

Institution: Lancaster University (LU)
Unit of Assessment: Lancaster Environment Centre (LEC)

1 Unit context and structure, research and impact strategy

1.1 Introduction

Lancaster Environment Centre (LEC) has a mission to address critical environmental and social issues through world leading research and impact, spanning Earth Systems and Environmental Sciences (UoA7) domain, but overlapping with Geography and Environmental Studies (UoA14), and Agriculture, Food and Veterinary Science (UoA6). It brings together one of the world's largest groups of Environmental professionals on a single site. Academics and researchers work alongside colleagues from 20 different environmentally focussed businesses, the UK Centre for Ecology and Hydrology, and the Environment Agency, together totalling **400 environmental professionals and 180 PhD students**. We are a diverse and inclusive community that recruits and retains the best natural and social scientists, supported by an internationally facing, collegiate research culture. **Since REF2014, we have made significant strides towards our ten-year goal of becoming a top-five global Environment Centre**, with the following highlights:

- **102 papers, 4.3% of output (2014-20) in the top 1% published world-wide** (by field-weighted citations SciVal analysis 14/8/2020).
- **Research awards of £53,320,297 over the REF census period.**
- **Our Global Centre for Eco-innovation delivered a return on investment of £28 for every £1 invested, comparing favourably to the £8 to £1 ratio for Knowledge Transfer Partnerships** and has funded **32 Industry-led PhD studentships** in LEC.
- **One newly elected Fellow of the Royal Society, making two in total, one CBE for services to science, an international prize for research and innovation, two national prizes for impact and 15 personal research fellowships.**

Our interdisciplinary approach to global challenges is built on strong disciplinary foundations, set within 10 Research Groups, and a culture of research excellence. We believe that our collegial and supportive environment, with no internal administrative barriers to cross-disciplinary collaboration, creates the interdisciplinary approaches needed to analyse and understand environmental and related social challenges, and to promote research with genuinely sustainable impact.

1.2 Research structure and our approach to interdisciplinarity

Our strengthened management structure and emphasis on research excellence, rather than quantity, has delivered a year-on-year increase in the proportion of papers in the top 10% of publications by field weighted citation impact. This now exceeds that of world-leading institutions and the Russell Group of Universities (Figure 1). Essentially, **we have created a space for excellent disciplinary and interdisciplinary research to flourish** based on a set of collective community values that empower researchers rather than attempting to manage every action.

LEC's research structure has been developed to deliver interdisciplinary research and impact underpinned by disciplinary strength (Figure 2). The LEC Management Group (see section 2.1), chaired by the LEC Director, sets the goals for the department, with input from the LEC Associate Director Research (ADR), who also chairs the LEC Research Committee (LEC RC), and the Associate Director of the LEC Partnerships and Engagement team (ADPET), as well as bottom-up inputs from across the department. The LEC RC leads the development of the department's research goals and strategy, co-created with all staff at an annual/bi-annual away

day, and is responsible for the strategy's implementation. The LEC RC has representation from all academic staff and key professional services staff. It comprises: the ADR; Research Challenge and Group leaders (see below); the ADPET and the Research Development Officer. The ADR ensures integration with the Faculty, by representing LEC on the Faculty of Science and Technology (FST) research committee. In addition, LEC has an external advisory board to offer external insights and offer challenge and support.

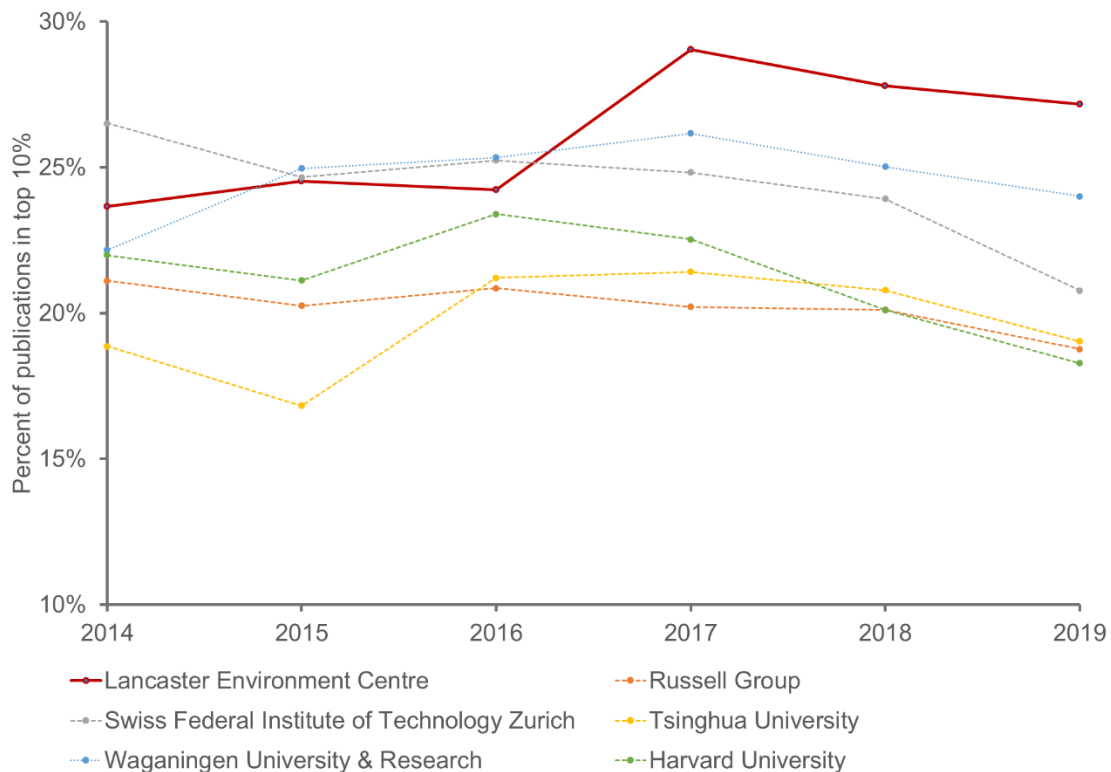


Figure 1. Analysis of publications in top 10% published according to Field-Weighted Citation Impact for Agricultural and Biological Sciences, Earth and Planetary Sciences and Environmental Science subject groups, benchmarked against world-leading institutions and the Russell Group of Universities (source SciVal 24/2/21).

Disciplinary strength and line management is achieved through our 10 Research Groups reflecting disciplinary/thematic areas of strength (Figure 2). The Groups have academics, post-docs and PhD students as members. LEC's Director and ADR line-manage a team of Professorial Group Leaders who each, in turn, manage a group of 6-10 academic staff. The Group Leaders mentor group members, carry out staff appraisals, and engender a supportive and positive group dynamic, including nurturing PhD students.

The Research Challenges (Box 1) require interdisciplinarity. Staff and students from disciplinary groups come together to discuss and develop research that addresses major environmental challenges and creates lasting impact. The Challenges are led by professors, who are charged with championing our internationally facing interdisciplinary work.

Further opportunities for interdisciplinary research and wider research collaboration are provided by the University Research Institutes (Figure 1 and Institutional Environment Statement). LEC's relationship with the Institutes is described in section 3.4.

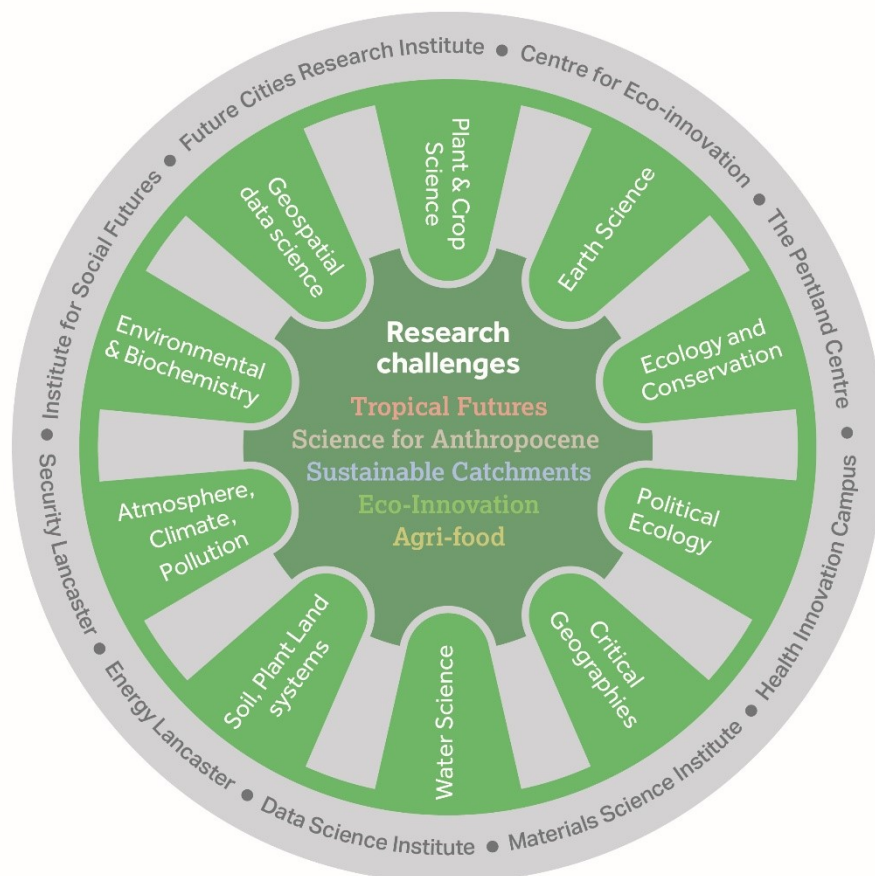


Figure 2. LEC structure diagram showing our interdisciplinary cross-cutting Research Challenges and Research Groups and the connections between them and linkages to University Research Centres and Institutes (outer ring).

Box 1 LEC Interdisciplinary Research Challenges

Tropical Futures develops new understanding of tropical environments and tackles the range of social and environmental challenges facing the tropics, drawing on diverse disciplinary strengths including ecology, political ecology, biogeochemistry, governance, and atmospheric and earth science. By setting **the global research agenda on the Future of Hyperdiverse Tropical Ecosystems** (see section 4.3), this challenge has made significant contributions to our understanding of: tropical forest and coral reef ecology; the provision of nutritious food; equitable futures for people of the tropics; and the threats to the environment posed by pollution. It has seen significant growth and development since REF2014: a new chair in Tropical Marine Science (GRAHAM) together with lecturers (HICKS, now a professor, and KEITH). The challenge has had significant success with personal research fellowships, including ERC (HICKS and SAYER), Royal Society (GRAHAM), Dorothy Hodgkin (PANGALA) and ESRC Future Leaders (L.PARRY and CHILDS). Research awards are significant at £6,436,208 **and its research quality recognised by two Phillip Leverhulme prizes.**

Box 1 LEC Interdisciplinary Research Challenges

Sustainable Catchments addresses the complexities that link upstream interventions (positive or negative) to the downstream consequences for people, business and environment. It brings together disciplines that include hydrology, biogeochemistry, soil science, crop science, ecology, eco-innovation and environmental governance, to tackle catchment management in the face of climatic and socio-political change. This has led to **significant multi-disciplinary research projects** funded by NERC, EPSRC and BBSRC, with research awards of £7,151,548, including the £1,232,264 NERC funded Natural Flood Management Quantification project. **The success of this research area is evidenced by: BEVEN being elected to a Fellowship of the Royal Society** for his leadership in hydrology; DAVIES awarded a five-year EPSRC fellowship and promoted to professor; and MILLS being awarded a 3-year NERC fellowship. Professor in Practice LAMB informed the Government's National Flood Resilience Review in 2016 and the Cabinet Office National Risk Assessment for Civil Emergencies in 2017. CHAPPELL, LAMB and HAYGARTH won the Defra competition for Innovation in Flood Modelling (2017).

Agri-food has an interdisciplinary agenda that aims to close the crop yield gap while using fewer resources and reducing environmental impacts. It also aims to deliver sustainable landscapes to provide food and fibre, reduce food waste and facilitate food justice. Building on a long tradition of plant science at Lancaster, **we have built an internationally significant photosynthesis group**, appointing M.PARRY and LONG (FRS) to chair and supporting them with three new appointments CARMO-SILVA, LUNDGREN and TOLEDO-ORTIZ. In addition, we appointed RUFINO to the N8 chair in Agricultural Systems. The challenge has generated over £20,530,037 in research awards, including **three Gates Foundation grants (£2,484,632), and significant publications, including those demonstrating a 15% improvement in photosynthetic efficiency.** This challenge led the Waitrose Collaborative Training Partnership (CTP), funded by BBSRC and supporting 18 PhD students, and Lancaster University's (LU) involvement in the £16,000,000 N8 Agrifood programme.

Eco-Innovation is intimately linked to the LEC-based Centre for Global Eco-Innovation (CGE) (see 1.3.4). The Eco-Innovation challenge is impact driven and aims to deliver innovation that reduces the environmental impact of products, processes and services, or improves the efficient and responsible use of resources. **The Centre has received sustained core funding from the European Regional Development Fund (ERDF), 2020-2023, to deliver clean and sustainable growth (£14,000,000).** The Centre's success has attracted the maximum Higher Education Innovation Fund (HEIF) grant awarded to the University for engagement activities (£4,100,000 in 2019). Since 2012, CGE has supported 52 PhDs across LU (32 in LEC), almost 30 Masters by Research at Lancaster and collaborated with 700+ SMEs. **The Centre led the Science and Innovation Audit on Clean and Sustainable Growth** (section 4.1.7). An independent audit forecasts it to have created £65,000,000 of gross value added (GVA) and £50,000,000 in net additional GVA by 2026. The Centre's success was recognised by winning the 2015 'Outstanding Knowledge Exchange and Commercialisation Initiative' category in the Impact Awards backed by all seven UK research councils, and the 'Research and Development' category in the 2015 Green Gown Awards.

Box 1 LEC Interdisciplinary Research Challenges

Science for the Anthropocene, our newest challenge, was co-created in 2019, emerging from an all staff away day. It will draw together work in social science and environmental and earth science to develop new approaches for dealing with fundamental instability and uncertainty regarding future socio-environmental conditions. **Early successes include a £1,250,000 Future Leaders Fellowship** in which WILLIS will explore how people respond to the challenge of achieving net-zero emissions.

1.3 Meeting our REF2014 aims

In REF2014, we set ourselves four key aims, geared towards exploiting the new multi-disciplinary research environment we had created and strengthening key areas of the department.

1.3.1 *Aim 1. Ongoing renewal and re-focusing of our appointments with a focus on society and the environment.*

We strengthened the society and environment area by creating two new groupings, **Political Ecology** and **Critical Geographies**, to sit alongside our natural science Research Groups with new appointments (see Figure 2 and section 2.3).

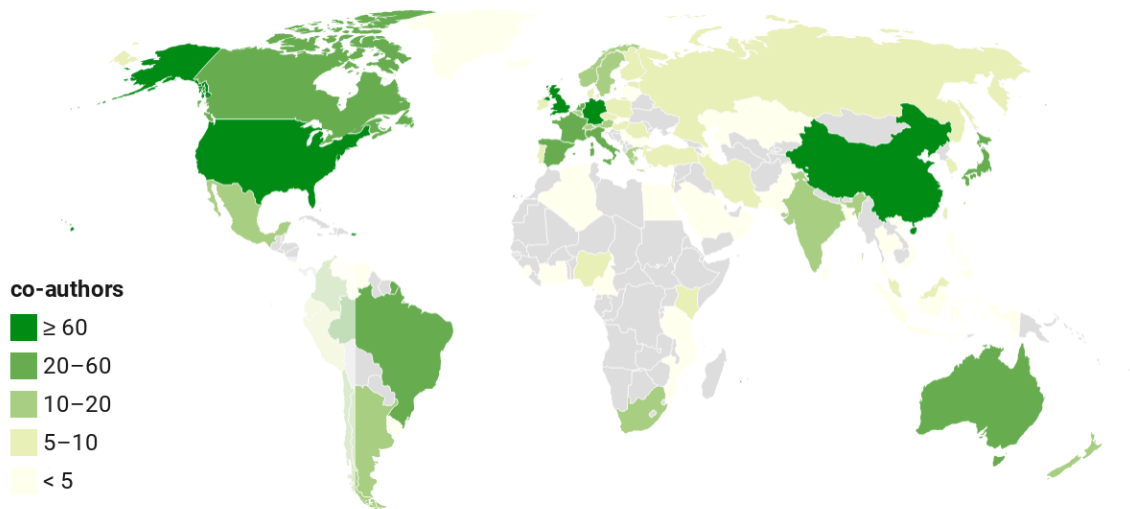
1.3.2 *Aim 2. We will extend the model of our 'integrating research centres (IRCs) to develop three new broad-based and directed 'research actions'*

As a department, we decided that contemporary environmental and societal issues require dynamic research challenges, rather than the more rigid centres and actions proposed in 2014. Therefore, we **introduced research challenges (Box 1) to capitalise on LEC's interdisciplinarity** (addressing Aim 1) and provide a vehicle for bringing together researchers from different disciplines to tackle some of the most pressing global issues.

1.3.3 *Aim 3. Grow and diversify our network of strategic partnerships nationally and internationally*

We have made great progress in expanding our national and international links. **We have deepened our engagement in China, Africa and Brazil** (sections 4.1.3, 4.1.4 and 4.1.5). In addition, **LEC now has 22 department level memoranda of understanding** with more than 20 international institutions, including in Switzerland, China, Mexico, and Kenya. LEC staff have jointly authored 2,855 papers with international authors from 1,205 institutions across 88 countries (Figure 3a) and a further 603 with national collaborators. **The proportion of our papers published with international co-authors has increased year-on-year during the REF period and now exceeds that of the Russell Group UK Universities and International comparator institutions** for the same subject groups (Figure 3b). Many of our international collaborations result from our strategic research partnerships (section 4.1). Nationally, we have developed strong and effective partnerships with CEH, Rothamsted and the British Geological Survey (sections 4.1.1 and 4.1.2) and with multiple industrial collaborators and NGOs via the Centre for Eco-Innovation (sections 1.3.4 and 4.1.6) and the Pentland Centre for Sustainability (section 4.1).

a



b

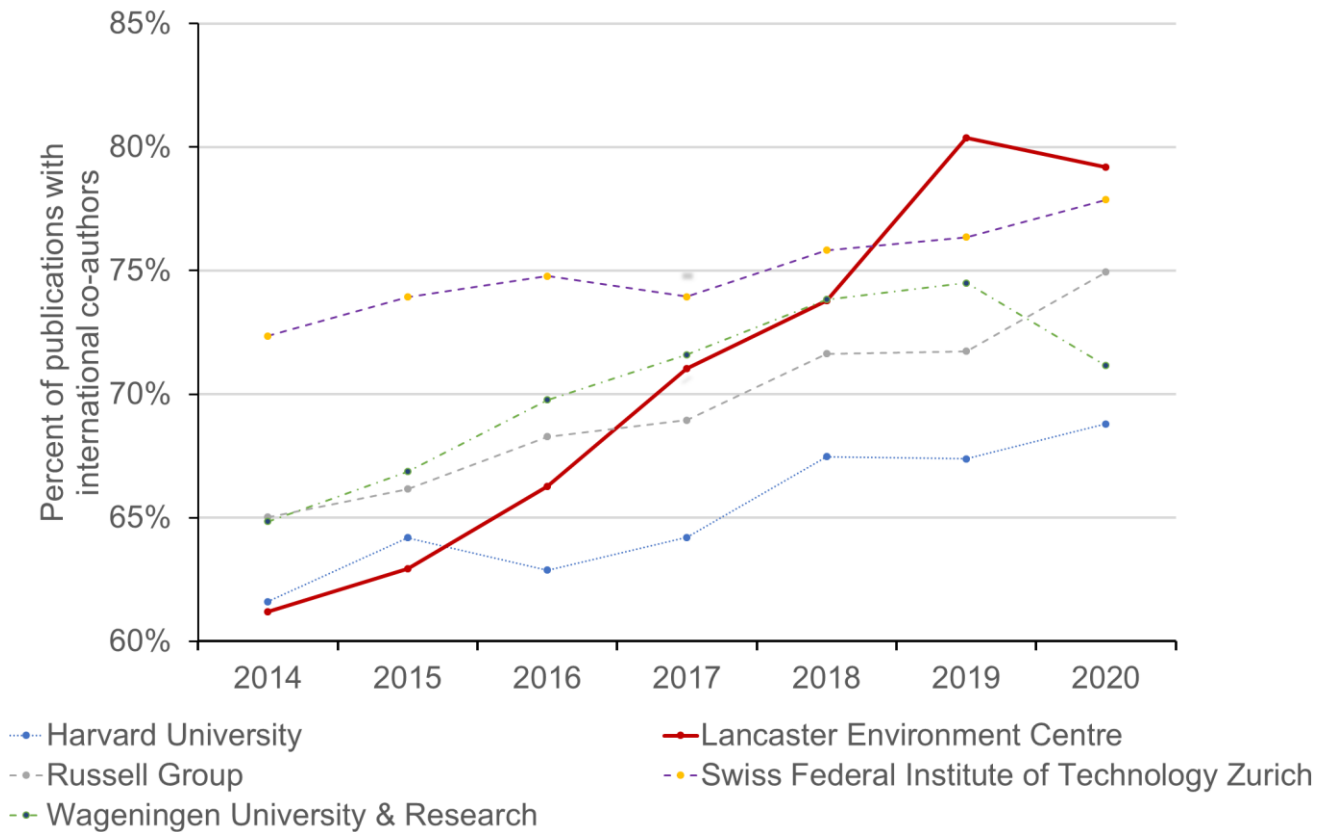


Figure 3a) Co-authorship of LEC papers by country (source SciVal all publications from LEC authors). b) Percent of publications with international co-authors benchmarked against UK Universities, Russell Group and International comparators. Data from SciVal limited to Agriculture and Biological Sciences, Earth and Planetary Sciences and Environmental Science. Search performed 31/7/20.

1.3.4 Aim 4. Developing the Centre for Global Eco-Innovation (CGE)

A key element in the research strategy defined in REF2014 was to build on, and internationalise, our CGE. In China, we helped to deliver the HEFCE-funded business-linked China Catalyst project, involving 88 postgraduate students working with our Chinese partners for 6 months. An independent assessment concluded that over 400 companies were engaged through the programme, with more than 60 developing partnerships in China, resulting in 38 agreements (MoUs, cooperation or commercial) between UK SMEs and Chinese partners. In 2016, **we established a satellite centre, ‘CGE Nigeria’, with the University of Benin**, which grew out of a side-event at COP21 in Paris, co-organised with the African Development Bank. CGE Nigeria is locating environmental SMEs within the University and using university research expertise to help businesses to develop low carbon products, services and processes, approaches we pioneered in LEC and China. The development of **CGE Nigeria was a key foundation for our £5,926,058 RECIRCULATE project** under Global Challenges Research Fund (GCRF) ‘Growing Research Capability’.

CGE became one of six University level Research Centres in 2019, in recognition of its success in engaging businesses regionally (700+) and internationally (100+) in the development of sustainable solutions, and of the potential for CGE to work with a broader set of partners and disciplines. Led by J.DAVIES from LEC, it draws together key University departments (Engineering, Physics, Chemistry, Management School, Computing) and several HEI partners, and is building a cross-sector, cross-disciplinary community of eco-innovators addressing key innovation challenges such as reaching net-zero carbon.

1.4 Approach to impact

Our approach to attaining impact is based on ten ‘actions’ **Error! Reference source not found.** These actions have helped us consolidate our reputation for creating impactful research, making us a preferred port-of-call for business and policy makers with high international visibility. Their relationship to our impact case studies can be seen in Table 1. Further auditable evidence of success is presented in section 4.1.6.



Figure 4. LEC’s ten actions supporting delivery of impact (see Table 1).

Table 1. Evidence of how our ten-actions for delivering impact Error! Reference source not found.) relate to the six impact case studies submitted to REF2021.

Case study	Approach to impact	Relationship to actions supporting impact
Leading the United Nations in a safe and effective biopesticide policy and practice to combat fall armyworm, an invasive global crop pest.	Builds on WILSON'S long-term international research partnerships and policy engagement towards improved pest control in sub-Saharan Africa.	1, 2, 3, 4, 6
Innovative sampling and attribution of industrial air pollution to resolve and reduce impacts from complex sources for improving health, compliance, industrial efficiency and public confidence.	LEC protected and licensed intellectual property arising from JONES, TIMMIS and WHYATT'S research, leading to a technology that benefits industry and health.	1, 3, 5
More crop per drop of water.	DODD and B.DAVIES's long-term international research and development combines fundamental research outputs with stakeholder input to deliver impact.	1, 2, 9
Strengthening environmental sustainability and social justice in the Brazilian Amazon: protecting secondary forest, guiding climate mitigation and expanding land rights.	Enhances resilience via policy and practice based on BARLOW and FRASER'S research, with impact delivered through close working links with international policy makers, practitioners and communities.	2, 4, 6
Practical carbon metrics to quantify and aid reductions in greenhouse gas emissions by corporations, to inform legislation and to engage the public.	Impact resulting from a long-term research collaboration between HEWITT, a co-located company and a Professor in Practice, BERNERS-LEE.	1, 4, 5, 6, 7, 10
Building a nation ready for, and resilient to, flooding: the impact of LU research on flood risk management to improve national resilience.	Impact facilitated by a collaborative relationship between BEVEN and a Professor in Practice, LAMB, working in the commercial sector.	1, 5, 9, 10

Our rapid growth in academic-business ties has helped us to carry out more impactful research. It has led to a strong increase in **co-publication with corporate co-authors** (Figure 5^{Error! Reference source not found.}), **now 11 times greater than in RAE2001 and 30% greater than in REF2014**. Both are much greater than the national increase and more than double the increase for the Russell Group since the 2001 RAE.

We detail further economic and policy impacts in sections 4.1.6 and 4.1.7.

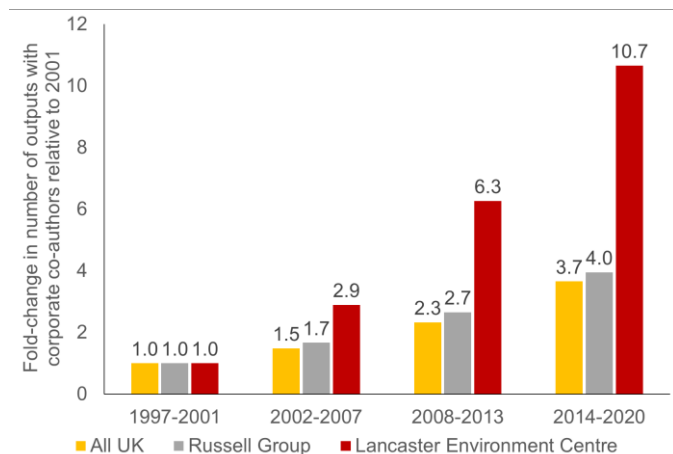


Figure 5. Fold-increase in the number of outputs with corporate co-authors as a multiple of those from the period 1997-2001, based on a SciVal analysis of Agronomic and Biological Sciences, Earth and Planetary Sciences and Environmental Sciences for LU, Russell Group and UK Universities (to 31/7/20).

1.5 Future strategic aims and goals for research and impact

LEC has seen important progress in research and impact in the last 8 years. Despite the Covid-19 pandemic, our community has remained active and resilient, and we are confident that our long-term future strategic plans are achievable. For the next REF period, we will continue building on our success by:

1) Advancing **world-leading disciplinary and interdisciplinary research** into the environment, **generating significant discoveries, innovative thinking and new research trajectories**. These will be evidenced by continued increases in the proportion of papers within the top 10% world-wide, continued growth in research income and the award of prestigious fellowships and prizes to our staff. Delivery will be enhanced by:

- **Supporting and nurturing research excellence through a research environment that celebrates diversity and inclusivity and allows everyone to excel**, evidenced by an Athena SWAN Silver award.
- **Providing world class facilities** such as (i) a unique state-of-the-art plant growth facility, comprising an automated, sensor-rich phenotyping centre with controlled environment chambers; and (ii) enhanced biogeochemistry capabilities via a major investment in our Environmental Science laboratories.
- **Enhancing vertical integration within Research Groups**, creating fora for discussion and knowledge exchange between undergraduates, post-graduates, post-doctoral and academic staff.
- **Using the ‘Research Challenges’ model to ensure state-of-the-art interdisciplinarity and innovation is directed to tackle some of the most important contemporary socio-environmental challenges.**

2) **Co-developing** solutions to the most pressing global environmental challenges with our international partners, industry and the third sector to deliver a significant and wide-reaching impact. We have made significant investments in both international and national partnerships (see section 4.3) and will maximise the impact from these. This will involve the following approaches:

- **For business, we will lead clean and sustainable innovation** through collaborative R&D. We expect to work with 500+ SMEs to create over 1,300 new jobs and generate an increase of £600-950,000,000 net GVA in the next 5 years.
- **In policy, we will seek to further our influence over UK government and international policy, building on our close ties with the Cabinet Office, the Climate Assemblies, the UN Food and Agriculture Organisation and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services** (see section 4.3.7).
- **For wider society, we will engage with public and civil society organisations in generating new knowledge, translating research findings and developing better public engagement in key sustainability and climate questions.** For example, we aim to develop a wide range of impact activities through our partnership with **the £85,000,000 Eden Project North development at Morecambe**, less than five miles from LEC. LU is a founding partner in this enterprise.

1.6 Open Research

In line with University policies and the UKRI concordat on open data, we have created a culture where research data is published alongside research outputs. 42 datasets have been deposited in the University data repository since 2015 and others with the NERC Data Centre amongst other repositories. Computer code is routinely archived using GitHub. The University's Research Data Management (RDM) service checks Data Management Plans including plans for curation. It validates datasets and metadata records, advises on licensing, metadata standards and repository choice. Engagement in data management has been promoted through LU's 'Data conversations,' focussed on planning, storing, transferring, archiving and sharing digital objects.

LEC staff have led major open access initiatives. In Political Ecology, BATTERBURY was a founder (2018) and steering committee member of the *Free Journal Network*, a group of 52 journals committed to the Fair Open Access model. QUINTON was a founder and is a current Executive Editor of *SOIL*, an open access not-for-profit European Geoscience Union journal and JAMES helped found the free-to-read journal *Volcanica*.

1.7 Research Integrity

LEC adheres to the university-wide research integrity and ethics procedures, implemented via the Faculty's Research Ethics Committee (FSTREC), which works under the University Research Ethics Committee. All research conducted by staff and students accords to the ethical standards set out in the University's Code of Practice, as written by the University Research Committee and approved by University Council. These standards have been regularly reviewed by the research council funding assurance visits and follow sector best practice. Doctoral projects and staff research involving human participants are approved by FSTREC. All applications are seen by the Head of Department before submission. Incoming applications are screened by the committee's Research Ethics Officer, before distribution to expert committee members. Most applications are reviewed twice: first by a committee member and then by Chair of FSTREC. Applications and revisions are dealt with swiftly, with most applications being processed in under four weeks. LEC has two members sitting on FSTREC.

2 People

2.1 Our culture

We embrace our diversity of disciplines and people and have created a supportive multidisciplinary research environment based on respect. This community-based approach is the foundation for everything we do, from enhancing research excellence and opportunity to promoting wellbeing and mitigating against mental health problems and supporting staff when these occur.

The success of this approach is validated by the results of the 2018 university-wide staff survey, run by Capita, in which 93% of LEC respondents thought that the department was well managed. In addition, LEC director, BARKER, won the 2019 University Staff Award for his 'inspiring, supportive and inclusive leadership.'

We want all our staff to fulfil their potential, regardless of (and striving to overcome barriers related to) their gender and sexual orientation, socio-economic background, ethnicity, disability, and stage of their career. We have supported this by collectively developing a shared set of department values (Figure 6).

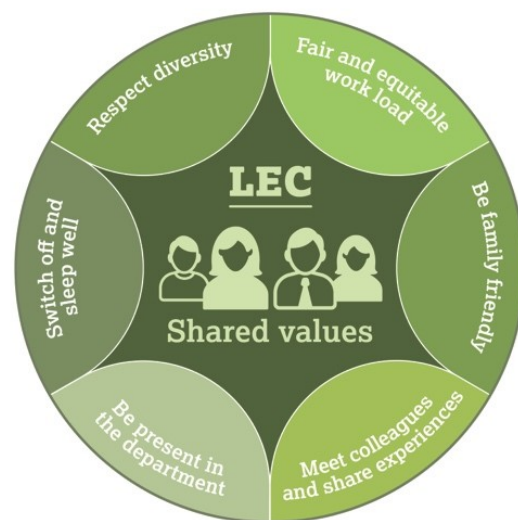


Figure 6. LEC shared values

We support diversity through our Equality Diversity and Inclusion Forum, which helps to coordinate, communicate and promote the department's efforts towards equality and inclusivity and is helping us work towards our goal of an Athena Swan Silver Award.

2.2 Staff development

In the 2017 staff survey, 85% of LEC female staff (80% male) felt 'strongly encouraged to participate in training'. Staff are effectively trained in relation to equality, diversity and inclusion (EDI), wellbeing and mental health, including compulsory EDI and interview training. Research-specific training includes writing retreats, writing more impactful papers, impact workshops, high-level statistics courses, as well as management courses and leadership development. Staff are encouraged to build their CVs by taking leadership roles within and outside the department.

LEC is fully committed to the Vitae Researcher Concordat, to which the University is a signatory. Departmental policies align with LU's People Strategy that sets out goals and priorities. LU aims to conduct excellent research, within an environment which nurtures and cultivates its staff, encouraging them to fulfil their career ambitions. **Since 2013, LEC has had a departmental concordat co-developed with researchers.**

Annual Performance and Development Reviews provide the chance **to review progress, identify any barriers, target support and look ahead in terms of research, teaching and academic leadership and engagement.** Group leaders ensure that these targets reflect both short-term and longer-term research objectives and career development. Outcomes are discussed with the LEC senior management team, who act on workload, promotions and sabbaticals.

Our promotion systems are transparent and accessible. In order to identify modest or reticent individuals, CVs are proactively sought and benchmarked. To further break down barriers, we run department workshops on 'Making Professor/Senior Lecturer/Lecturer' for all staff and specifically for those who undervalue their potential. Promotion cases always take reduced FTE into account and we highlight any career breaks. Outcomes are based on quality rather than volume.

2.3 Staffing and recruitment policy

Our strategy for appointments is based on recruiting the best researchers: (a) to maintain and enhance strength in core areas; (b) where there are opportunities for strengthening; and (c) to grow key areas allied to our objectives.

The department has appointed 27 new academic staff, including 19 Lecturers, 2 Readers, and 7 Professors in this REF period and lost three to retirement while seven have moved on.

Since REF2014 we have: enhanced our capability in Plant Science by appointing FRS LONG and M.PARRY as professors and CARMO-SILVA as lecturer; strengthened our Critical Geography and Political Ecology with new professors BATTERBURY and CLEAVER and four lecturers (see sections 1.3.1 and 1.3.2); targeted marine science as a key area for expansion, appointing GRAHAM to Professor, HICKS and KEITH to lecturers; created 6 Professors in Practice (PiP) posts (section 2.4) to help us deliver our impact agenda.

Our focus on recruiting excellent researchers is exemplified by the achievements of GRAHAM and HICKS (section 3.1) and the seven staff appointed in the REF period who have gone on to win personal fellowships, and the creation of indefinite contracts for four staff on five-year fellowships (2 Royal Society (PANGALA, ASHWORTH), 1 NERC (HOSSAINI), 1 Leverhulme (LUNDGREN)).

Overall LEC has 231 staff members of which 135 (51 post-doctoral researchers) are on research & teaching, and research only (RTR) contracts. There are 28 technicians, 25 administrators, 16 business facing staff and 11 journal staff. Of the RTR staff: 34% are female and 65% are male; 19% are international (excluding EU), 12% EU and 67% UK. 55% are under 45, with 83% being under 55 years old. Of the 75.85 FTE category A staff submitted in this REF, all are on indefinite contracts.

Sabbaticals (or Academic Research and Education Leave) are encouraged as they provide space for the development of significant outputs, impact and research proposals. All academic staff are eligible, and applications are invited two years in advance and the research case evaluated. **Since 2014, LEC has granted 27 individual sabbaticals totalling 24.3 FTE years.**

2.4 Recognition of, resourcing and support for, Impact

As part of our strategy for Impact (section 1.4) in 2007, we created a **dedicated in-house Partnerships and Engagement Team (PET)**. This has now grown to 18 staff that help LEC researchers to deliver knowledge exchange (KE) and impact from research. LEC staff have also been supported by the LU Impact Fund (£56,000), and Impact Acceleration Account (IAA) funding from EPSRC (£152,113), ESRC (£25,000), HEIF (£77,000) and GCRF (£45,000).

The University recognises engagement and impact as key promotion criteria (e.g. STEVENS to Professor 2020) **and through an annual awards process.** The PET was awarded the Dean's Award for Impact in 2018 and LU Impact Award in 2019. Individuals are also recognised: ARMSTRONG won the Dean's award for External Engagement and Impact in 2019 for her research with the solar industry.

In 2015, we were the first UK environment department to appoint Professors in Practice (PiPs) (Box 2) to actively bridge the gap between academia, industry, the third sector and policy. Using the model deployed by some UK business schools, PiPs support co-design and co-delivery of our research and impact (Table 1).

Box 2. LEC's Professors in practice

 <p>Rebecca Willis</p> <p>Was a member of the Scientific Advisory Committee of UKRI's Energy Programme and NERC Council. She is an Expert Lead for Climate Assembly UK, the Citizens' Assembly established by the UK Parliament, and was named in the 2020 Women's Hour power list.</p>	 <p>Rob Lamb</p> <p>Leads the JBA Trust, a charity linking academia, industry and the 3rd sector. He received an innovation award from the Royal Academy of Engineering for improving flood predictions.</p>	 <p>Mike Berners Lee</p> <p>Is CEO of Small World Consulting with its head office in LEC. He is an influential author and advises governments and corporations on carbon footprinting. He regularly contributes to TV and radio programmes.</p>
 <p>Johnathan Grey</p> <p>As Professor in Practice with the Wild Trout Trust, he is focussed on research to tackle issues affecting the sentinel species, the brown trout.</p>	 <p>Camilla Toulmin</p> <p>Former Director, and now Fellow, of the International Institute for Environment and Development. Her career has focused on policy research about agriculture, land, climate and livelihoods in Africa.</p>	 <p>Duncan McClaren</p> <p>Former Chief Executive of Friends of the Earth in Scotland (2003-11), he has acted as advisor to the UK Government's Energy Research Partnership. His research centres on the politics of novel technologies and climate change.</p>

2.5 Training and Supervision of PhD Students

LEC's Graduate School for the Environment manages our PGT, PGR and professional training in a cohesive manner that exposes students to a wide range of environmental thought, perspectives and experiences. It manages: LEC-led doctoral training programmes (Table 2); the LEC International PG initiatives in China, Africa and Brazil; and collaborative PG provision with the Graduate School's institutional partners - UKCEH and Rothamsted Research. Since the launch of our Graduate School, we have seen a significant uplift in PGR numbers, whilst maintaining our PhD completion rates close to 90% (Table 3).

LEC's approach to the recruitment of research students is open and inclusive, and is evidenced by the gender parity in PhD students (Table 2). All funded positions are externally advertised, and in adverts we explicitly encourage applications from underrepresented-backgrounds. LEC has a standardised application procedure: formal interviews with gender balanced panels are held for competitive studentships and prior to the offer of a place to self-funded or sponsored students.

Table 2. PhD student funding during the REF period split by funding source (note total (236) higher than REF period registrations (217) due to some multiple funding sources).

Funding source	Dates	Number
Envision DTP (NERC)	2014-	30
Waitrose CDT (BBSRC)	2017-	12
STARs CDT (NERC/BBSRC)	2015 -	11
Food security CDT(BBSRC)	2011-2015	7
North West Social Science DTP (ESRC)	2017-	10
Faculty studentships	2014-	59
Self-funded	2014-	25
Other sources		50
Centre for Global Eco-Innovation (ERDF)	2015-2020	32

Table 3. LEC research student registrations and completion rates for students completing in that academic year within 4-years

Date	2014-15	2015-16	2016-17	2017-18	2018-19
PGR registrations (Total)	30	26	38	34	31
PGR registrations (male)	15	18	17	17	13
PGR registrations (female)	15	8	21	17	18
PhD completion rate	83%	96%	90%	92%	89%

Studentships are funded from a variety of sources. We have used regional development funds to support 29 business-facing PhD studentships over the REF period, all with a financial contribution from the company partner. We have also been successful with Centre for Doctoral Training (CDT) and Doctoral Training Partnerships (DTP), taking the lead on four UKRI DTPs (STARs, ENVISION1, ENVISION2 and Waitrose) and participated in a further two (Table 2). Additionally, we have participated in three Marie Skłodowska-Curie Innovative Training Networks (NEMOH, IMPROVE, ITECC).

LEC directly funds 5-10 fully funded home/EU studentships each year. An additional 1-2 funded places per year are offered for international students from developing countries. We offer a fee waiver to 1-2 Chinese students per year to sustain our research relationships with China, and the Sew-Reap project funded 10 UK and EU students to spend up to 24 months in China. LU has supported the Tropical Futures challenge by funding 6 PhD studentships for African students and offering fee waivers to 10 Brazilian students on a split PhD with Lavras University.

All students are supported by at least two academic supervisors from within the university, a Director for Postgraduate Research Students, and a team of postgraduate administrators. Internal progress monitoring starts at 4-months and occurs every 6-months thereafter and consists of a written report on progress and plans, plus a record of supervision meetings and training. Students complete the report with supervisors and then supervisors provide feedback on progress. All reports are reviewed by independent subject-specific panels. Compliance with our internal system is 100%.

Training and support for PhD students is mapped against Vitae's Researcher Development Framework centred around four domains: (a) knowledge and intellectual abilities; (b) personal effectiveness; (c) research governance and organisation; and (d) engagement, influence and impact. There are over 50 courses available to research students, plus access to our partner's (Rothamsted Research and UKCEH) courses, and to our Masters modules. Our CDTs and DTPs offer their own bespoke training programmes and, wherever possible, these are made available for wider participation. All students are members of Lancaster's Graduate College, which provides additional wellbeing support and a social home. **To prepare students for life after their research degree we provide training** on career options inside and outside academia, and on effective CV preparation, complemented with 3-month placements offered in industry, government and 3rd sector organisations. Of the 114 PhD graduates who responded, all were in employment within six months of graduating (Table 4). Of these, the majority were post-doctoral researchers or in the private sector.

Table 4. First destination returns for 114 LEC PhD graduates who responded

Destination	Percent of graduates
Education (teaching, university administration)	11%
University lecturer	10%
NGO	4%
Post-doctoral research	36%
Private sector	31%
Public sector	9%

2.6 Equality, diversity and Inclusion (EDI)

LEC has held Athena SWAN Bronze since 2013 and is working towards a Silver Award.

Through our values and culture, (see Figure 6) we have made diversity and inclusion central to our research practices. The gender split for academics and researchers is 67% male and 33% female. We expect this to approach parity as older male staff retire and our EDI recruitment practices continue to bear fruit: 13 of the 19 new lecturers recruited in the REF period are female, of which 3 have since been promoted to Senior Lecturer, 1 to Reader and 2 to Professor. **The number of female professors has increased by 70%, via recruitment and promotion** and the number of male professors by 30%. Of the 9 additional female professors, 4 were recruited and 5 promoted.

We are proactive in providing support for funding applications on equality and diversity grounds. Two colleagues in receipt of Royal Society Dorothy Hodgkin Fellowships were supported by senior colleagues in the preparation of their applications and have adjusted working arrangements and financial support in line with their Fellowship applications.

Female grant success rates (53%) tend to be higher than their male counterparts (43%) and the average size of grant awarded is the same across genders. However, we have identified that as co-investigators, female academics tend to apply for proportionally fewer and smaller grants, and their success rates tend to be lower with smaller awards than their male counterparts.

We are addressing this through better mentoring by research group leaders (see 1.2) and peer-to-peer support.

We encourage and support all staff to **develop their leadership potential and pursue research-related leadership roles, and we have a number of examples when females have done so and been successful** (e.g. LU Pro-VC for Research and Enterprise (HEATHWAITE), REF2014 panel member (MAHER), and Director of the Global-Eco-Innovation Centre (J.DAVIES).

Through staff meetings and workshops, we have begun a process of **tackling inequalities facing BAME staff and students through our ‘Decolonising LEC’ initiative**, aimed at raising awareness and exploring how, as a department, we can remove barriers for BAME colleagues. LEC has also been actively involved in university-wide efforts to fight discriminatory behaviour and hate speech and is supporting LU’s aspiration to join the Race Equality Charter in April 2021.

Our approach to the rating of outputs **for the REF submission followed the University Code of Practice and was underpinned by the principles of transparency, consistency, accountability and inclusivity**. Only outputs were rated and no judgement on individuals was made as part of this process. LEC is submitting 94.4% of academic staff for assessment and currently only has 4.4 FTE on teaching and scholarship contracts. We have undertaken an initial equality impact assessment for REF equality profile – in terms of age, disability, gender and ethnicity – of staff who are Category A eligible, providing a baseline of eligible staff.

2.7 Supporting our Staff

2.7.1 *Structured support*

Recognising the importance of ad-hoc meetings and interactions with students for development of new ideas and staff well-being, pre-pandemic we encouraged staff to be in the office. Core meetings are not held at the start and end of the school day and our main Staff Meeting is repeated twice to enable broad participation. Internet conferencing platforms, now commonplace since the pandemic, have enabled staff who are off campus to join meetings and take part in research seminars.

The department has two rounds a year for travel funding for conferences, which are open to all staff.

2.7.2 *Supporting staff through the pandemic*

LEC has supported staff to keep in touch with colleagues and to continue their research. At the start of the initial lockdown, weekly staff briefings occurred via Microsoft teams. Covid risk assessment procedures were put in place to allow fieldwork and access to research labs and office space for research staff and research students.

2.7.3 *Wellbeing*

Wellbeing is at the heart of our values (see Figure 6 and section 2.6). **We were the first LU department to have a dedicated wellbeing role and the first to launch initiatives around staff mental health**. Those staff that require support are assisted on an individual basis and in line with LU’s commitments to the Disability Confident Scheme and the Stonewall Global Diversity Champions programme. We have procedures relating to bullying and harassment, with two internal contact points and a further contact point outside the department. We deal with any problems sensitively, bringing in support from professionals in occupational health where needed. Core staff have attended mental health first-aid training. LEC took the initiative in 2018 to set up a university-wide working group to enhance support for staff members who have dyslexia. All staff have access to the University wellbeing support through the Employee Assistance programme, which uses the Government’s five steps to wellbeing framework. Students can access pastoral support through the Graduate College advisor team and help with mental health issues through the Counselling and Mental Health Service.

We have developed department policies to provide support before, during, and after periods of extended leave. For those returning from parental leave this includes a place for resting and expressing milk and, for academic staff, conversations about reducing teaching commitments and encouragement to apply for the LU Maternity and Adoption Research Support funding (up to £10,000). **Parental leave entitlements also apply to research students.** We also support staff members with other caring responsibilities and well-being issues e.g. by reducing teaching.

2.7.4 Community

Since REF2014, **LEC has fostered a bottom-up researcher community, the Early Career Support Network (ECSN).** It provides career development support on funding, induction, career pathways, peer-to-peer support, work-life balance, and mentoring. The ECSN has grown from the first programme in 2015, which was organised by the department, with 12 mentoring pairs and training sessions delivered by LU's organisational education and development group, to the third researcher mentoring programme in 2018, organised by the ECSN, with 20 mentoring pairs linking senior and junior staff.

We strongly promote a culture of community and collegiality for our staff and research students. For example, we have a family-centred Christmas Party, a Diwali, wellbeing breakfasts (aimed at our PhD students), yoga, and staff social activities. LEC holds a winter research conference to celebrate research achievements. **In 2018, we introduced the 'LEC Good Colleague' scheme to celebrate and recognise contributions made to our day-to-day work life and our inclusive culture.** In 2020, the award went to an ECR (EVANS), who brought the department and UKCEH together through the Covid-19 crisis by organising weekly online quizzes with up to 197 participants.

3 Income, Infrastructure and facilities

3.1 Research funding

LEC's research income has grown by 38% from a mean of £5,510,000 per annum in the last REF period to £6,714,052 per annum for the current period. This equates to a mean per capita annual research income of £88,517 based on the 75.85FTE submitted in this REF. Success rates are 39% overall and, 32% for UKRI (2016-2020).

Our challenge based research structure (Box 1) has enhanced our ability to win major and prestigious funding awards has allowed us to carry out significant research, which has resulted in major scientific discoveries and advances in understanding (see **Table 5** for examples).

Table 5. Examples of grant funding leading to major scientific discoveries and advances in understanding.

PI	Funding	Funder	Contribution
GRAHAM	£1,876,332	Royal Society, Leverhulme Trust, Bertarelli Foundation and others	New discoveries concerning long-term outcomes for reefs severely disturbed by climatic disturbances and mass coral bleaching
HICKS	£1,427,953	ERC, Leverhulme Trust	New knowledge of relationships individuals and societies form with nature and how they shape people's social, environmental, and health outcomes
RUFINO	£1,585,402	GCRF, German Ministry for Economic Cooperation and Development, International Fund for Agricultural Development	Important strides forward in our understanding of the impacts of land-use change on biogeochemical cycling in Africa
LONG and M.PARRY	£2,484,632	Gates Foundation	LONG directs the \$45 million Realizing Increased Photosynthetic Efficiency project and is making world-leading advances in photosynthetic efficiency with enormous implications for global food security
BARLOW	£2,151,132	NERC	Significant advances in our understanding of the ecology of secondary tropical forests
OSTLE	£1,725,665	BBSRC, NERC	Fundamental understanding of the impacts of climate change on the soil carbon cycle
CARMO SILVA	£2,322,156	BBSRC, EU	Important advances in how environmental factors impact on crop photosynthetic efficiency
J.DAVIES	£1,421,986	EPSRC, BBSRC, NERC	Significant steps forward in our ability to model the control of nitrogen and phosphorus on the soil carbon cycle

3.2 Strategies for generating research income

Our strategy for securing research funding has seven elements:

- 1) We work to enhance grant writing quality through rigorous peer review of grant applications prior to submission and by early engagement with the University's Senior Research Development Managers and other technical and professional support staff.** LEC has a dedicated professional Research Development Officer who supports the financial and logistical aspects of grant preparation.

2) **We have increased support for new academic staff.** All are line-managed by their Professorial Group Leader and have an academic mentor within a broader culture of providing support for grant applications, papers and mock panel interviews. **Early career academics have reduced teaching loads that increase over a three-year probation period.** Start-up funds are provided to enable conference attendance and ensure no loss of research momentum during the transition to a full academic post. All new academic staff are allocated a PhD studentship within their first two years. **Our support for ECRs has increased the number of prestigious fellowships held by department members from three at the last REF to 15 during this REF period** (Table 6).

3) **The ADR, ADPET and HOD identify large grants that LEC can lead** and task key colleagues with developing bids. Our RECIRCULATE GCRF project (£5,926,058) exemplifies this approach. We collaborated with eight academics across Engineering, Faculty of Health and Medicine and the Management School to develop a successful proposal led by LEC.

4) We have **sought to increase the diversity of LEC's grant income to make us more resilient** to changes in funding patterns. **We received grants from 469 different funders during the REF period.** Our income is still dominated by UKRI, but even here, we are not reliant on one Research Council (Figure 7). European Union research funding is a case in point: it has been an important source of funding for us (6.8%), but we are not reliant on it and expect to weather the post-Brexit changes to the funding landscape.

Table 6. Funders of LEC's 15 personal research fellowships

Funder	Number of fellowships
Royal Society Dorothy Hodgkin	2
EPSRC	1
ERC	2
ESRC	2
Leverhulme	1
NERC	3
Royal Society	2
UKRI Future leaders	2

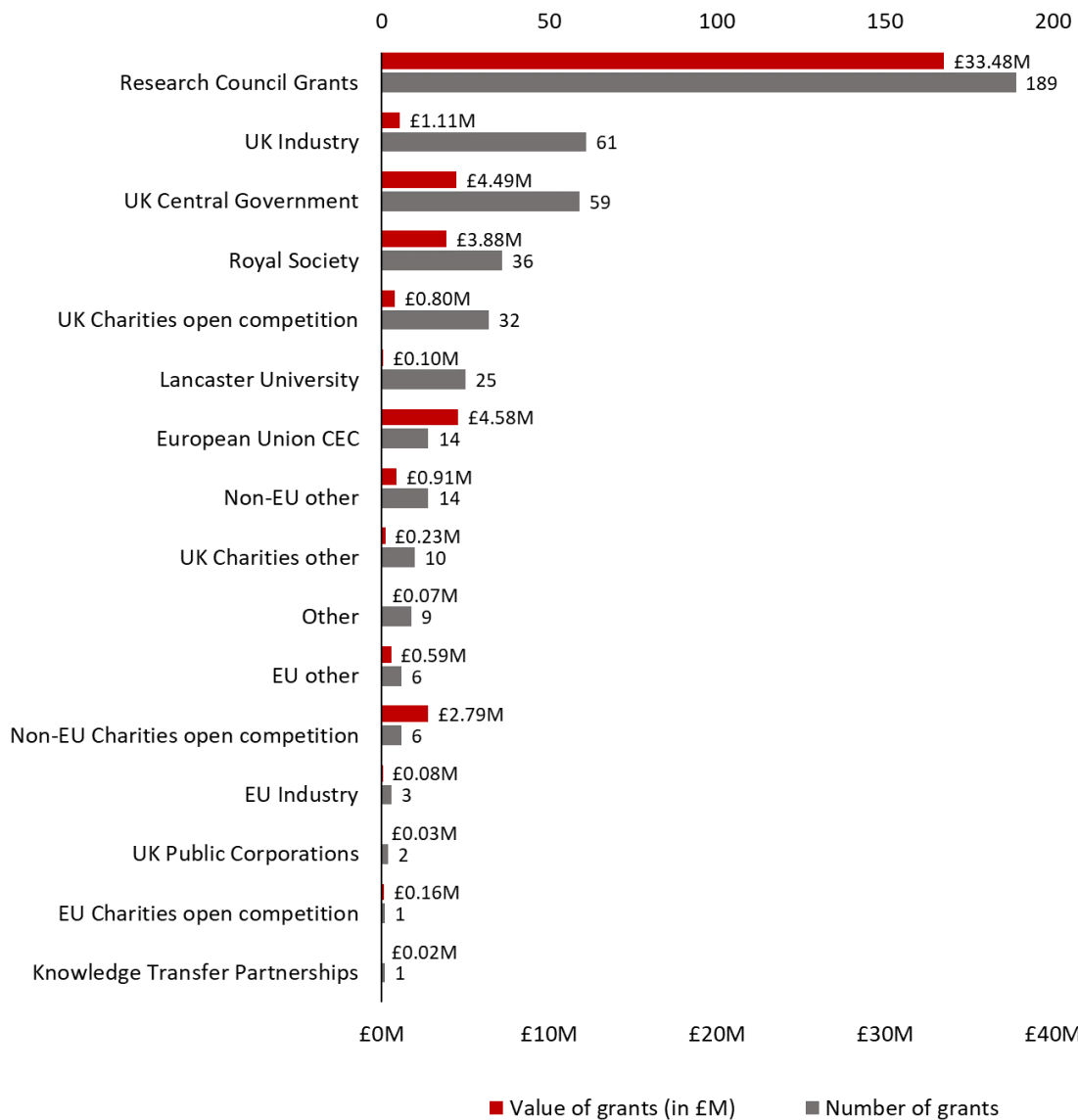


Figure 7. Funders of 412 grants (2014-2020) by grant value and number

- 5) We stimulate and facilitate exchanges between academia and business, industry or public or third sector bodies (see section 2.4).
- 6) We are generating more activity from/with existing National and International partnerships.

Internationally, our partnerships in Brazil, led by BARLOW, have generated a series of publications **shining new light on the management of forest and wildlife in Amazonia**. Partnerships in China (DODD, OSTLE, ZHANG, HEWITT, WILD) have produced significant research outputs concerning air quality and plant responses to drought and **the commercialisation of water quality sensors developed in LEC with the establishment of a Chinese manufacturing facility (ZHANG)**. In the Pacific Rim and Indian Ocean countries, our Tropical Futures Challenge has led to significant outputs pertinent to the future of coral reefs and the people who depend upon them (see Box 1).

We have focussed on generating income where we already have strong partnerships in Africa, Brazil and China (see sections 4.1.3, 4.1.4 and 4.1.5) and on the development of new partnerships with international research centres e.g. Centre for International Forestry Research (CIFOR) and the Centre for Maize Improvement (CIMMYT). **The success of this approach is evidenced by considerable growth in our international research portfolio since REF2014, resulting in publications with co-authors from 89 countries**, particularly in China, Brazil and Africa, generating many high impact research publications. We have taken full advantage of the GCRF, leading a £7,200,000 (£5,926,058 to LEC) capacity-building grant, and winning an additional eight grants with a value of £3,330,773.

Nationally, outside of the University sector, we have built on our strong relationships with UKCEH (see 4.1.1) and Rothamsted Research (see section 4.1.2), generating 10 grants with UKCEH (£1,616,438) and 7 with Rothamsted (£564,734).

- 7) **Our participation in LU Research Institutes and Centres has been a significant success.** We lead the action on Environmental Data Science in the Data Science Institute and in 2019, **together with UKCEH, we launched the Centre of Excellence in Environmental Data Science (CEEDS)**, with joint directors from LEC and UKCEH, a new Reader (MCMILLAN) and lecturer (ZHANG). By working more closely with scientists from cognate LU groups in Maths, Statistics, and Computing, we have seen significant new grant activity, including the Data Science of the Natural Environment project, **a £3,200,000 EPSRC project on environmental data science**. LEC also plays a key role in 'Energy Lancaster', (ARMSTRONG is the deputy director and GORMALLY is the Energy and Society lead). This has helped better position LEC researchers in the energy research landscape with successes including two prestigious fellowships (UKRI Future Leaders & NERC Industrial Innovation) and inclusion in three key national networks (EnergyREV within the Prospering from the Energy Revolution Industrial Strategy Challenge Fund; the UK Energy Research Centre; and the Supergen Energy Storage Network).

3.3 Research facilities and organisational infrastructure supporting research and impact

LEC's purpose-built 12,730m² building (Figure 8a) houses all staff, laboratories, partner companies and UKCEH Lancaster on a single site. The laboratories range from general research support - such as our water quality laboratories - which serve a range of staff, to specialised facilities (Box 3). To enhance opportunities for impact we have 20 co-located Environmental businesses within the LEC building (Figure 8a) with 78 employees. **Resident companies have access to our laboratories and equipment, resulting in impactful research collaborations with a value in excess of £3,000,000**, for example on developing fertilisers from anaerobic digestates in collaboration with Stopford Projects (NERC funded £669,554).

a



b

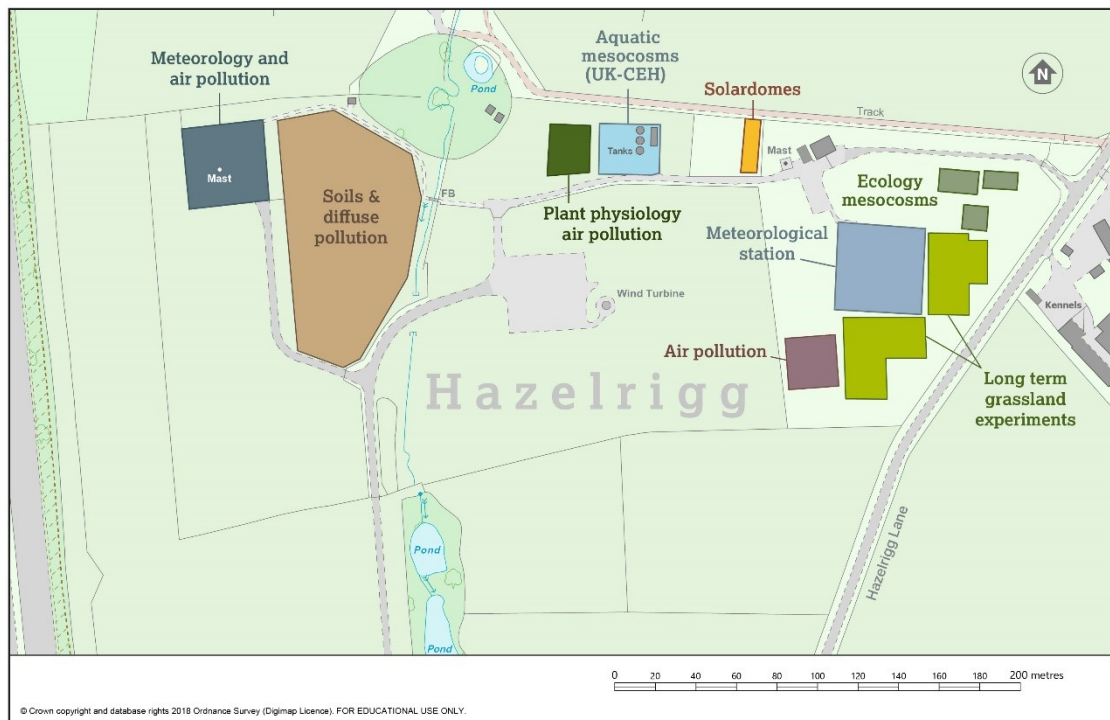


Figure 8a. Aerial image of part of the Lancaster campus to highlight LEC. LEC is spread over three connected buildings, four floors and incorporates the UKCEH site. It occupies the largest footprint of any department on the campus. b) LEC’s field station at Hazelrigg, 2 km from campus, with main thematic research areas highlighted.

Box 3. Specialist research facilities

Our **Subsurface Fluid Isotope Geochemistry Laboratory** (REF period investment >£600,000) is **the only lab in the UK with magnetic sector noble gas instrumentation and a dual laser quantum cascade laser clumped methane monitor**, providing a high sensitivity analysis of noble gases and methane isotopologues in a range of environmental sample types. These have **made the tracing of crustal fluids from source to sink possible (ZHENG)**. This laboratory has been funded by research councils and industrial partners (e.g. PetroChina).

LEC has excellent **laboratories for environmental organic chemistry research**. Equipment includes time-of-flight, tandem and high-resolution mass spectrometry, with bespoke field-deployable apparatus including proton transfer reaction mass spectrometry. This has yielded notable discoveries including **the first measured fluxes of sesquiterpenes from tropical Amazonian soils (ASHWORTH)** and evidence **that the official air pollution inventory for Beijing underestimates the emissions of reactive volatile organic compounds (HEWITT)**, which was supported by three NERC grants totally £513,026. Our **stable isotope facility (joint with UKCEH)** includes two Elementar Vario elemental analysers C, H, N, O and S, and a multiflow analyser for determination of C and O isotopes. All analysers are coupled to Isoprime 100 continuous flow isotope ratio mass spectrometers, enabling state-of-art analytical precision. **The application of a unique headspace analysis technique led to the first direct isotopic evidence of biogenic methane emissions from beneath a temperate glacier (WYNN, BARKER, OSTLE, TUFFEN, ZHOU)**, a hitherto unknown source of methane to the global atmosphere.

The Photosynthesis suite has been key to delivering fundamental advances in our knowledge of photosynthesis, for example the finding that slow induction of photosynthesis on shade to sun transitions may cost at least 21% of productivity in crop plants (LONG, M.PARRY, CARMO-SILVA). It includes glasshouse modules and eight high-specification growth chambers, **allowing the study of natural variation in large diversity sets and transgenic plants** under a range of controlled environments. **With support from the Gates Foundation (£2,484,632), the lab has developed a unique system to enable high throughput screening of leaf material during transitions from low to high light (photosynthetic induction)**.

The Soils and Ecosystem Ecology Research Facility has delivered **major new insights into the greenhouse gas exchange between soils and the atmosphere (OSTLE) the impact of biodiversity on soil functioning (OSTLE, QUINTON, STEVENS) and the development of novel fertilizers (SEMPLE)**. It has been supported by **grants totalling £8,166,325**. The main laboratory has instrumentation to enable detailed investigations into plant-soil interactions, soil and ecosystem biogeochemistry, macronutrient cycles and greenhouse gas emissions. Seven satellite labs allow soil preparation, soil enzyme assays, C-14 tracer studies, GC-FID and GC-MS measurements, CT scanning, rainfall simulation and separate, dedicated environments for research into digestate and amended soils.

LEC's **Environmental Magnetism & Palaeomagnetism Laboratory** has enabled **ground-breaking research on the presence of metal-bearing air pollution nanoparticles lodged in the human brain and heart (MAHER)**. A £377,000 NERC Strategic Environmental Science Capital grant supported purchase of a 2G RAPID cryogenic magnetometry system (**unique among the three UK RAPID systems**), allowing magnetic and palaeomagnetic analyses of environmental samples (rocks, soils, sediments, airborne particles) and also of human tissues (brain, heart).

Hazelrigg Environmental Research field station has provided the platform for **major findings on the impact of nitrogen enrichment on plant biodiversity (STEVENS) and of biodiversity on soil processes (OSTLE, QUINTON), as well as new insights into trace organic air pollution (JONES, SWEETMAN)**. The 6-hectare site (Figure 8b) has a number of long-term ecological experiments: a field laboratory equipped with high speed internet; a full Met Office climatological station with sonic anemometers for surface-atmosphere flux research (HEWITT) and a 3-axis fluxgate magnetometer as part of the Sub-Auroral Magnetometer Network (SAMNET); and glasshouses and air quality monitoring.

In 2018, together with UKCEH, we created The Atrium, **an accessible and disability-friendly area, that serves as an open meeting and social space**. It is accessible to all University, UKCEH and co-located business staff and students, increasing opportunities for informal networking (LU investment £900,000, NERC contribution £300,000, Figure 9). The space hosts our annual PGR poster sessions, with over 150 posters, as well as international meetings and outreach activities.



Figure 9 LEC Atrium

All staff and research students are provided with desktop computers and computing in the department, which is supported by the University's Information Systems Service, with one FTE permanently based in LEC. **We benefit from £1,750,000 University investment in Secure Data Science Infrastructure**. For computational research that requires high performance and high throughput computing, LEC utilises Lancaster's **High-End Computing Cluster**. This combined facility offers 10,000 CPU cores, 49TB aggregate of memory, 230TB of high-performance filestore, and 4PB of medium performance filestore.

The Library not only provides access to literature but has underpinned our approach to open research (see 1.6.) and data management. It provides research intelligence, advice on publication data, citations analysis and altmetrics (see also University Environment Statement).

3.4 Evidence of cross-HEI shared or collaborative use of research infrastructure

Here we pick out four exemplars of our collaborative approach to the use of research infrastructure

- **We operate a stable isotope facility with UKCEH**, where we share expertise and resources to deliver high-quality isotopic data and pioneer novel techniques (see Box 3).
- **We developed shared research laboratories for biogeochemical research with two Chinese Academy of Science institutes, the Guangzhou Institute of Geochemistry (GIG-CAS) and the Institute of Urban Environment (IUE-CAS) in Xiamen, and with the South China Agricultural University (SCAU) in Guangzhou**. These partnerships have supported the major SEWREAP project and delivered numerous joint publications in environmental organic chemistry (JONES, SWEETMAN). GIG-CAS has provided world-leading mass spectrometry equipment at no cost to facilitate our air quality research in Beijing (HEWITT).
- Together with Durham and Newcastle Universities, we operated the Defra 'Demonstration Test Catchment' platform in Cumbria (2009-2018, Phase II and III investment £587,427). It provided **high-resolution data on macronutrient losses from agricultural catchments** and led to significant findings on the **impact of climate change on diffuse pollution and the implications for mitigation strategies** (HAYGARTH, BARKER).

- **In 2019, together with UKCEH, we launched the Centre of Excellence in Environmental Data Science (CEEDS)**, with joint directors from LEC and UKCEH and drawing in scientists from cognate groups in Maths, Statistics and Computing in LU. CEEDS operates across a range of scientific areas (air, land/soil, water/ice and biodiversity), representing the breadth of environmental science across LU and UKCEH.

LEC staff also make use of other major research facilities. For example they:

- Regularly use the **NERC-STFC Jasmin super data cluster cloud computing facility**. This has underpinned numerous grants and PhD studentships, including the £2,656,400 EPSRC-funded Data Science of the Natural Environment project, which has delivered, amongst other things, a new statistically robust method for combining large scale atmospheric models (YOUNG).
- Access the **Genetically Modified Crop field facility at Rothamsted Research** for work with its International Wheat Yield Improvement grant and use Rothamsted's wheat transformation facility to field test transgenic wheat lines. These have delivered important new findings on the regulation of Rubisco activity (M.PARRY, CARMO-SILVA).
- Work closely with the **NERC Isotope Geoscience Laboratory and the NERC labs at Scottish Universities Environmental Research Centre** for analysis of soil, sediment and rock samples. This has led to new insights into the evolution of mountain belts, Antarctica and the River Nile (NAJMAN) and the world's first isotopically derived soil formation rates for agricultural soils (QUINTON, DAVIES).

4 Collaboration and contribution to the research base

4.1 Research collaborations, networks and partnerships

Collaboration is central to our approach (see section 3.2). Here we highlight our **most significant research partnerships**.

4.1.1 *Research partnership with the UK Centre for Ecology and Hydrology*

Nationally, UKCEH is one of our primary strategic partners. With over 100 staff on site at Lancaster, UKCEH makes a significant contribution to the LEC research environment. Since 2014, we have had shared posts (SWEETMAN, LI, ZHANG, WANG) and secondments (HEATHWAITE, JONES). UKCEH are a major partner in our Graduate School for the Environment, and partners on DTPs. UKCEH work closely with us internationally, especially in China. We created CEEDS, and share an isotope facility including coordinated equipment purchases and infrastructure (section 3.4). This has led to significant scientific discoveries, and significant joint grant activity (10 grants, £1,616,438).

4.1.2 *Research Partnership with Rothamsted Research*

We selected Rothamsted Research as a strategic partner because it is a world-leading research centre with a long history of ground-breaking discoveries in agricultural science. They are a major partner in our Graduate School for the Environment and STARS CDT. Rothamsted works closely with us in our development of SINO-UK research relationships (see section 4.1.4), where we have received support from the Foreign and Commonwealth Office, STFC and NERC (JONES, OSTLE, SWEETMAN, ATKINSON) to support research and network development. They are key partners for our Plant and Crop Sciences, and Soil and Land Systems Groups, providing access to trials and field sites.

4.1.3 *Research & Innovation Partnerships across Africa*

Over the last 5 years, LEC has increased its research and engagement footprint in West Africa, mainly in Ghana and Nigeria. **Our LU-Ghana campus offers a hub at which we hold research workshops involving LEC researchers and African partners from Ghana and other African countries.** Another significant strategic partnership is with the University of Benin in Nigeria, with whom we have established a West African hub for CGE Nigeria. This was recognised in 2016 with an award of £5,926,058 from GCRF, focused on building research and innovation capability in research organisations in Africa.

LEC has also increased **research activities in East Africa**, by forming partnerships with local universities and the Consortium of Agricultural Research Centres (CGIAR) to deliver transformative research and capacity building to conserve natural capital. This research has been supported by funding from CGIAR, the German Science Foundation and GCRF (total £2,112,000) and aims to provide clear evidence and practical metrics on how to protect and restore fragile environments.

4.1.4 *Research & Innovation Partnerships in Guangzhou, China*

In addition to our work with the China Catalyst project (see section 1.3.4) **our most mature partnerships in China are in Beijing with the Chinese Research Academy of Environmental Sciences (CRAES), the applied research institute of the Chinese Ministry of Ecology and Environment.** We have led and influenced the research agenda and development of China's **chemicals management and pollution research with CRAES** (JONES, SWEETMAN) and co-hosted international research meetings organised with CRAES and UKCEH. In southern China, we partner with two Chinese Academy of Science institutes: Guangzhou Institute of Geochemistry (GIG-CAS) in Guangzhou and the Institute of Urban Environment in Xiamen. GIG-CAS has world leading and unique facilities for environmental organic geochemistry and air quality research, which we freely access (JONES, ZHENG, ZHANG, SWEETAN, HEWITT). We have developed

tripartite research links with GIG-CAS and the South China Agricultural University (SCAU) in Guangzhou, with shared research laboratories.

4.1.5 *Research and Innovation Partnerships in Brazil*

LEC has a **mature research partnership with Brazilian institutions**. We have co-developed research with the Federal University of Lavras in Brazil, focusing on various aspects of tropical and agri-food research. **The partnership has resulted in a joint PhD programme with 14 joint PhD students who have spent time in the UK and Brazil**. In 2016, it was the base for a **joint NERC-funded advanced course on tropical soils for 30 UK and Brazilian PhD students**. BARLOW, L.PARRY and FRASER have all held visiting positions at research institutions and universities in the Brazilian Amazon and have engaged with a broad range of practitioners and policy makers, including Federal prosecutors, health agencies and environmental secretariats. These partnerships have resulted in major research findings and have had significant traction in influencing Brazilian forest protection legislation that is featured as one of our impact case studies (Table 1).

4.1.6 *Supporting sustainable economic growth*

CGE has played a significant role (~£11m of the £28m total awarded) in the performance of Lancaster's ERDF project portfolio in the 2014-20 programme. An independent review of the first phase of CGE's work with **regional SMEs** forecast that **by 2026 it will have created £65,000,000 of gross value added (GVA)** and £50,000,000 in net additional GVA. The review showed that in terms of efficiency, CGE outperformed the regional benchmark for net additional jobs identified in the review of Regional Development Agency spending, at £20,922 per new job compared with the regional benchmark of £37,600. In terms of **return on investment** an independent economic evaluation in 2019 calculated **a return on investment of £28 for every pound invested** which compares very positively with the £8 of net additional GVA is generated for every £1 of Knowledge Transfer Partnership grant funding invested.

To help lead the sustainability agenda on the global stage we have a 50% stake in **The Pentland Centre for Sustainability in Business**, alongside the LU Management School. The Centre is funded by the Rubin Foundation Charitable Trust, the charitable arm of Pentland Group and was established with a new chair (WHITEMAN) and a lecturer (DAVIES, now Professor) in 2015. It has generated £5,500,000 of research income and worked alongside the World Business Council for Sustainable Development (WBCSD), a CEO-led, global association of some 200 international companies on sustainable soil use, and with Nestlé to help it meet its obligations within the Taskforce for Climate-related Financial Disclosures (TCFD). Research with **Energy Lancaster and the solar power industry** has led to the development of a decision support tool that is revolutionising the solar industry's approach to environmental management (ARMSTRONG). Additionally, WALKER co-directed **the UKRI funded DEMAND Centre** (2013-2019, £7,200,000) with expertise from across three LU faculties and nine external partners, into a 6-year programme of research. Impacts included working with EDF Energy to generate new analyses of temporal patterns of energy demand to inform their strategic planning and approach to smart metering.

4.1.7 *Policy*

Our impact on policy is exemplified in the following examples:

- **Global policy implementation for the protection of stratospheric ozone.** PAUL was appointed as co-chair of the Environmental Effects Assessment Panel of the Montreal Protocol for the Protection of the Stratospheric Ozone layer, building on his collaborative and multidisciplinary research into the impacts of ultraviolet-B radiation on terrestrial ecosystems, environmental microbiology and chemistry, and biomedicine. Through a series of 'non-technical' articles commissioned by UNEP's OzonAction unit, he has ensured that those implementing ozone protection 'on the ground', especially in developing countries, are fully informed of the wider benefits of the Montreal Protocol.

- **Fall armyworm can affect millions of hectares, causing massive losses to staple grain crops and damaging livestock production.** WILSON's research into the pest led to him being the only non-African to join a crisis meeting in Zimbabwe in 2017 that recommended the development of farmer education and the development of integrated pest management (IPM) strategies. He was subsequently invited to chair the Food and Agriculture Organisation (FAO) committee on biopesticides. This committee has organized and informed FAO's Integrated Pest Management Strategy, which has now been implemented in 45 countries and benefited tens of thousands of farms.
- **Informing industrial strategy.** Another powerful expression of cooperation across our network of regional partners has been the development of a Science & Innovation Audit (SIA) on Clean and Sustainable growth. Led by LEC, in partnership with ten universities, over 40 large businesses and 100s of SMEs, the audit was published by BEIS in March 2019. The starting hypothesis of the SIA was that the region '*...will realise its potential as a global market leader for low-carbon and sustainable products, processes and services through greater networking, integration and connectivity across the whole of the region's research base and business community....*'. This was informed directly by our experience with CGE: the SIA's evidence and recommendations effectively define the Centre's growth trajectory and identify new opportunities to widen and deepen what we have already achieved within LU and across our network of collaborators.
- **Tropical Futures and marine policy.** Since 2002, research in the Chagos Archipelago has mostly focused on the coral reef fish communities (GRAHAM), their unique biomass, and stability in the face of disturbance. This has informed the policy on impact of rats on coral ecology and led to rat eradication becoming one of the mainstays of the British Government's Conservation Management Plan for the British Indian Ocean Territory. This research has also resulted in the Australian government adopting metrics arising from the work into a long-term monitoring programme of the Great Barrier Reef.

4.2 Interaction and engagement with diverse communities and publics

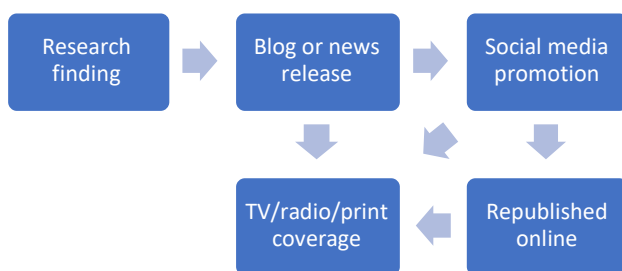
LEC sees outreach to diverse communities and the public as a key part of our efforts to foster wider participation in science. Activities are co-ordinated by its Outreach and Engagement committee and include:

- **Science Hunters, a project involving the Minecraft computer game,** developed by STEVENS in 2015 **to reach students with barriers to accessing higher education.** These barriers include but are not limited to: disability; low family income; the first student in a family to apply to University; being of Black, Asian and Minority Ethnic background; and being in care/a care leaver. Extensive work is also undertaken with children with Autism Spectrum Disorder (ASD) and Special Educational Needs. **More than 14,000 children have been engaged with our research** by creating Minecraft clubs creating Minecraft 'worlds' linked to research, including GRAHAM's world on coral reef conservation and BARLOW's world on fires in tropical forests. **In 2019 alone, we ran sessions for 3968 children in 63 schools** across the UK. The work has resulted in six peer-reviewed papers and received external funding, for example from NERC and the Linnaean Society.
- Led by SURRIDGE, LEC has designed and delivered a series of **Outreach and Engagement activities based on research within the department.** Combining on-campus and remote activities that predominantly target Year 9 to Year 13 students, this work supports the University's Widening Participation strategy and seeks to increase access to higher education for under-represented students. These activities include **Environment Summer Schools** (e.g. drawing on research of GRAHAM and LUNDGREN); **STEM Taster Days** (e.g. drawing on research of JAMES and TUFFEN); and **Research in a Box** activities (drawing on collaboration between LEC and UK-CEH and on research from WHITTLE). To date, these activities have engaged 55 schools and have led to emerging collaborations between LEC and learned societies, including the Royal Geographical Society.

- The **Sex & Bugs & Rock ‘n Roll roadshow** has been a regular feature of Glastonbury Festival (2015-) and at other public events around the UK (2013-), engaging over 20,000 visitors in our ecological research, including forest ecosystem interactions (SAYER), dung beetle ecosystem function (MENEDEZ, BARLOW) pollinator diversity and extinction risk (MENEDEZ, WILBY, WILSON).

We recognise that translating our academic findings into more accessible forms and promoting these to both traditional and emerging media is critical to impact and agenda setting. In addition to the University press office, **we employ a BAFTA winning journalist, to ‘hunt out’ and write stories about our research.** Our media ‘process’ is outlined in Figure 10.

This process has led to experts from LEC receiving extensive coverage for their research findings,



giving **more than 65 TV interviews from 22% of staff** with an estimated reach of 172,533,000 and **at least 190 radio interviews from 48% of staff with an estimated reach of 121,233,000**, including >30 on BBC national radio.

For example, MAHER’s research into magnetic nanoparticle pollutants entering the human brain generated media interviews for the BBC News at Ten, BBC World Service, Radio 4, Radio 5, all major broadsheet

Figure 10 . The LEC media process

newspapers, CNN and many others with an estimated reach of 100 million people. GRAHAM was interviewed about coral bleaching research on BBC Breakfast, Reuters, the BBC News Channel, BBC Radio 4’s Today Programme and many others with a combined reach of more than 21,800,000.

Alongside this, **LEC academics have also used their expertise to comment on stories within the daily news agenda.** During the build-up to the 2019 General Election, WILLIS gave multiple interviews about climate change and political parties’ climate policies on BBC One and Channel 4 (where she was part of a panel of experts in the Channel 4 leaders’ debate) as well as BBC Radio Five Live, BBC Radio 4’s Today Programme and BBC Radio 4’s Six O’ Clock News, with a combined reach of more than 32 million. BERNERS-LEE’s expertise on carbon footprinting led to an appearance on Sir David Attenborough’s BBC One documentary Climate Change – the Facts, Horizon, the BBC’s World Business report and Radio 4’s Beyond Today amongst others.

LEC makes extensive use of social media to promote research to a wider audience. BIGGER and NEIMARK’s blog article in *The Conversation*, based on their paper on the Environmental Impact of the US military, has been tweeted 17,000+ times and shared 186,000 times on Facebook with the 5th highest altmetric of any *Conversation* article. The original paper has the highest altmetric score of any paper published in the *Transactions of the Institute of British Geographers*.

4.3 Discipline sustainability and support for and exemplars of interdisciplinary research

LEC has taken leadership in supporting key disciplines that are under pressure. Soil Science is a case in point. Rather than lead a single institute bid to NERC for the Soil Science CDT, in 2015 LEC masterminded a bid from eight key Soil Science active UK Universities and Institutes. This resulted in a highly integrated CDT, which has trained 39 students, over three cohorts, in multidisciplinary Soil Science, helping to sustain and develop a discipline key to food production and environmental quality.

We have promoted interdisciplinarity by creating five research challenges (section 1.3.1) and by promoting interactions between Research Groups to develop interdisciplinary research ideas.

Exemplars include: our Tropical Futures Research Challenge leading a high profile paper on ‘the

future of hyperdiverse tropical ecosystems' with seven of the 17 authors being from LEC, drawn from the Ecology, Political Ecology and Atmosphere Research Groups; work addressing the Catchment Science Research Challenge, highlighting the major agricultural changes required to mitigate phosphorus pollution under climate change, brought together 10 LEC authors from the Environmental Chemistry, Water Science, Soil Plant Land Systems Research Groups.

Recognising a lack of an international platform in Political Ecology for sharing the latest developments and facilitating the cross fertilization of ideas, in 2015 CHILDS and NEIMARK at LEC, together with seven globally leading Political Ecology research institutions, founded the POLLEN network. The network is an umbrella organization of political ecology researchers, groups, projects, activist, civil society and political groups and has in excess of 500 'nodes' across the globe (Figure 11).



Figure 11. The globally significant Political Ecology POLLEN network has grown from eight to 500 nodes (multicoloured markers) in just four years.

4.4 Indicators of wider influence, contributions to and recognition by the research base including Esteem indicators since REF2014

The following provides indicators of LEC staff members' far-reaching influence on, contributions to, and recognition by the broader research community (Table 7).

LEC staff have received prestigious awards and medals, including a **Fellowship of the Royal Society for BEVEN recognising his hydrological research**. He joins LONG, the Department's other FRS, who **was elected a Member of the National Academy of Sciences (NAS) of the USA and awarded a Fellowship of the American Academy for the Advancement of Sciences (AAAS) for his work on photosynthesis**. **HEATHWAITE was awarded a CBE in 2018 for her services to scientific research and scientific advice to government**. JONES was awarded the American Chemical Society Award for Creative Advances in Environmental Science and Technology. HEATHWAITE and TOULMIN were elected **Fellows of the Royal Society of Edinburgh**, ATKINSON to the **Learned Society of Wales** and WALKER to the **Academy of Social Sciences**. PAUL was presented with an award from UNEP for outstanding service as a co-chair within the Montreal Protocol process and M.PARRY was presented with China National Friendship Award by Vice Premier Ma Kai. **LONG (2006-20), GRAHAM (2016-20) and RUFINO (2019) were named as highly cited researchers by Clarivate Analytics**. HICKS is co-ordinating lead author for 'Sustainable Use' for the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. BARKER's contribution to freshwater science was honoured with the

naming of a new species of diatom 'Afrocymbella barkeri', while S.KEITH's significant contributions to understanding and protecting the coral reef was honoured by naming 'Cyphastrea salae' after her.

Most staff perform editorial roles, including 11 Editor-in-Chief positions (13% of academic staff), in disciplines ranging from Soil Science, Hydrology, Energy, Environmental Chemistry, Political Ecology, Applied Ecology, Plant Science and Food Security.

LEC staff give large numbers of invited (341) and keynote talks (172) at international conferences and present their work to Government (54) and International bodies (54). They chair and sit on UKRI (102) and International grant panels (61).

Awards		
	Learned society awards	16
	Named medals	5
	Fellowships	15
	Honorary membership of learned societies or degrees	5
	CBE	1
	Other awards	10
Invited talks		
	Keynote conference talks	172
	Invited conference talks	341
	Invited talks to government e.g. Defra, Select committee	54
	Invited talks to International bodies e.g. UNEP, IPCC	54
Research funding committees		
	UKRI	102
	EU and international	61
Editorial		
	Editor in Chief	11
	Associate Editor	56
Patents		
	Awarded	4
	In progress	6
Outside influence		
	Board member/trustee learned society	7
	Non-executive director	3
	Charity trustee	8