Annex 5:
Approach and methodology in auditing excellence in science and research

A5.1 Approach

We audited scientific production and scientific quality using SCIVAL, the bibliometric analysis tool of SCOPUS (https://scival.com/home). We adopted a step-by-step approach to the audit of scientific production and scientific quality.

The first step used the "high level" subject areas defined by SCOPUS, selecting a "basket" of eleven subject areas that a "pre-audit" of our activity showed were pertinent to eco-innovation. For example, the first phase of the Centre for Global Eco-Innovation (see page 20) supported collaborative academic-SME research projects at the Departments of: Lancaster Environment Centre, Physics, Engineering, Computing and Communications, Chemistry, Lancaster University Management School and Faculty of Health and Medicine at Lancaster University. At Liverpool projects were in the School of Engineering, School of Electrical Engineering, Electronics and Computer Science, School of Physical Sciences, School of Environmental Sciences, Management School, Chemistry and Architecture.

At this high level we compared the NWCA with the UK as a whole as well as against international comparators which were:

+ EU28 (i.e. all 28 EU member states, including the UK);

+ The USA and Canada;

+ The G20 (including the EU, USA and Canada plus 17 other leading global economies)

+ China

Having confirmed the NWCA's research strength at this low resolution, we then focused on the research base supporting the four capabilities that had emerged in the planning and development of this SIA. This recognised that eco-innovation has a fundamentally trans-disciplinary perspective, so that the four capabilities of this SIA do not map simply on to the high-level subject areas in SCOPUS. Therefore, we explored secondary subject areas that come together to form the research base for the four capabilities.

For example, the Environmental Industries, Technologies and Services capability (EITS) draws on many but not all research areas that come under the SCOPUS "Environmental Science" (Figure A5.1) and not exclusively from this main heading. For example, our research, innovation and development activities under EITS also includes "Agronomy and Crop Science", "Food Science" and "Plant Science", which are sub-disciplines under the Agricultural and Biological Sciences main subject heading of SCOPUS.

Clearly, the NWCA performance would appear much stronger if compared against nations or groups of nations, as the comparators used in our high-resolution analysis are "research intensive" and may be seen as the "gold standard" for comparison. This is a very rigorous comparison for a group like the NWCA, which includes a diverse group of universities and other research partners with complementary balances of specialisation in research, translation and training but, in our view, best illustrates our real strength internationally.

A2.2 Methodology

We audited scientific production and scientific quality using the following SCIVAL metrics.

A2.2.i Research production was measured by the number of publications (outputs) from the NWCA in the SCOPUS database for the period 2010-2015. This metric is clearly extremely scale dependent. For example, over this period, total publications (i.e. all SCOPUS subject areas) totalled 10,423 from the NWCA, 193,662 from the whole UK and 2,146,663 for the G20. For that reason, we present data as (i) NWCA as percentage of all UK publications in a particular research area and (ii) location quotient calculated using the Technopolis method which is:

Location Quotient (LQ) =

$$\frac{\text{Outputs from NWCA in discipline} \div \text{Outputs from UK in discipline}}{\text{Outputs from NWCA in all disciplines} \div \text{Outputs from UK in all disciplines}}$$

A2.2.ii Research quality was measured using the "outputs in top citation percentile" metric in SCIVAL. For our initial low-resolution audit (see above) we used the percentage of outputs in the top 5% of citations in a SCOPUS subject heading. For our more detailed analysis of our four capabilities, we used the more rigorous criterion of the percentage of outputs in the top 1% of citation in a SCOPUS subject heading. Since these metrics are percentages of total publications they are independent of scale, removing any need to calculate location quotients. In addition, all our citation data were field weighted, i.e. corrected for between-discipline differences. This normalisation allows direct comparison of citations across disciplines.

We typically present the citation data using spider plots that allow easy comparison between NWCA and comparators across disciplines. In the spider plots the area delimited by the component points visualises the integrated research strength across all the disciplines included in the plot. We have formalised this as a means to compare overall research quality across the disciplines included within a capability by explicitly calculating the area bounded by the citation data for the component disciplines. This was calculated as the sum of the areas of all the component "segments" of a spider plot. Each segment is an irregular triangle, so its area can be calculated by:

Area = ½ sin(360/N) x Citation datum1 x Citation datum2

Where Citation datum1 and Citation datum2 are the two citation data bounding the triangle and N is the number of segments in the spider plot (six in this audit).

In our detail audit of our four capabilities, we also used two additional SCIVAL metrics.

A2.2.iii Percentage of publications co-authored with colleagues from more than one country as a measure of the extent of international collaboration in the NWCA and comparators.

A2.2.iv Number of publications arising co-authored with colleagues from a non-academic (corporate) organisation as a measure of one aspect of academic-corporate collaboration in the NWCA and comparators.

Figure A5.1 SCOPUS Environmental Science main subject area and its component sub-disiplines.

Environmental Science
Ecological Modeling
Ecology
Environmental Chemistry
Environmental Engineering
Environmental Science (miscellaneous)
General Environmental Science
Global and Planetary Change
Health, Toxicology and Mutagenessis
Management, Monitoring, Policy and Law
Nature and Landscape Conversation
Pollution
Waste Management and Disposal
Water Science and Technology

We audited six secondary research areas for each capability, based on our previous experience of eco-innovative collaborations across the NWCA, as follows.

	CAPABILITY			
SCOPUS sub-disciplines	Environmental Industries, Technologies & Services	Future Energy Systems	Advanced Manufacturing, Chemicals and Materials	Cross-cutting Research and Innovation
	Agronomy & Crop Science	Transportation	Aerospace Engineering	Computers in Earth Science
	Food Science	Geography, Planning & Development	Automotive Engineering	Management Science & Operations Research
	Plant Science	Architecture	Materials Chemistry	Management of Technology and Innovation
	Environmental Engineering	Building and Construction	Ceramics and Composites	Multidisciplinary
	Waste Management & Disposal	Energy Engineering & Power Technology	Metals and Alloys	Statistics, Probability and Uncertainty
	Water Science & Technology	Renewable Energy, Sustainability & Environment	Polymers and Plastics	Strategy and Management

For this high-resolution audit of the research specialisations within the four capabilities of this audit, we initially compared NWCA with the UK and other nations or groups of nations, as above. However, we were conscious that analysis of these large or very large geographies might be more prone to exaggerating our relative strength due to the potential "dilution effect" of making comparison with very large number of institutions. For this reason, we adopted a more focused comparison against groups of universities or regions, as follows.

GROUP	Number of members	Description and website
AEARU	17	Leading research-oriented universities in East Asia (http://www.aearu.org/members.html)
California	N/A	Included as a region with a global reputation for innovation and using SCIVAL data for the state as a whole rather than just its universities (as is the case with the NWCA)
German U15	15	Coalition of fifteen major research-intensive and leading medical universities (https://www.german-u15.de/index.html)
Russell Group	24	Member universities are world-class, research-intensive universities. (http://russellgroup.ac.uk/about/our-universities/)
Allenvi	12	France's 'national alliance for environmental research" including agri-food, climate, and water with 12 founding and 16 associate members: (https://www.allenvi.fr/)