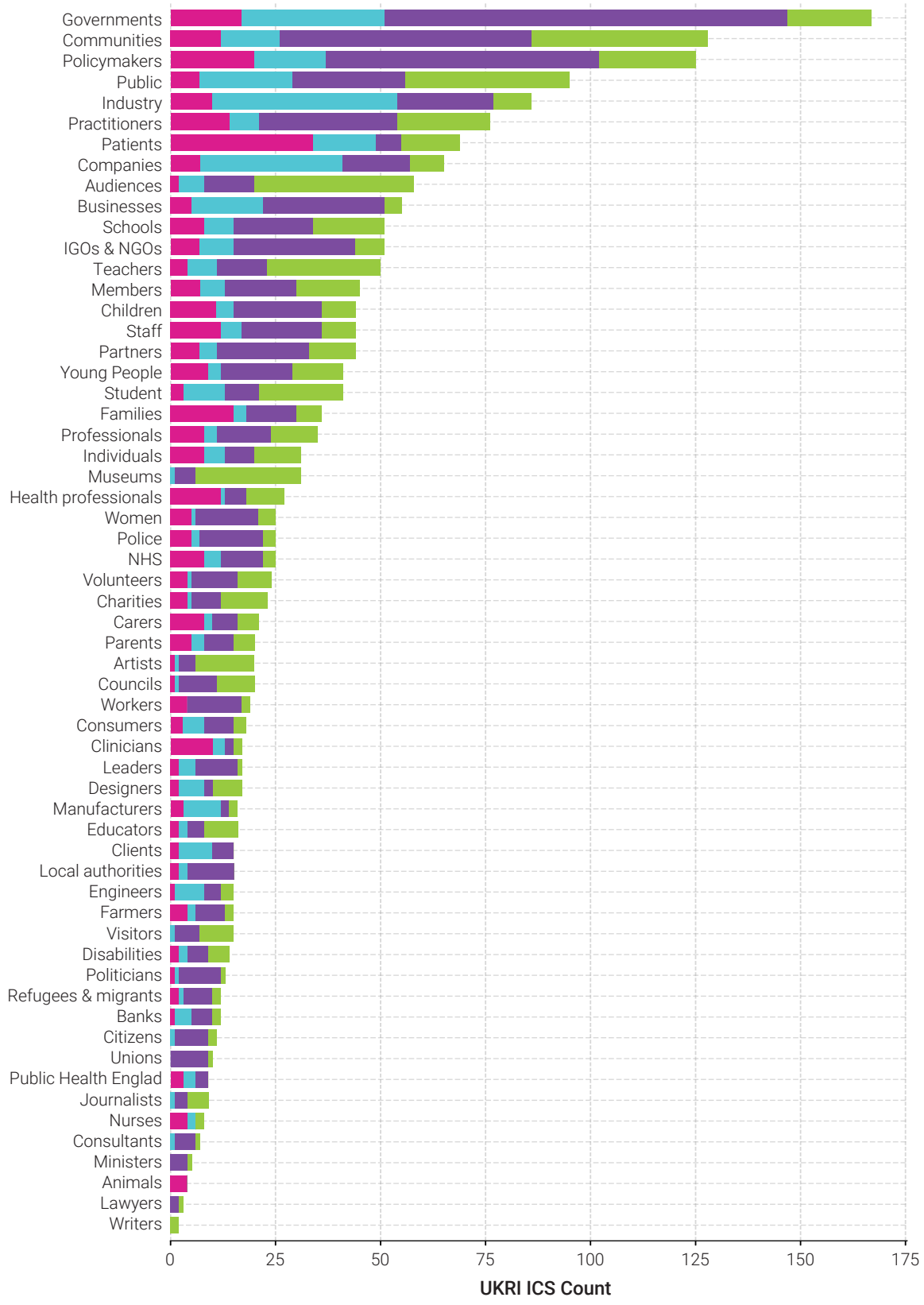

Table 44. Collaboration by impact topic

Topic	Topic label	Total no. of ICSs	% 'None'	% 'Domestic'	% 'International'	% 'Multilateral'	% 'Health'	% 'Corporate'	% 'Government'	% 'Nonprofit'
0	Public health	104	38	81	73	21	36	6	31	9
1	Treatment and disease	665	28	79	75	37	68	20	34	16
2	Computing and software development	104	47	61	72	19	2	29	28	15
3	Applied technology	489	54	67	71	17	11	24	29	9
4	Teaching and education	493	50	45	37	8	3	2	8	6
5	Northern Ireland	184	43	55	35	2	1	3	7	1
6	History and cultural heritage	105	38	29	26	4	1	1	5	5
7	Music and live performance	188	33	25	20	3	1	2	4	2
8	Policing	146	63	69	40	4	3	4	7	3
9	Communities and urban planning	263	51	52	38	5	3	2	9	2
10	Cancer diagnostics and therapy	192	21	79	78	34	70	28	48	27
11	Climate change	164	39	57	73	38	2	8	45	23
12	Environmental management	208	49	62	72	23	5	10	33	13
13	Museums and curation	236	32	25	15	3	2	1	4	2
14	Sports	156	44	69	62	20	20	4	11	0
15	Children and childcare	305	44	62	52	13	21	3	12	8
16	NHS	98	39	85	64	18	44	5	20	7
17	Scotland	88	44	73	28	6	12	1	8	1
18	Human rights	92	43	38	27	0	0	2	5	2
19	Environmental conservation	222	29	52	77	46	5	6	50	43
20	Drug discovery and clinical trials	236	26	71	83	39	53	48	47	25
21	International development	64	36	41	58	14	5	0	12	5
22	Film and documentary	213	35	31	18	4	1	1	6	3

Topic	Topic label	Total no. of ICSs	% 'None'	% 'Domestic'	% 'International'	% 'Multilateral'	% 'Health'	% 'Corporate'	% 'Government'	% 'Nonprofit'
23	Wales	101	53	53	32	4	4	0	11	2
24	Procurement and supply chains	55	64	53	67	15	2	7	11	7
25	Gender equality	204	44	48	42	10	22	5	12	5
26	Dentistry	62	39	79	60	21	42	16	31	3
27	Theatre and performing arts	59	31	14	7	0	0	0	0	0
28	Viruses and vaccination	104	21	62	90	46	47	30	67	36
29	Stroke and brain injury	65	40	89	72	37	62	14	22	5
30	Pollution and air quality	95	40	60	73	25	8	14	45	17
31	Language and linguistics	139	38	44	29	6	4	1	4	1
32	Archaeology and heritage	84	36	44	37	15	4	0	24	11
33	Prisons and criminal justice	114	52	54	25	4	9	1	4	2
34	Banking and finance	178	29	58	65	10	0	3	22	7
35	Justice system	245	40	44	32	2	3	2	5	3
36	Science and science engagement	142	41	51	78	48	3	17	54	35
37	Business and entrepreneurship	298	50	64	61	12	1	5	13	3
38	Sexually transmitted infections and HIV	65	23	46	80	46	57	14	54	20
39	Computer science and data analysis	336	42	60	67	25	16	12	38	17
40	Dementia and Alzheimer's	70	33	71	41	9	26	1	9	3
41	Domestic abuse and gender-based violence	114	54	50	35	4	4	0	4	3
42	Energy	162	56	67	59	11	2	12	14	4
43	Employment conditions	65	43	62	62	5	0	3	5	17
44	Mental health	186	43	74	51	16	26	3	10	7
45	Genetic testing and diagnostics	226	30	77	79	44	53	26	48	35

Topic	Topic label	Total no. of ICSs	% 'None'	% 'Domestic'	% 'International'	% 'Multilateral'	% 'Health'	% 'Corporate'	% 'Government'	% 'Nonprofit'
46	Climate resilience	168	42	61	71	23	7	8	38	12
47	Young people and youth support	240	52	51	36	5	10	2	7	2
48	Poetry and literature	175	37	19	9	1	1	2	1	0
49	Students and education	502	47	45	40	10	4	4	9	6
50	European policy	385	38	51	63	24	13	9	29	15
51	Nuclear energy and research	71	48	55	73	23	3	20	54	18
52	World War 1 and World War 2	158	41	27	15	0	1	0	1	2
53	Slavery and human trafficking	56	41	32	36	4	5	2	5	2
54	Housing and homelessness	129	50	57	42	6	4	3	11	2
55	Environmental sustainability	168	51	65	64	21	4	16	30	8
56	Food policy	224	51	67	71	26	13	12	33	18
57	Safety and risk management	357	55	71	64	21	19	16	26	7
58	Diabetes	93	31	81	76	31	60	22	33	10
59	Creative and participatory arts	406	28	23	15	2	1	0	3	2
60	Social services and primary care	394	41	77	55	20	42	6	16	6
61	Museums and cultural heritage	388	36	29	21	4	0	1	6	4
62	Media and communication	883	40	40	33	9	6	3	10	6
63	Marine environment and fishing	177	35	60	80	39	3	14	49	26
64	Ethics and artificial intelligence	180	51	51	46	14	8	9	16	6
65	Farming and animal welfare	344	47	64	73	28	12	14	40	16
66	Gambling	32	44	69	62	16	16	3	6	9
67	Hate crime and criminal activity	122	53	48	26	6	2	2	7	2
68	Performance and dance	88	34	36	28	7	16	3	9	6
69	Intelligence and cyber security	272	50	55	56	11	2	7	20	6
70	Engineering	264	57	65	69	16	3	25	24	8

Topic	Topic label	Total no. of ICSs	% 'None'	% 'Domestic'	% 'International'	% 'Multilateral'	% 'Health'	% 'Corporate'	% 'Government'	% 'Nonprofit'
71	Health screening and preventative treatment	250	29	78	68	34	54	16	40	18
72	Training and skills	1185	49	62	49	12	15	4	10	4
73	Digital environments	619	49	49	41	8	7	8	8	5
74	Manufacturing and emissions	303	46	62	76	30	4	15	41	19
75	Trade unions and trade policy	208	39	50	50	12	4	2	15	11
76	Infectious disease	131	23	53	87	54	48	18	65	32
77	Refugees and migration	218	44	43	37	4	3	2	4	2
78	Disability and inclusion	235	43	61	42	8	15	3	5	1

Source: Data from Web of Science, provided by Clarivate

Annex E. **Methodology**

The sample used in this report included all the ICSs submitted by UK HEIs to REF 2021 that could be made publicly available, totalling 6,361 case studies. This corpus of ICSs is available on the REF 2021 Impact Case Study database.[242] A total of 6,781 ICSs were submitted to REF 2021.

E.1. Analytical approach

Our analysis for this study focuses on the information provided within the ICS submitted to the REF 2021. Each case study has a common format, as shown in Box 1. In addition, metadata (also referred to as contextual data) is submitted alongside each ICS (not used as part of the assessment), which includes:

- Name(s) of funder(s)
- Global Research Identifier of funder(s)[243]
- Name(s) of funding programme(s)
- Grant number(s)
- Grant amount (in GBP)
- Each researcher's ORCID (where held)
- Name(s) of formal partner(s)
- Country/countries where the impact occurred.

This information and any additional data sets that can be linked to the case studies (e.g., via the publications referenced in the 'references to the research' section) formed the basis for our analysis.

To conduct the analysis required for this study, we developed a bespoke, mixed-methods approach consisting of diverse analytical tools. We detail these analytical tools and approaches below.

E.1.1. Topic modelling

We used a topic modelling approach to explore the impact types described in the REF ICSs. Topic modelling is a natural language processing technique that determines how to use specific clusters of related words (topics) to categorise underlying data. Because it is data-driven, results are derived from the data itself and thus not dependent on subjective notions of structure or conceptual categorisations of impact. We conducted the topic modelling based on the text provided in Section 4 of the ICS ('Details of the impact'), meaning the analysis focuses on the impact itself rather than other aspects of the ICS. Based on this empirically driven topic modelling approach, we identified 79 impact 'topics'.

We implemented topic modelling using Python and the open-source libraries Scikit-learn[244] and the Natural Language Toolkit (NLTK).[245] We normalised raw text from Section 4 using the following steps: lowercasing, replacing diacritic

242 UKRI (2022).

243 Global Research Identifier Database (2023).

244 Scikit-learn (2023).

245 NLTK (2023).

characters with ASCII equivalents, removing punction characters and normalising URLs (i.e. replacing full URLs with the associated domain name). We did not use lemmatisation. We extracted trigrams (i.e. up to three-word sequences) for each ICS, subsequently removing common stop-words, short words and digits with only one or two characters. In addition, we removed words appearing in more than 50% of documents or less than five ICSs. The final list of words included 136,147 unique tokens weighted using TF-IDF.

Following text processing, we used nonnegative matrix factorization (NMF) to create the topic model for a range of target topics (between 65 and 85). We used the topic coherence metric to measure each model, revealing a local maximum for 79 topics – the final number used in the analysis. We chose up to three topics for each ICS; the primary topic was that with the largest weight, alongside optional secondary and tertiary topics if their weight exceeded a minimum threshold (higher than 95% of all weights).

We used indicative labels created using the top 20 most highly weighted words to inform the creation of short topic labels. In addition, we grouped related topics into 12 clusters based on Ward similarity of the resulting topic-token matrix that were also assigned indicative labels.

E.1.2. Analysis of the underpinning research

As part of this study, we associated the ICSs with additional metadata to support our analysis. ICSs contained a description of the underpinning research that led to the reported impact (Section 2) and a list of research artefacts (such as publications, patents and grant awards) exemplifying the research (Section 3). We used text mining to identify and extract fragments from the ICS documents that matched patterns typically seen in bibliographic referencing. We associated each ICS with a list of underpinning research DOIs by searching for mentions or hyperlinks to DOIs in these text fragments or using the CrossRef Simple Text Query Service[246] to match them with CrossRef records. We identified a total of 25,433 unique DOIs. We cross-referenced each DOI with corresponding bibliographic records in the Web of Science, of which we matched 20,548 (81%) with a unique document ID (Accession Number/UT).

We used data from OpenAlex and Clarivate to analyse the publications listed in Section 3 of the ICSs, exploring aspects of collaboration modes, interdisciplinarity and complimentary classification systems (FoR).

FoR

This approach used the Australian and New Zealand Standard Research Classification (ANZSRC) 2008 Fields of Research (FoRs) to capture subject categories based on a publicly available journal mapping, extracting cited reference lists from the OpenAlex database. The classification system has three levels of detail: (i) 'divisions' (two-digit codes), (ii) 'groups' (four-digit codes) and (iii) 'subjects' (six-digit codes). We used the second level in the three-tier hierarchy of research subjects, four-digit FoRs (groups), for this analysis.

We used the public ERA Journal mapping file from 2018 to determine subject categories.[247] This file maps 25,017 journals to their respective FoRs (up to three per journal). However, not all listed journals have mappings to a four-digit FoR code. For example, the Lancet only maps to Division 11 (Medical and Health Sciences). However, 21,570 journals

246 Crossref (2023).

247 Australian Research Council (2018).

Box 14. REF 2021 ICS template

Institution:		
Unit of Assessment:		
Title of case study:		
Period when the underpinning research was undertaken:		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting Higher Education Institution (HEI):
Period when the claimed impact occurred:		
Is this case study continued from a case study submitted in 2014? **Y/N**		
1. Summary of the impact (**indicative maximum 100 words**)		
2. Underpinning research (**indicative maximum 500 words**)		
3. References to the research (**indicative maximum of six references**)		
4. Details of the impact (**indicative maximum 750 words**)		
5. Sources to corroborate the impact (**indicative maximum of 10 references**)		

map to at least one four-digit FoR code. Using OpenAlex data, we calculated each DOI's weighting to every four-digit FoR code. If at least ten referenced works for the DOI were indexed in OpenAlex, we used this weighting as the proportion of references made to journals that map to the FoR code. If referenced works for the DOI were not indexed, we used the average weight for the journal. This average weighting is based on a sample of 200 recent works, following the same methodology as above (i.e. assessing the proportion of cited references to journals in the ERA mapping list). For each ICS, we calculated the average weighting for each FoR code based on all the DOIs mentioned (i.e. under Section 3, 'References to the Research'). For each DOI in the dataset, we calculated a weight for each four-digit FoR code based on the proportion of references to journals assigned to those categories in the ERA mapping.

We used the average weight across all linked DOIs for each ICS to determine the final subject categories, assigning up to three of the most highly weighted FoR codes above a threshold of 0.05 (i.e. 5% of references on average).

When no FoR groups could be suggested (either because no DOIs were linked or none of the linked DOIs had sufficient data in OpenAlex), we manually assigned FoR groups (n=448) by reading the ICSs and scanning for mentions of specific fields or subjects in Section 2 ('Underpinning Research') and

Box 15. OpenAlex and Clarivate

- **OpenAlex** is a free, open-source catalogue of the world's scholarly papers, researchers, journals and institutions.[248] Using OpenAlex, we retrieved the list of cited references for each linked DOI and associated them with FoR codes by following the mappings in the ERA journal list. We assigned FoR codes to ICSs based on the most frequently referenced research fields.
- **Clarivate Analytics** is a data analytics organisation with an extensive track record in undertaking bibliometric analysis and responsibility for the Web of Science platform.[249] Clarivate provided citation data for the REF 2021 exercise to help inform the expert panel assessment of the quality of research outputs for some UoAs.

journal names, conference venues and book titles listed in Section 3 ('References to the research'). We selected appropriate FoR groups from the full list that best matched the field(s) of underpinning research. However, we note that this is a somewhat subjective assessment of the nature of underpinning research. When only one DOI was linked to an ICS, we undertook an additional manual review to verify suggested categories (n=561).

Inter and multidisciplinary analyses

Bibliometric indicators have been developed to measure various aspects of disciplinarity, utilising information from the underlying publication records, such as cited references, citing papers, author affiliations or text processing of the article abstracts. Each indicator provides a measurement aligned with different interpretations of disciplinarity. For example, we can use the variety of subjects referenced in a paper to measure the disciplinarity of the underlying research. Similarly, we can use the variety of subjects citing the research to gauge how it was utilised. Examining authors' affiliations on papers or clustering authors according to co-author networks also makes it possible to measure variety in the research team's disciplinary makeup. Although prior research[250] highlights challenges with interpreting such indicators, largely because different methodologies produce conflicting results, they are still widely used to report on research collections' relative disciplinarity.

One of the most commonly used bibliometric disciplinarity indicators is based on the Rao-Stirling metric,[251] which defines interdisciplinarity using three aspects: variety (the number of different subjects), balance (the skew towards certain subjects), and disparity (how unusual the combination of subjects is). The value produced ranges from '0' (least interdisciplinary) to '1.0' (most interdisciplinary). This metric was one of several interdisciplinarity metrics recently investigated in another commissioned report.[252] Hence, for this analysis, we use the term IDR to refer generally to inter, multi, and trans-disciplinary research

248 Priem et al (2022).
249 Clarivate (2023).
250 Adams et al. (2016).
251 Stirling (2007).
252 Rosemberg et al. (2022).

as operationalised by Rao-Stirling and do not attempt to differentiate them.

For each ICS, we used the proportion of subject categories referenced by underpinning research articles as the feature vector. As discussed above, we used FoRs to capture subject categories based on a publicly available journal mapping, with cited reference lists extracted from the OpenAlex database, using four-digit FoRs (groups). We only used publications that contained at least ten cited references, meaning the metric could not be calculated for all ICSs. Coverage of the RS-IDR metric was good for Panels A, B and C but was lower for Panel D because some ICSs did not link to any bibliographic items.

Bibliometric impact

We matched 20,548 DOIs to records in the Web of Science. The Web of Science database tracks citations to articles and provides a range of citation indicators that bibliometricians use widely to report on citation impact. 'Best practice' uses a normalised metric that accounts for relative differences in citation behaviour across disciplines, publication type (article, reviews, books, etc.) and publication year. Citations are expressed either as a fraction of the global average (defined by Clarivate as the CNCI) or as a percentile.

E.1.3. Overton

To explore how the impact described in the ICSs relates to government economic and industrial strategies, we used Overton data (Box 9) to explore the degree to which DOIs referenced in the ICSs were referenced in policy documents in Overton.

Box 16. Overton grey literature database

Overton[253] is a grey literature database that provides a searchable index of policy documents from UK and international sources. It indexes more than 31,000 global sources and links more than 7.5 million documents to individual researchers and scholarly literature via a network of 16 million citations. It is possible to filter the database to identify policy documents from specific sources (such as UK-based organisations).

E.1.4. Geotagging

Using the open-source Edinburgh Geoparser, we used geotagging to identify all geographic locations mentioned in Section 4 of the ICSs, 'Details of the impact'. The Edinburgh Geoparser system automatically recognises place names in text and disambiguates them from a gazetteer. We used the open-source Geonames[254] gazetteer for this study, as it provides global coverage and an extensive list of place names. We also used the *limiting geographical area* feature that enables users to provide a rectangular locality box. The geoparser prefers places in the area specified but will still choose locations outside it if other factors give them higher weight. For this analysis, we used a bounding box surrounding the UK, helping disambiguate commonplace names that appear in multiple geographies.

253 Overton (2023).

254 Geonames (2023).

Following the automatic tagging process, we used a series of manual curation steps to ensure high-quality, accurate data. We created custom spreadsheets showing the matched tokens, their context (a text fragment included ten tokens before and after the match) and basic gazetteer information (e.g. country name, region, population) for manual review. In particular, we reviewed tokens containing location names that were part of a longer proper noun. For example, the geoparser often incorrectly matched 'research at the University of X' to location 'X'. Other examples of this filtering include project names, strategies, report titles, television station names, charity names, governmental departments, prisons, military facilities, hospitals and NHS trusts.

E.1.5. Text searches

We used text searches to identify relevant ICSs for matching sets of keywords or phrases. Below, we provide details on what this entailed for the COVID-19 and net zero deep dives.

COVID-19 deep dive

We searched for the key terms 'covid' and 'coronavirus' and determined the number of mentions in Section 4 ('Details of impact') of the ICSs. As illustrated in Figure 22, the distribution of mentions ranged from 15% for a single mention to 0.6% for ten or more mentions. Although about a third of ICSs mentioned COVID-19, these were in passing in most cases (e.g. impacts of the pandemic on data collection) and not the ICS's subject. Therefore, we reviewed a subset of ICSs and concluded that a threshold of eight or more mentions was the most appropriate, subsequently confirmed when we identified no false positives. We identified 48 case studies as a result. We also included case studies where 'covid' or 'coronavirus' were mentioned at least once in the case study title, as these were also likely to describe COVID-19-related impacts, resulting in a further 44 case studies. Once we removed duplicate case studies, the final number of ICSs for this deep dive was 66.

Net zero deep dive

We searched for the key terms 'net-zero' and 'net zero' and determined the number of mentions in Section 4 ('Details of impact') of the ICS. This search identified 80 ICSs that mentioned these terms one or more times. An initial review demonstrated these were relevant, with no false positives identified. Therefore, we included all 80 for the thematic analysis and the deep dive.

Annex F. **RS-IDR metric by impact topic**

Topic	Topic_label	Cluster	Cluster_label	Median percentile (RS-IDR)
19	Environmental conservation	6	Food, Environment and Ecology	0.82
11	Climate change	3	Energy, Environment and Engineering	0.79
56	Food policy	6	Food, Environment and Ecology	0.77
32	Archaeology and heritage	12	History, Heritage and Creative Arts	0.73
65	Farming and animal welfare	6	Food, Environment and Ecology	0.70
12	Environmental management	6	Food, Environment and Ecology	0.70
46	Climate resilience	6	Food, Environment and Ecology	0.68
64	Ethics and artificial intelligence	8	Policy, Ethics and Security	0.68
40	Dementia and Alzheimer's	1	Public Health and Health Services	0.67
63	Marine environment and fishing	6	Food, Environment and Ecology	0.67
30	Pollution and air quality	3	Energy, Environment and Engineering	0.66
44	Mental health	1	Public Health and Health Services	0.66
8	Policing	7	Criminal Justice and Human Rights	0.65
6	History and cultural heritage	12	History, Heritage and Creative Arts	0.65
73	Digital environments	11	Culture and Society	0.64
55	Environmental sustainability	3	Energy, Environment and Engineering	0.62
61	Museums and cultural heritage	12	History, Heritage and Creative Arts	0.62
22	Film and documentary	12	History, Heritage and Creative Arts	0.61
47	Young people and youth support	5	Training, Education and Skills	0.61
59	Creative and participatory arts	12	History, Heritage and Creative Arts	0.61
9	Communities and urban planning	9	Business, Planning and Economics	0.61
42	Energy	3	Energy, Environment and Engineering	0.61
54	Housing and homelessness	9	Business, Planning and Economics	0.60
49	Students and education	5	Training, Education and Skills	0.60
48	Poetry and literature	12	History, Heritage and Creative Arts	0.59
23	Wales	10	Devolved Nations	0.59

Topic	Topic_label	Cluster	Cluster_label	Median percentile (RS-IDR)
74	Manufacturing and emissions	3	Energy, Environment and Engineering	0.59
33	Prisons and criminal justice	7	Criminal Justice and Human Rights	0.59
31	Language and linguistics	5	Training, Education and Skills	0.59
41	Domestic abuse and gender-based violence	7	Criminal Justice and Human Rights	0.59
51	Nuclear energy and research	3	Energy, Environment and Engineering	0.58
13	Museums and curation	12	History, Heritage and Creative Arts	0.58
67	Hate crime and criminal activity	7	Criminal Justice and Human Rights	0.57
4	Teaching and education	5	Training, Education and Skills	0.57
78	Disability and inclusion	5	Training, Education and Skills	0.56
7	Music and live performance	12	History, Heritage and Creative Arts	0.56
66	Gambling	8	Policy, Ethics and Security	0.56
76	Infectious disease	2	Clinical Medicine	0.55
24	Procurement and supply chains	9	Business, Planning and Economics	0.55
39	Computer science and data analysis	4	Information, Applied Technology and Analytics	0.55
62	Media and communication	11	Culture and Society	0.55
72	Training and skills	5	Training, Education and Skills	0.55
15	Children and childcare	5	Training, Education and Skills	0.54
68	Performance and dance	12	History, Heritage and Creative Arts	0.53
69	Intelligence and cyber security	8	Policy, Ethics and Security	0.53
57	Safety and risk management	4	Information, Applied Technology and Analytics	0.50
45	Genetic testing and diagnostics	2	Clinical Medicine	0.49
0	Public health	1	Public Health and Health Services	0.49
16	NHS	1	Public Health and Health Services	0.49
53	Slavery and human trafficking	7	Criminal Justice and Human Rights	0.49
60	Social services and primary care	1	Public Health and Health Services	0.48
77	Refugees and migration	11	Culture and Society	0.48
52	World War 1 and World War 2	12	History, Heritage and Creative Arts	0.48
50	European policy	8	Policy, Ethics and Security	0.47
3	Applied technology	4	Information, Applied Technology and Analytics	0.47
38	Sexually transmitted infections and HIV	1	Public Health and Health Services	0.46

Topic	Topic_label	Cluster	Cluster_label	Median percentile (RS-IDR)
35	Justice system	7	Criminal Justice and Human Rights	0.46
70	Engineering	3	Energy, Environment and Engineering	0.45
2	Computing and software development	4	Information, Applied Technology and Analytics	0.45
14	Sports	5	Training, Education and Skills	0.45
28	Viruses and vaccination	2	Clinical Medicine	0.44
37	Business and entrepreneurship	9	Business, Planning and Economics	0.44
36	Science and science engagement	5	Training, Education and Skills	0.42
75	Trade unions and trade policy	8	Policy, Ethics and Security	0.42
21	International development	9	Business, Planning and Economics	0.41
27	Theatre and performing arts	12	History, Heritage and Creative Arts	0.41
26	Dentistry	1	Public Health and Health Services	0.40
43	Employment conditions	8	Policy, Ethics and Security	0.40
25	Gender equality	11	Culture and Society	0.40
29	Stroke and brain injury	2	Clinical Medicine	0.39
20	Drug discovery and clinical trials	2	Clinical Medicine	0.39
17	Scotland	10	Devolved Nations	0.38
18	Human rights	7	Criminal Justice and Human Rights	0.37
71	Health screening and preventative treatment	2	Clinical Medicine	0.36
34	Banking and finance	9	Business, Planning and Economics	0.36
58	Diabetes	2	Clinical Medicine	0.35
5	Northern Ireland	10	Devolved Nations	0.35
1	Treatment and disease	2	Clinical Medicine	0.31
10	Cancer diagnostics and therapy	2	Clinical Medicine	0.19