Insights from Embedding Research Impact and Sustainability into Engineering Education

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Swansea University
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Seminar agenda

1. Background on the challenge of embedding research impact and sustainability into engineering education

2. New material prepared on research impact, sustainability and the Sustainable Development Goals (SDGs)

3. Summary of assessment framework

4. Final remarks

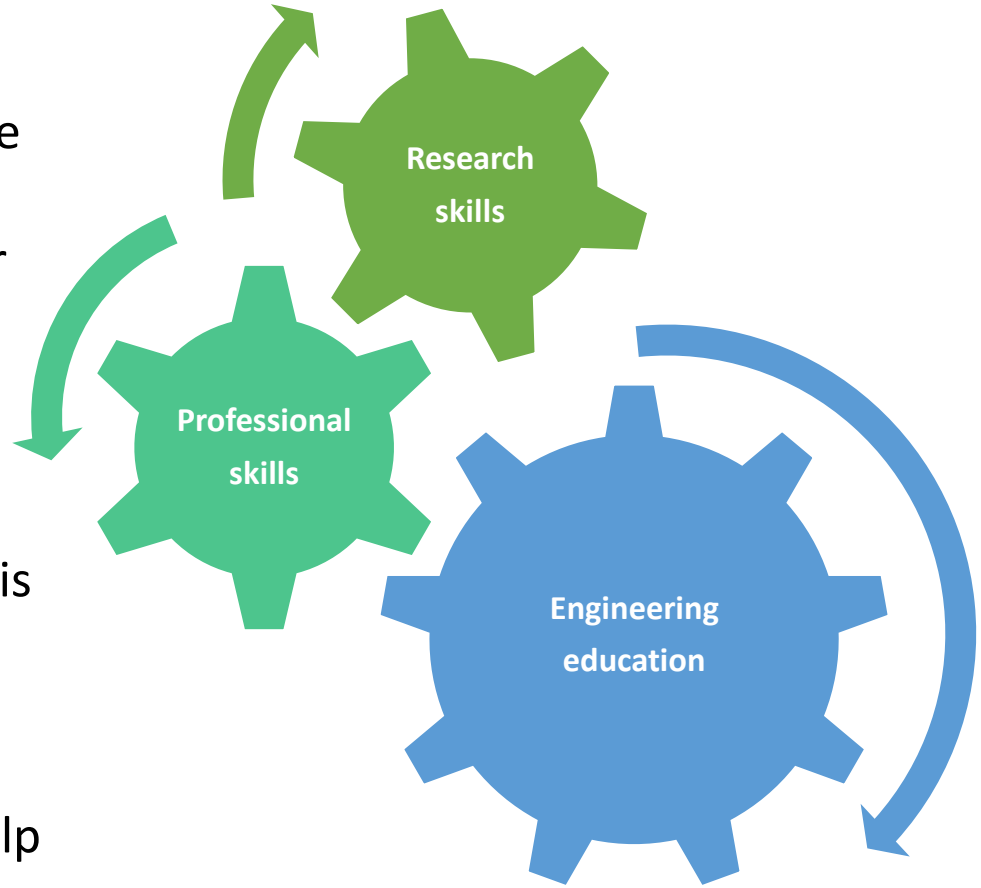
Introduction to the challenge

- Engineering education is based on developing skills and knowledge according to a core foundation of science and mathematics as well as engineering analysis, design and practice

- But engineering students also need to acquire research skills for successful completion of the research project in the near-term combined with enhanced professional skills for long-term development

- The Technical, Research and Professional Skills (TRAPS) module is delivered at LSBU to provide students with both research and professional skills

- Adding material on research impact and sustainability would help students to understand how engineering research can be of value to industry and wider society and help students to gain a broader appreciation of their engineering studies



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Redesigning the TRAPS module

- The challenge was to redesign the Technical, Research and Professional Skills (TRAPS) module to meet the MSc accreditation requirements of the IET (Institution of Engineering & Technology)
- Scope would remain as a 13-week module focused on providing skills for successful completion of the research dissertation in engineering studies in the near-future combined with skills for professional development in the long-term future
- Needed to develop new content for the module covering ‘sustainability’ and the sustainable development goals (SDGs)
- It was decided that this would also link to the wider area of ‘research impact’

New learning outcome added to the module

Ability to assess how technologies and engineering applications support sustainable development including use of numerical techniques where appropriate.

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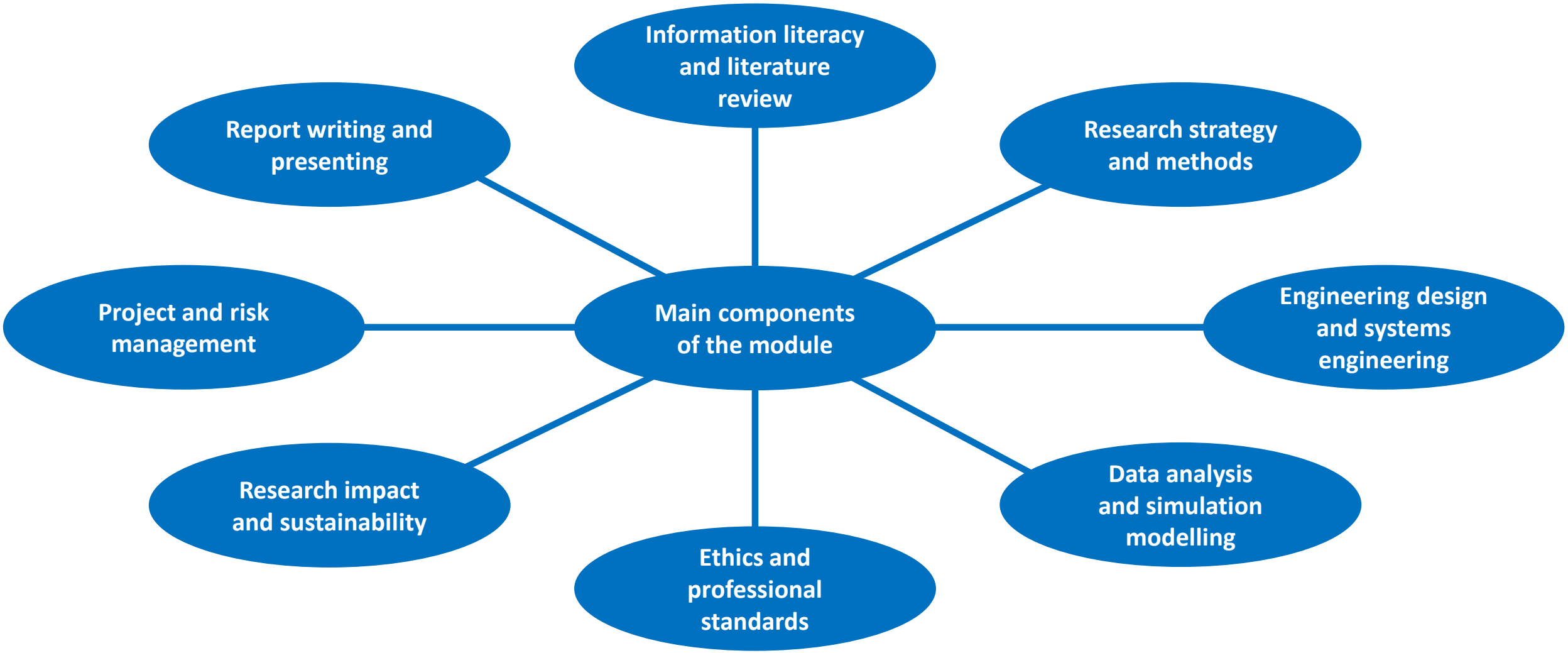
Main components of the redesigned module



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Overall module assessment (summative)

- **Assignment report**:
  - This component is assessed through a formal report covering the feasibility study of the proposed research project
  - 70% of the final mark for the module
- **Presentation**:
  - This component is assessed through a presentation covering the topic of the feasibility study of the proposed research project
  - 30% of the final mark for the module

Learning outcomes across the following engineering areas

- Science and mathematics
- Engineering analysis
- Economic, legal, social, ethical and environmental factors

Plan of action for module redesign

Key steps taken to introduce research impact and sustainability into the TRAPS module (as part of the accredited MSc programme):

1) Produce new lecture material dedicated to research impact and sustainability & the SDGs

2) Integrate research impact and sustainability into the module assessment framework (formative and summative assessment)

Step 1 – Produce new lecture material dedicated to research impact and sustainability & the SDGs

Lecture contents

1) Understanding research impact:
    a) Importance of academic research
    b) Types of research impact
    c) Measuring research impact
    d) Research outputs, bibliometrics and altmetrics

2) Introduction to sustainability:
    a) Sustainability and sustainable development
    b) The triple bottom line
    c) The Sustainable Development Goals (SDGs)
    d) Circular economy

3) Tutorial session

4) Weekly reading exercise

Question – What is research impact, and can you think of some examples?

What is research impact?

Research impact is "*the demonstrable contribution that excellent research makes to society and the economy*".

This can involve academic impact, and economic & societal impact, or both:

a) **Academic impact** is the demonstrable contribution that research makes in shifting understanding and advancing scientific method, theory and application across and within disciplines

b) **Economic & societal impact** is the demonstrable contribution that research makes to society and the economy, and its benefits to individuals, organisations and/or nations

Source: Adapted from the Economic and Social Research Council (ESRC) https://esrc.ukri.org/research/impact-toolkit/what-is-impact/

Examples of the types of impacts

Impact category	Examples
Impact on the economy	Increased productivity; GDP gains; attracting capital investment; improving resilience and diversification of the economy
Commercial impact	Generating revenue; improving processes; opening up new markets; creating employment in industry
Impact on public policy and services	Informing policy debate within the general public, in a government body, or at a non-governmental organisation; increasing public engagement with the policy process; improving efficiency of or access to public services; improving the equity of public service provision
Impact on health and wellbeing	Improving health outcomes; changing healthcare practice; improving health equity; increasing patient/user choice; increasing access to health services; improving the management of healthcare performance; improving patient/user satisfaction
Impact on education and training	Changing curricula; improving training materials, text books or other teaching resources; creating materials for specialised teaching contexts; changing the structure of a course; increasing access to education; improving educational outcomes
Impact on public engagement, awareness and perceptions	Shaping the nature of public debate; increasing public engagement with research findings; increasing public awareness; creating publicly available tools or resources; increasing public curiosity about science, technology, the arts or other disciplines
Cultural impact	Preserving cultural heritage; increasing accessibility of culture; improving artistic/cultural methods; improving the quality of cultural events/activities
Impact on social cohesion	Reduced inequality; reduced bias and intolerance; improved social integration; increased social capital
Impact on safety and security	Improving infrastructure security/resilience; improving policing practices; creating new tools for policing; improving safety in the workplace, at home or in other settings; increased regional security; improving national security and defence capabilities
Impact on the environment	Reducing pollution levels; improving measures of environmental condition; contributing to conservation; improving waste management, environmental efficiency or environmental management; reducing the depletion of a natural resource; developing adaptations to environmental conditions/changes

Source: Guthrie, S., d'Angelo, C., Ioppolo, B., Shenderovich, Y., & McInroy, G. R. (2018). *Evidence synthesis on measuring the distribution of benefits of research and innovation*. RAND Corporation.

https://www.rand.org/pubs/research_reports/RR2610z1.html

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An example of the impact of academic research in society

THE LANCET

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ARTICLES | VOLUME 397, ISSUE 10269, P99-111, JANUARY 09, 2021

Safety and efficacy of the ChAdOx1 nCoV-19 vaccine (AZD1222) against SARS-CoV-2: an interim analysis of four randomised controlled trials in Brazil, South Africa, and the UK

Merryn Voysey, DPhil * · Sue Ann Costa Clemens, PhD * · Shabir A Madhi, PhD * · Lily Y Weckx, PhD * · Pedro M Folegatti, MD * · Parvinder K Aley, PhD · et al. Show all authors · Show footnotes

Open Access · Published: December 08, 2020 · DOI: https://doi.org/10.1016/S0140-6736(20)32661-1 ·

Check for updates

PDF (368 KB)

Summary

Introduction

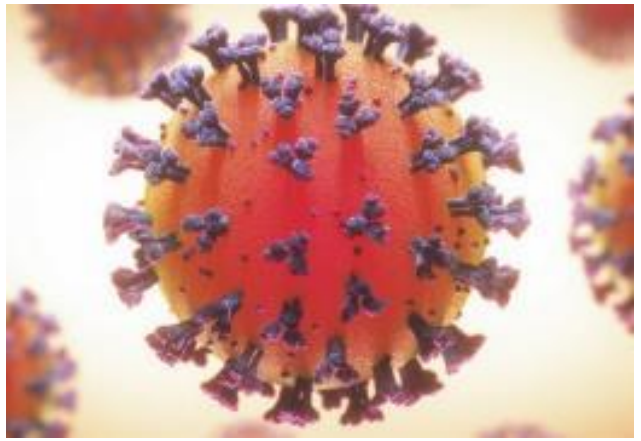
Methods

Results

Summary

Background

A safe and efficacious vaccine against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), if deployed with high coverage, could contribute to the control of the COVID-19 pandemic. We evaluated the safety and efficacy of the ChAdOx1 nCoV-19 vaccine in a pooled interim analysis of four trials.



Source: Voysey, M., Clemens, S. A. C., Madhi, S. A., Weckx, L. Y., Folegatti, P. M., Aley, P. K., ... & Bijker, E. (2021). Safety and efficacy of the ChAdOx1 nCoV-19 vaccine (AZD1222) against SARS-CoV-2: an interim analysis of four randomised controlled trials in Brazil, South Africa, and the UK. *The Lancet*, *397*(10269), 99-111.

https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)32661-1/fulltext

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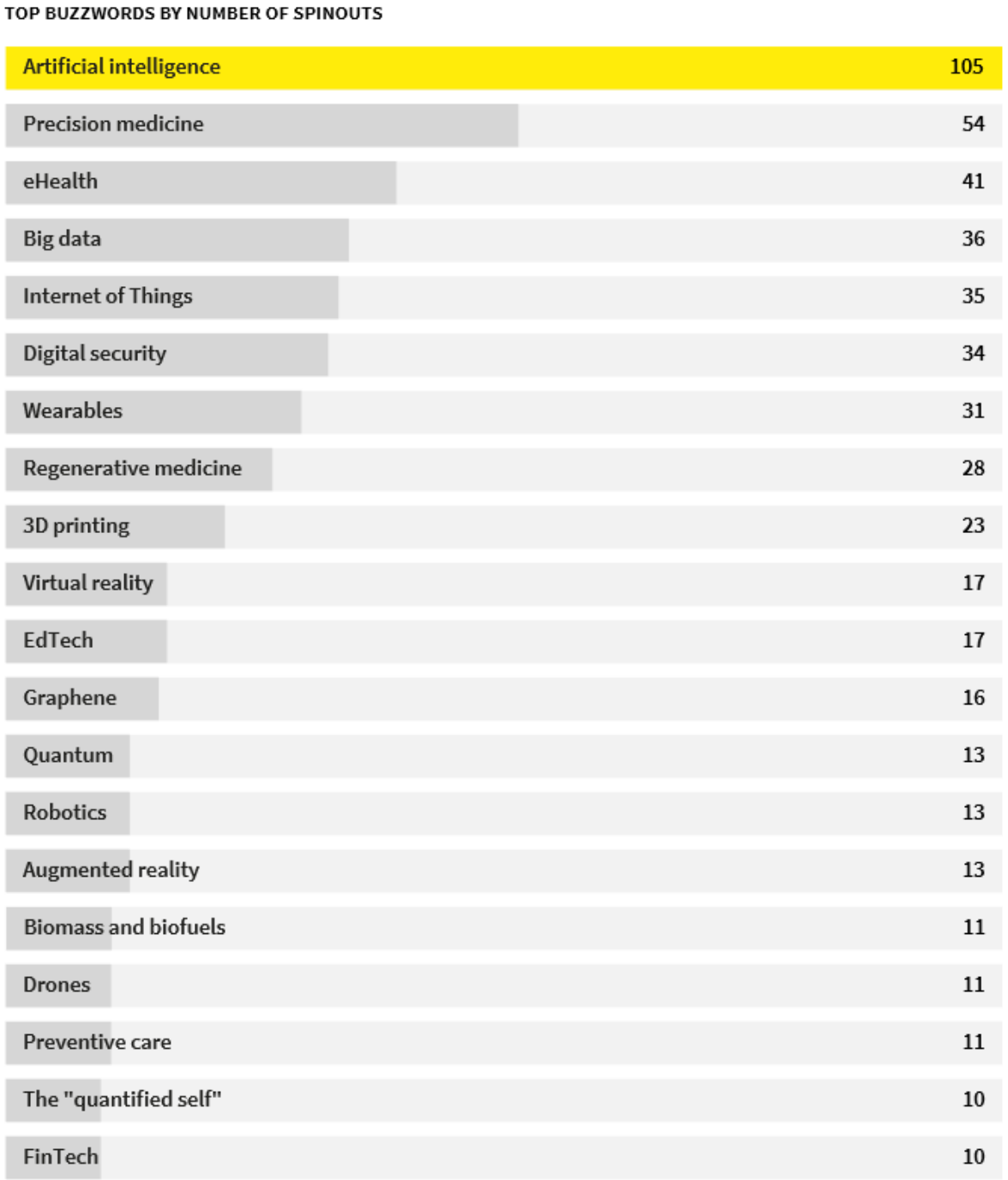
Economic and industrial impact: Top emerging technologies in UK spin-out companies



Source: Royal Academy of Engineering (2021). Spotlight on spinouts - A new report on the successes and trends of spinouts from UK universities.

https://www.raeng.org.uk/publications/reports/spotlight-on-spinouts

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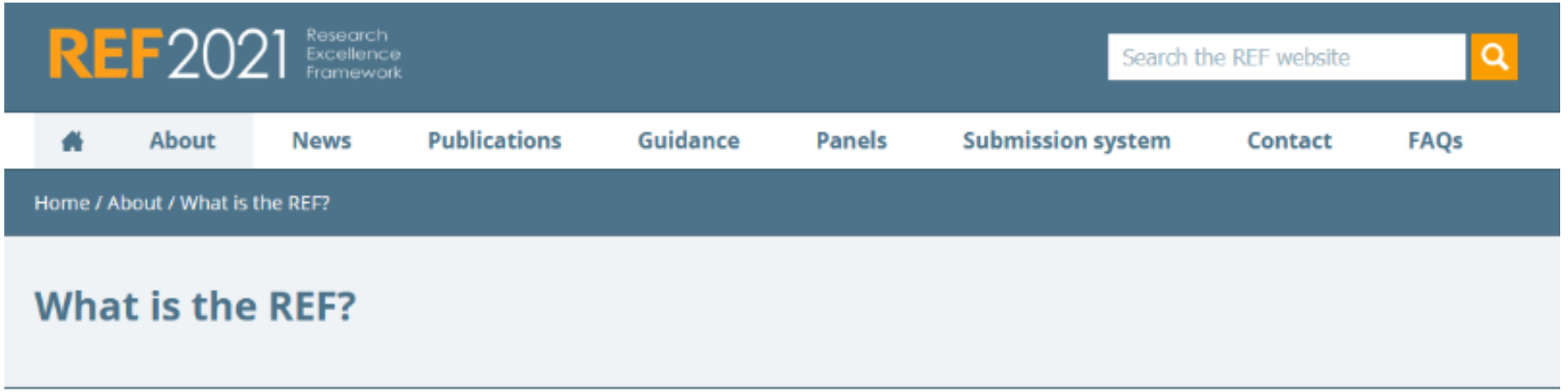
REF Process



What is the REF?

The REF was first carried out in 2014, replacing the previous Research Assessment Exercise. The REF is undertaken by the four UK higher education funding bodies: Research England, the Scottish Funding Council (SFC), the Higher Education Funding Council for Wales (HEFCW), and the Department for the Economy, Northern Ireland (DfE).

What is the REF's purpose?

The funding bodies' shared policy aim for research assessment is to secure the continuation of a world-class, dynamic and responsive research base across the full academic spectrum within UK higher education. We expect that this will be achieved through the threefold purpose of the REF:

- To provide accountability for public investment in research and produce evidence of the benefits of this investment.
- To provide benchmarking information and establish reputational yardsticks, for use within the HE sector and for public information.
- To inform the selective allocation of funding for research.

Source: https://www.ref.ac.uk/about/what-is-the-ref/

REF 2021 Impact Case Study

REF 2021 Impact Case Study, London South Bank University, School of Engineering

Based on doctoral research by Dr. Paul Mansell

Source: https://results2021.ref.ac.uk/impact/9367cef7-ab10-4433-b996-99cc976b922a/pdf

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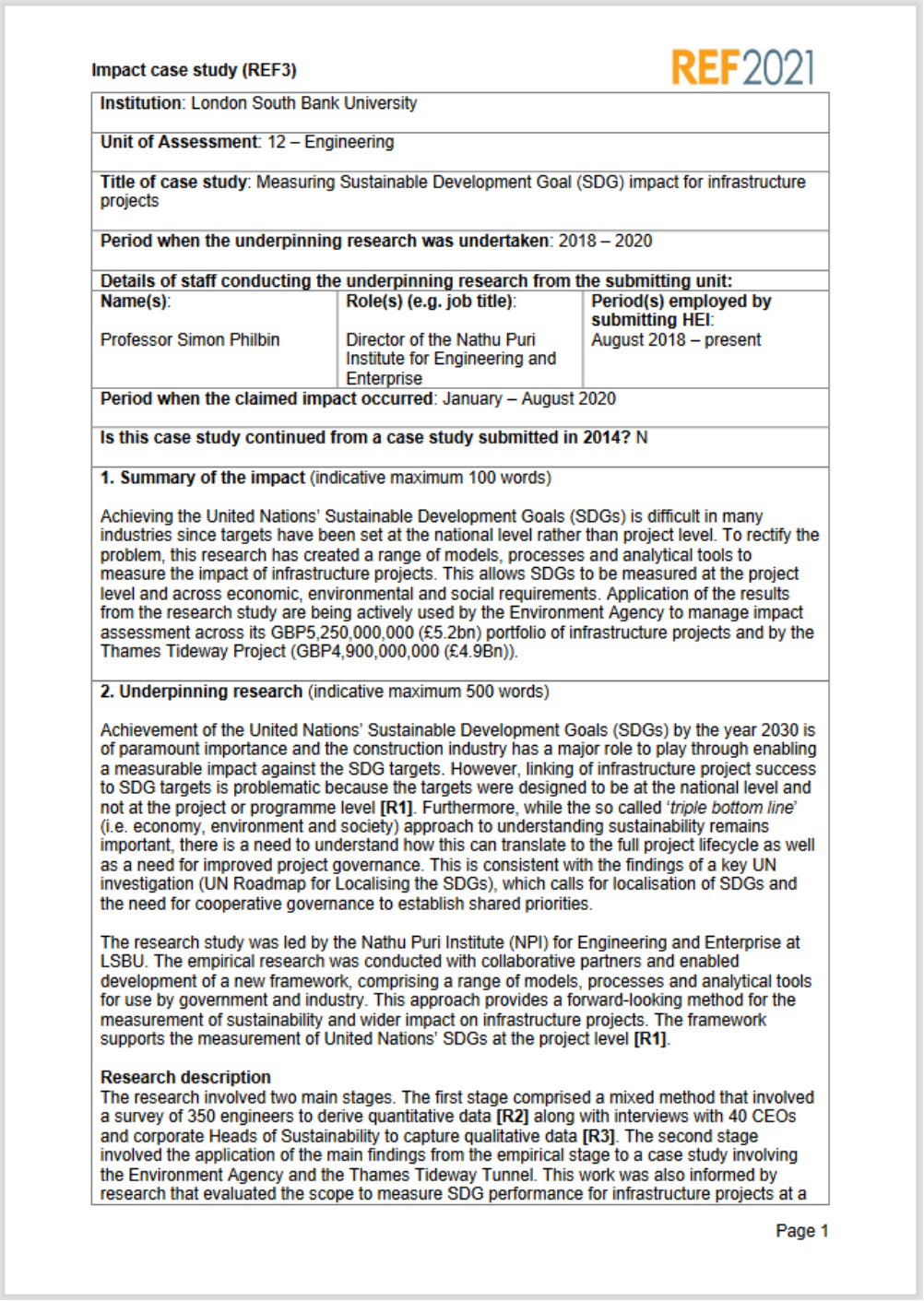

Impact case study (REF3) REF2021

Institution: London South Bank University

Unit of Assessment: 12 – Engineering

Title of case study: Measuring Sustainable Development Goal (SDG) impact for infrastructure projects

Period when the underpinning research was undertaken: 2018 – 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Simon Philbin	Director of the Nathu Puri Institute for Engineering and Enterprise	August 2018 – present

Period when the claimed impact occurred: January – August 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Achieving the United Nations' Sustainable Development Goals (SDGs) is difficult in many industries since targets have been set at the national level rather than project level. To rectify the problem, this research has created a range of models, processes and analytical tools to measure the impact of infrastructure projects. This allows SDGs to be measured at the project level and across economic, environmental and social requirements. Application of the results from the research study are being actively used by the Environment Agency to manage impact assessment across its GBP5,250,000,000 (£5.2bn) portfolio of infrastructure projects and by the Thames Tideway Project (GBP4,900,000,000 (£4.9Bn)).

2. Underpinning research (indicative maximum 500 words)

Achievement of the United Nations' Sustainable Development Goals (SDGs) by the year 2030 is of paramount importance and the construction industry has a major role to play through enabling a measurable impact against the SDG targets. However, linking of infrastructure project success to SDG targets is problematic because the targets were designed to be at the national level and not at the project or programme level **[R1]**. Furthermore, while the so called '*triple bottom line*' (i.e. economy, environment and society) approach to understanding sustainability remains important, there is a need to understand how this can translate to the full project lifecycle as well as a need for improved project governance. This is consistent with the findings of a key UN investigation (UN Roadmap for Localising the SDGs), which calls for localisation of SDGs and the need for cooperative governance to establish shared priorities.

The research study was led by the Nathu Puri Institute (NPI) for Engineering and Enterprise at LSBU. The empirical research was conducted with collaborative partners and enabled development of a new framework, comprising a range of models, processes and analytical tools for use by government and industry. This approach provides a forward-looking method for the measurement of sustainability and wider impact on infrastructure projects. The framework supports the measurement of United Nations' SDGs at the project level **[R1]**.

Research description
The research involved two main stages. The first stage comprised a mixed method that involved a survey of 350 engineers to derive quantitative data **[R2]** along with interviews with 40 CEOs and corporate Heads of Sustainability to capture qualitative data **[R3]**. The second stage involved the application of the main findings from the empirical stage to a case study involving the Environment Agency and the Thames Tideway Tunnel. This work was also informed by research that evaluated the scope to measure SDG performance for infrastructure projects at a

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"Following on from the MISI Project, we will be able to embed the knowledge that was generated by the project to support the measurement of SDG performance across our new portfolio of Environment Agency projects to be launched on 1st April 2021, which will total £5.2billion and include around 15 major projects in excess of £50million.

Moreover, the approach to SDG measurement developed in the MISI Project will directly help us deliver our new sustainability strategy (known as eMissiion2030) and this will have huge positive impact that directly contributes to: saving lives; protecting hospitals, schools and homes; and regulating environmental impacts; as well as providing value for money for the UK Government" –

Deputy Director Allocation & National Programme Management, Environment Agency

Summary of lecture contents on research impact

(1). Material provided on research impact and its significance

(2). Class asked to think about some examples of research impact

(3). Discussion on societal, economic and academic impact of research projects

(4). Material provided and discussion on the main outputs of research projects

(5). Class asked how can we measure the performance of research projects

(6). Material provided on bibliometrics (such as h-index) and altmetrics (online interactions)

Question – What is sustainability and why is it important?

Definition of sustainability

Definition

- *"The quality of being able to continue over a period of time"*
  - For example: The long-term sustainability of the community

- *"The quality of causing little or no damage to the environment and therefore able to continue for a long time"*
  - For example: The company's commitment to environmental sustainability

Source:
https://dictionary.cambridge.org/dictionary/english/sustainability

*"**Environmental sustainability** defines a boundary for us to satisfy our current needs without anyway compromising the quality of environment/ ecosystem so that it remains equally capable of supporting the future generations too"* (Kaswan et al., 2019)

Kaswan, V. et al., (2019). Green Production Strategies. *Encyclopedia of Food Security and Sustainability*, 1, 492-500.

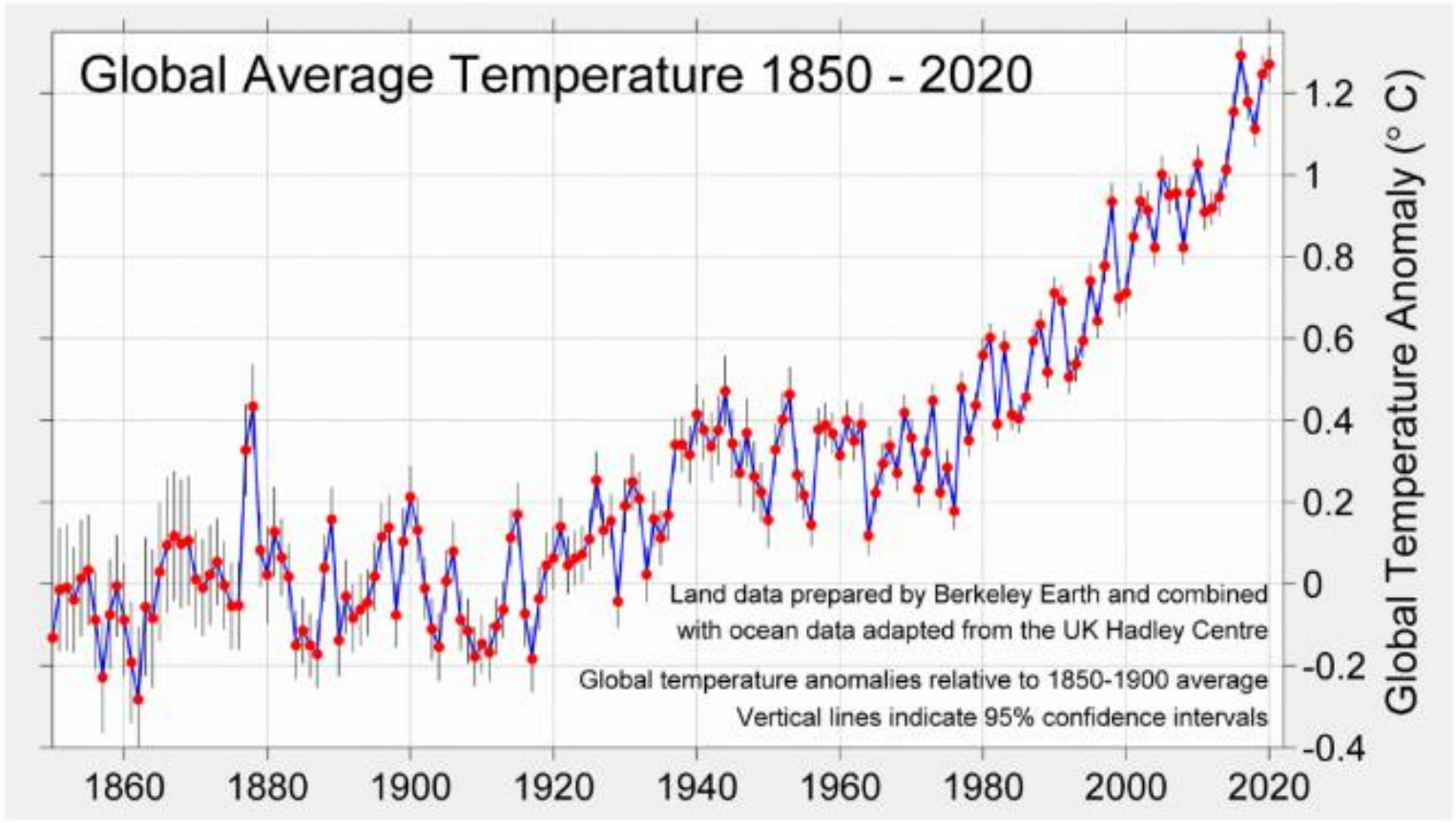
Climate change and the impact of global warming

Pedersen Glacier, at Aialik Bay in Alaska's Kenai Mountains, in 1917 (left) and 2005 (right)

"Global warming is causing global mean sea level to rise in two ways. First, glaciers and ice sheets worldwide are melting and adding water to the ocean. Second, the volume of the ocean is expanding as the water warms".

Source: https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

Global temperature and climate change



"The global mean temperature in 2020 is estimated to have been 1.27 °C (2.29 °F) above the average temperature of the late 19th century, from 1850-1900, a period often used as a pre-industrial baseline for global temperature targets"

Source: https://berkeleyearth.org/global-temperature-report-for-2020/

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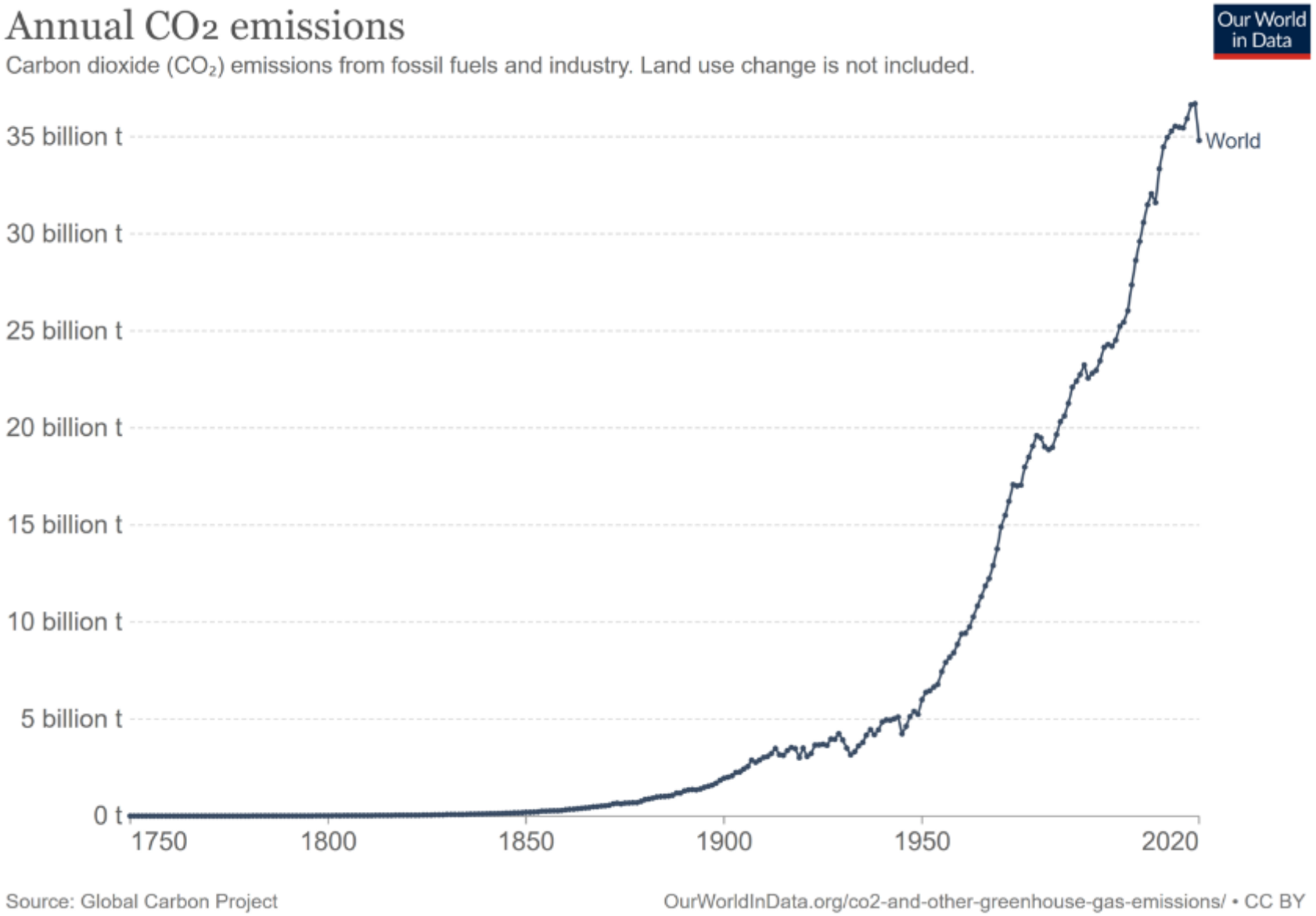
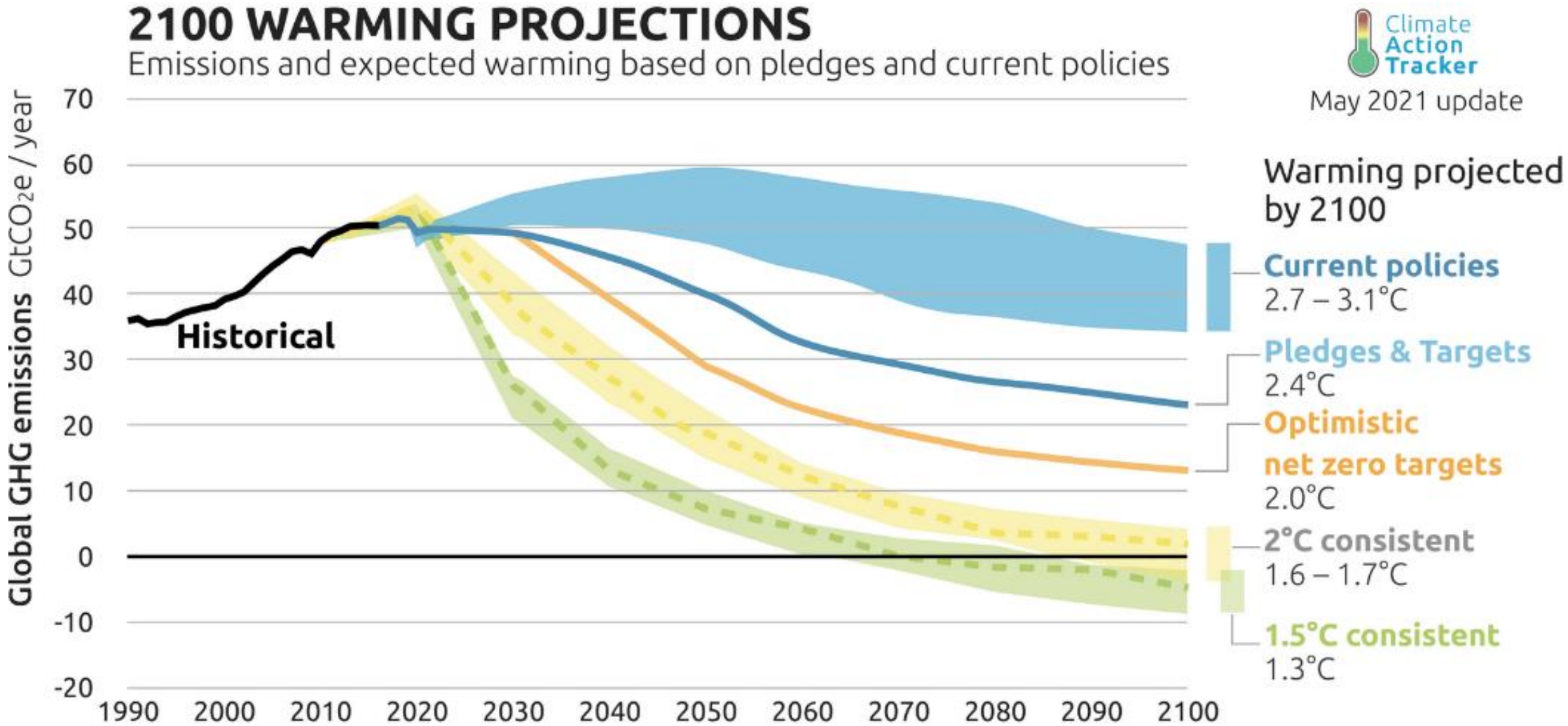
Global carbon dioxide emissions from burning fossil fuels

- Global CO_2 emissions from burning fossil fuels have risen steadily over the last several decades and show no sign of peaking
- Global CO_2 emissions were expected to be *ca*. 60% higher in 2019 than in the year 1990 when the first IPCC report was issued



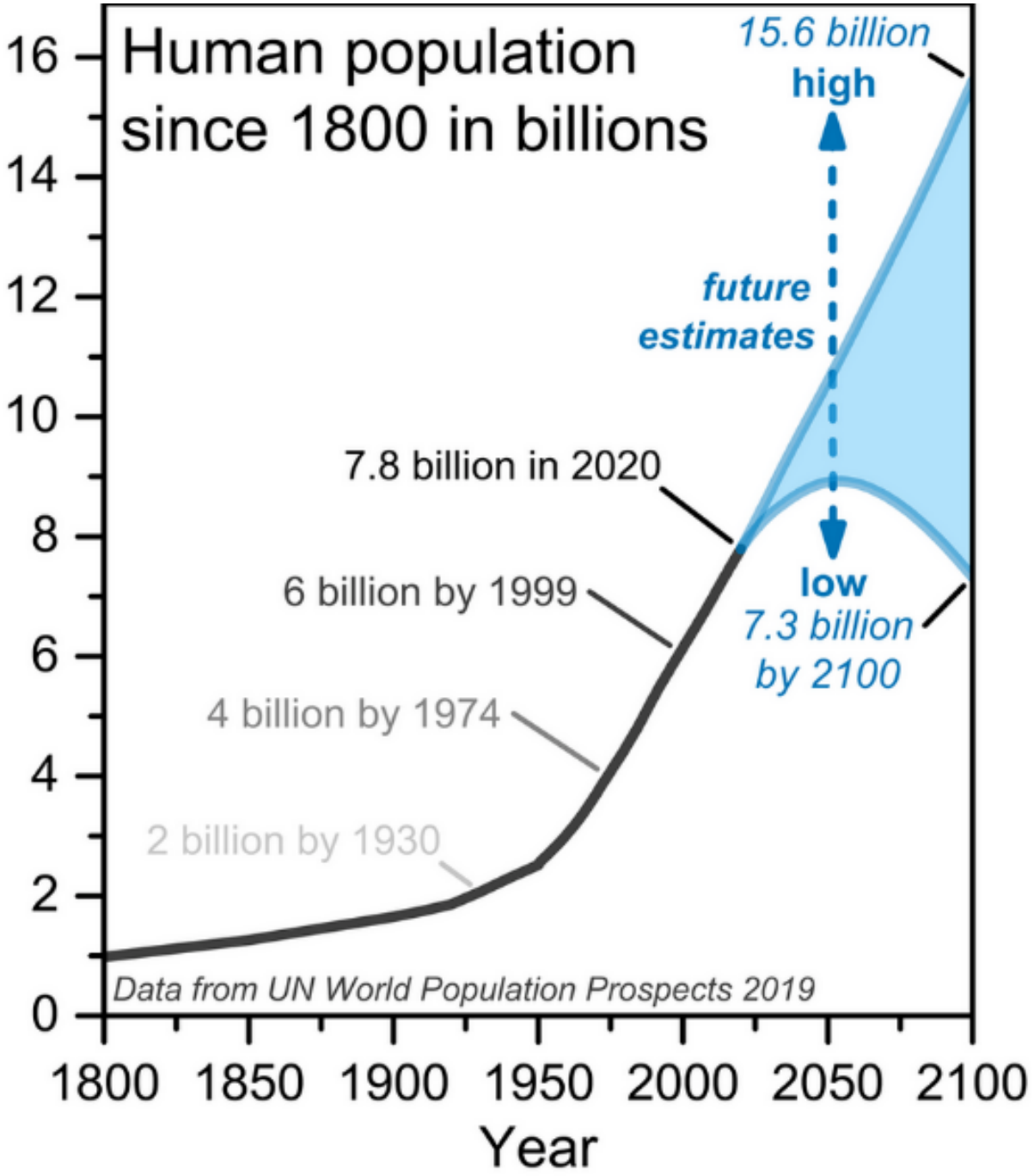
Source: https://ourworldindata.org/co2-emissions

Global warming projection



Source: https://climateactiontracker.org/global/temperatures/

Projected growth in the world's population



Source:
https://population.un.org/wpp/

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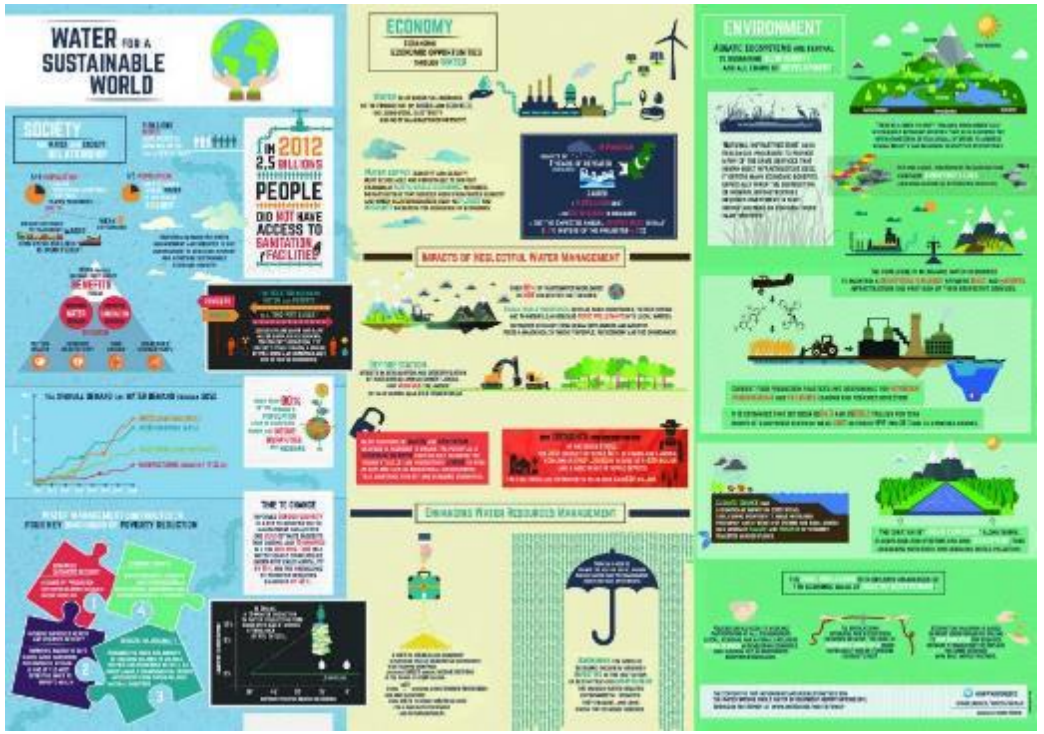
Water – some key facts

- Over **1.7 billion** people are currently living in river basins where water use exceeds recharge, leading to the desiccation of rivers, depletion of groundwater and the degradation of ecosystems and the services they provide

- According to some estimates, over **80% of wastewater** is discharged without treatment

- Water-related disasters are the most economically and socially destructive of all natural disasters. Since the original Rio Earth Summit in 1992 floods, droughts and storms have affected **4.2 billion people** (95% of all people affected by disasters) and caused **USD 1.3 trillion** of damage (63% of all damage)



United Nations

Source:
https://www.un.org/waterforlifedecade/water_and_sustainable_development.shtml

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The concept of sustainable development

- The UN General Assembly, in its resolution 38/161 of 19th December 1983, welcomed establishment of a special commission that would make available a report on the environment and appropriate development solutions

- This led to formation of the World Commission on the Environment and Development and the 1987 Brundtland Report, which defined 'Sustainable Development' as

  - ***"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"***

Source:
https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf

Gro Harlem Brundtland
Former Prime Minister of Norway and Chair of the 1987 Brundtland Commission

Question – What are the Sustainable Development Goals (SDGs)?

Sustainable Development Goals (SDGs)

- The Sustainable Development Goals (SDGs), also known as the Global Goals, were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity

- SDG related thematic areas: Water, energy, climate, oceans, urbanization, transport, science and technology

Source: https://www.undp.org/sustainable-development-goals

Full list of United Nations SDGs

- Goal 1: End poverty in all its forms everywhere
- Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- Goal 3: Ensure healthy lives and promote well-being for all at all ages
- Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
- Goal 5: Achieve gender equality and empower all women and girls
- Goal 6: Ensure availability and sustainable management of water and sanitation for all
- Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all
- Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
- Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- Goal 10: Reduce inequality within and among countries
- Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable
- Goal 12: Ensure sustainable consumption and production patterns
- Goal 13: Take urgent action to combat climate change and its impacts
- Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
- Goal 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
- Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development

SDGs, Targets and Indicators

There are 17 SDGs along with 169 specific targets and 244 indicators. For example, in the case of 'SDG #7: Ensure access to affordable, reliable, sustainable and modern energy for all'

Targets	Indicators
Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all	
7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	7.1.1 Proportion of population with access to electricity
	7.1.2 Proportion of population with primary reliance on clean fuels and technology
7.2 By 2030, increase substantially the share of renewable energy in the global energy mix	7.2.1 Renewable energy share in the total final energy consumption
7.3 By 2030, double the global rate of improvement in energy efficiency	7.3.1 Energy intensity measured in terms of primary energy and GDP
7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology	7.a.1 International financial flows to developing countries in support of clean energy research and development and renewable energy production, including in hybrid systems
7.b By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States and landlocked developing countries, in accordance with their respective programmes of support	7.b.1 Installed renewable energy-generating capacity in developing countries (in watts per capita)

Source: https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework%20after%202021%20refinement_Eng.pdf

Interesting tool to highlight SDG trade-offs

Some issues with the SDGs:

"On one hand, achieving one goal or target may contribute to achieving other goals or targets. For example, enhanced food security (Goal 2) will reinforce poverty eradication (Goal 1).

On the other hand, the pursuit of one target may conflict with the achievement of another. For example, an increase in agricultural production to help end hunger (Goal 2) can result in an increase in water use that may compete with water demand for achieving universal access to drinking water (Goal 6)"

Source: https://sdginterlinkages.iges.jp/index.html

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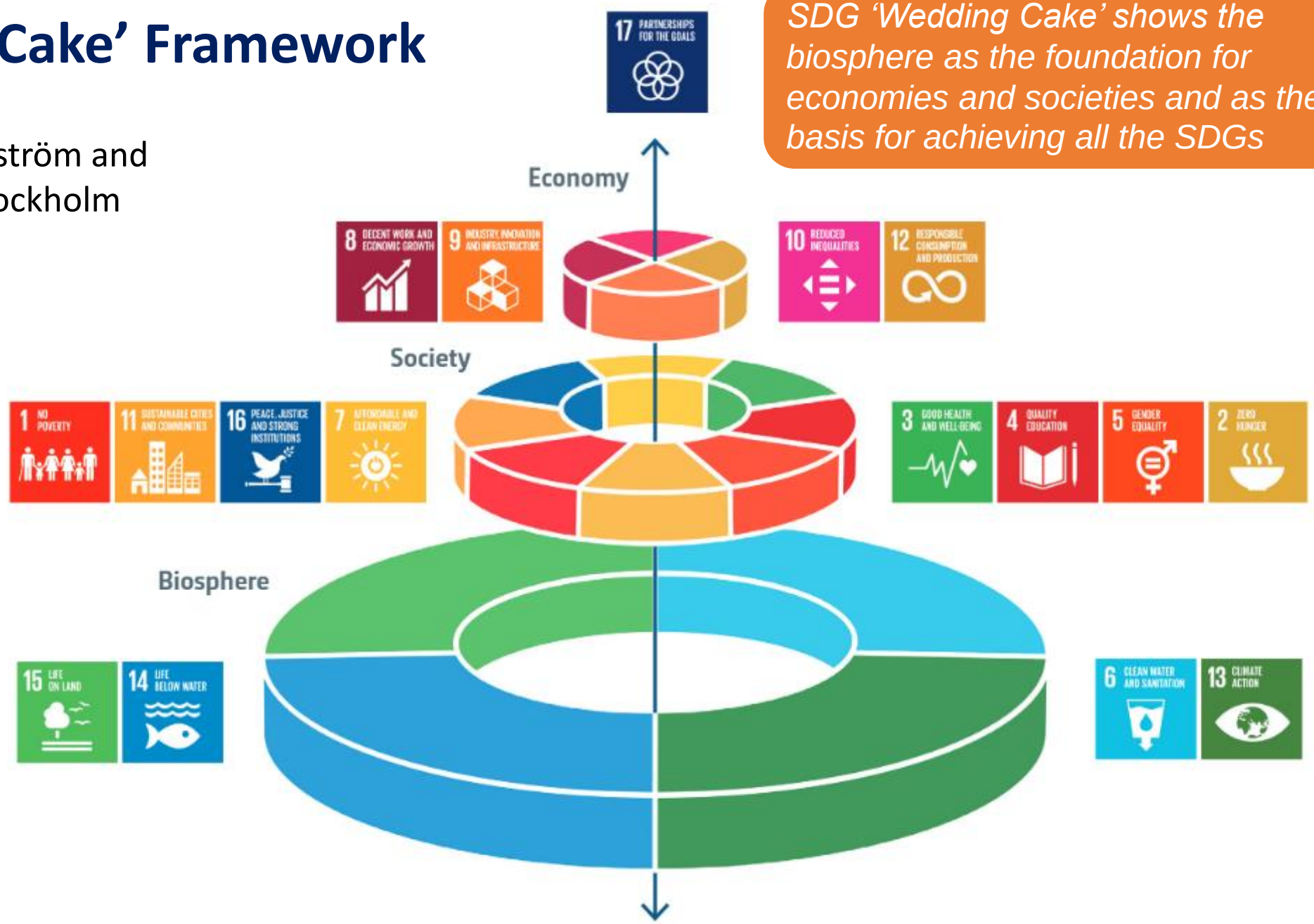
SDG ‘Wedding Cake’ Framework

SDG ‘Wedding Cake’ shows the biosphere as the foundation for economies and societies and as the basis for achieving all the SDGs

Proposed by Johan Rockström and Pavan Sukhdev at the Stockholm EAT Food Forum in 2016



Sources:
Obrecht, A., Pham, M., Spehn, E., Payne, D., Brémond, A. C., Altermatt, F., ... & Geschke, J. E. (2021). Achieving the SDGs with biodiversity. Akademie der Naturwissenschaften Schweiz (SCNAT), Forum Biodiversität Schweiz

https://www.stockholmresilience.org/research/research-news/2016-06-14-the-sdgs-wedding-cake.html

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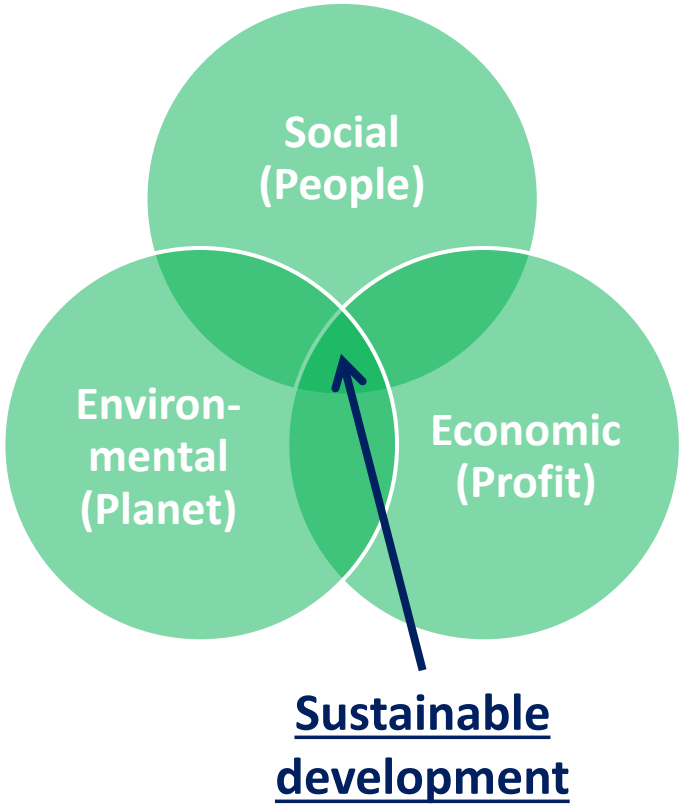
Step 2 – Integrate research impact and sustainability into the module assessment framework (formative and summative assessment)

The triple bottom line

- In 1994, author and entrepreneur, John Elkington, built upon the concept of the ***Triple Bottom Line*** (TBL) in hopes to transform the current financial accounting-focused business system to take on a more comprehensive approach in measuring impact and success

- Historically, businesses operated in service solely to their financial bottom line. However, as a result of the triple bottom line theory and application, some businesses began to realize the connection among environmental health, social well-being and the organization's financial success and resilience

- Therefore, driving companies towards sustainable outcomes requires adherence to the 'Triple Bottom Line' of social, environmental and economic considerations – or people, planet and profit (or prosperity) (Elkington, 1998)



Source:
https://sustain.wisconsin.edu/sustainability/triple-bottom-line/

Elkington, J. (1998). Partnerships from cannibals with forks: The triple bottom line of 21st-century business. *Environmental Quality Management*, *8*(1), 37-51.

Short exercise on the TBL (formative assessment)

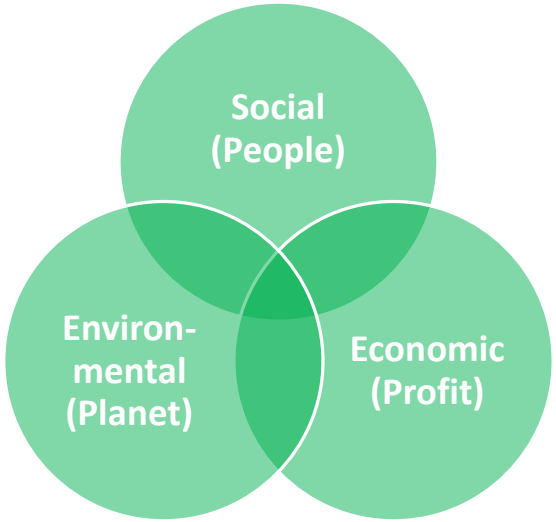
Background

- You are the General Manager for a new factory that will be producing automotive machine parts, such as gear trains, chain drives, cam systems, brakes and clutches.

- In order to receive permission for the new factory to be built, there is a need to identify the impact on the local area in terms of economic, environmental and social outcomes?

Question

- What are the economic, environmental and social measures for the new factory?



Tutorial exercise on the sustainability of plastics

Background

- Plastic pollution has become one of the most pressing environmental issues, as the rapidly increasing production of disposable plastic products overwhelms the world's ability to deal with them

- Plastic pollution is most visible in developing Asian and African nations, where waste collection systems are often inefficient or nonexistent. But the developed world, especially in countries with low recycling rates, also has trouble properly collecting discarded plastics

- Production increased exponentially, from 2.3 million tons in 1950 to 448 million tons by 2015. Production is expected to double by 2050

- Every year, about 8 million tons of plastic waste escapes into the oceans from coastal nations

Questions

1) How do plastics currently impact achievement of the SDGs? For at least six of the SDGs, try to identify a possible area of impact.

2) Identify a research project designed to address one of the areas, including three research objectives for the research project.

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Source: https://www.nationalgeographic.com/environment/article/plastic-pollution

Reading exercise for week # 7

Read the following article:

Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., & Rockström, J. (2019). Six transformations to achieve the sustainable development goals. *Nature Sustainability*, *2*(9), 805-814.

https://www.nature.com/articles/s41893-019-0352-9

Questions and reflection:

1) What are the six transformations proposed by the authors?

2) How can the transformations be implemented?

3) Why can't the transformation be designed and imposed from the top down?

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nature sustainability

PERSPECTIVE

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Six Transformations to achieve the Sustainable Development Goals

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The Sustainable Development Goals (SDGs) and the Paris Agreement on Climate Change call for deep transformations in every country that will require complementary actions by governments, civil society, science and business. Yet stakeholders lack a shared understanding of how the 17 SDGs can be operationalized. Drawing on earlier work by The World in 2050 initiative, we introduce six SDG Transformations as modular building-blocks of SDG achievement: (1) education, gender and inequality; (2) health, well-being and demography; (3) energy decarbonization and sustainable industry; (4) sustainable food, land, water and oceans; (5) sustainable cities and communities; and (6) digital revolution for sustainable development. Each Transformation identifies priority investments and regulatory challenges, calling for actions by well-defined parts of government working with business and civil society. Transformations may therefore be operationalized within the structures of government while respecting the strong interdependencies across the 17 SDGs. We also outline an action agenda for science to provide the knowledge required for designing, implementing and monitoring the SDG Transformations.

By adopting the 2030 Agenda with its 17 SDGs (Supplementary Section 1) and the Paris Agreement, member states of the United Nations have created a framework for national action and global cooperation on sustainable development[1]. The SDGs focus on time-bound targets for Prosperity, People, Planet, Peace and Partnership—known as the five Ps. The Paris Agreement commits countries to achieve net-zero greenhouse-gas emissions by the middle of the century[2]. SDG 13 on climate change links to the Paris Agreement, noting that the UN Framework Convention on Climate Change "is the primary international, intergovernmental forum for negotiating the global response to climate change"[3].

Evidence suggests that international development goals, such as those around public health, can accelerate progress towards complex development goals[4], but achieving the SDGs will require deep, structural changes across all sectors in society. This raises the critical question of how strategies to achieve the 17 SDGs can be organized.

Several authors have shown that SDG outcomes, including the objectives of the Paris Agreement, are interdependent[1,5,6] with complex coupling between human, technical and natural systems. Yet the available studies do not emphasize how the implementation of the SDGs should be organized.

To help fill these gaps, we outline a systemic policy approach to achieve each SDG (Supplementary Section 4). As with the much simpler Millennium Development Goals[7], many policy interventions (such as public investments and regulations) are needed to achieve each SDG, and each intervention generally contributes to several goals. Governments need a strategy to design and implement key interventions. Building on The World in 2050[1] and earlier work (Supplementary Section 2), we propose six Transformations to organize SDG interventions through a semi-modular action agenda that can be designed by discrete, yet interacting, components of government. Each Transformation engages a different subset of business and civil society, facilitating targeted problem-solving, clear communication and the mobilization of stakeholders[8]. We describe how the Transformations can be operationalized with a focus on government action and conclude with an action agenda for science.

Organizing the implementation of the 17 SDGs

We first consider which key interventions are necessary to achieve the SDG outcomes (Table 1 and Supplementary Section 4) and how their implementation might be organized into a limited set of six Transformations. To simplify the discussion of interlinkages between interventions and SDGs, we identify intermediate outputs generated by combinations of interventions, which in turn contribute to the achievement of each SDG. Drawing on established methodologies[5,6], we describe the strength of the relationship between intermediate outputs and each SDG on a four-point scale: 3, directly targets the SDG; 2, reinforces the SDG; 1, enables the SDG; and 0, has no interaction with the SDG (Supplementary Section 4).

Table 1 presents no negative relationships between intermediate outputs and SDG outcomes since major trade-offs, as identified in the literature[5,6], are addressed in three ways. First, some trade-offs (between agricultural production and biodiversity loss, for example) are addressed through systems-based approaches that combine potentially antagonistic interventions inside a Transformation. Second, key interventions are designed to be consistent with the leave-no-one-behind principle (Box 1) to ensure that investments in services, infrastructure and technologies promote equity. Third, natural resource trade-offs are addressed through the principle of circularity and decoupling within a stable Earth system (Box 2).

Our proposal to organize SDG interventions into six discrete SDG Transformations (Fig. 1) builds on The World in 2050[1] and categorizes using five principal characteristics (Supplementary Section 3). The Transformations must be: (1) mutually exclusive and collectively exhaustive; (2) systems-based; (3) aligned with government organization; (4) easily communicable; (5) few in number.

Each SDG Transformation describes a major change in societal structure (economic, political, technological and social) to achieve

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Module assessment: 100% coursework

Coursework breakdown

Component	Brief description	Weighting	Threshold
(a). Feasibility study report	Assessed by way of a formal report covering the feasibility study of the proposed Masters' research project	**70%**	**40%**
(b). Presentation	Assessed by way of a presentation covering the topic of the feasibility study of the proposed Masters' research project	**30%**	**40%**

Recommended feasibility study report sections

1) **Abstract** (brief summary of the proposed research project)
2) **Introduction** (background information about the research area)
3) **Aim and objectives** (aim and objectives of proposed research project)
4) **Literature review** (review of the technical/academic literature)
5) **Research problem or question** (clearly identified)
6) **Research methodology** (type of research you will be conducting and why)
7) **Data collection and analysis** (specific data collection methods and analysis to be adopted)
8) **Ethical considerations** (relate to engineering ethics and professional standards)
9) **Research impact and sustainability** (identify proposed research impact and any sustainability outcomes)
10) **Project management plan** (work breakdown structure and Gantt chart/project schedule)
11) **Risk assessment** (identifies risks and mitigation measures)
12) **Conclusions** (concluding remarks)
13) **References** (references in LSBU Harvard style)
14) **Appendix** (any supporting material)

Specific report guidance and summative assessment

Task: Identify proposed research impact and any potential sustainability outcomes of the research

Description: *This section should detail how the research project relates to wider research impact and any sustainability outcomes. The envisaged research impact (such as academic knowledge, economic and societal aspects) should be identified, including discussion of how such impact could potentially be achieved. Additionally, where the research has the potential to link to sustainability outcomes should be identified and described according to the sustainable development goals (SDGs).*

Assessment: Marks awarded for evaluating the research impact and identifying specific links to the SDGs for the proposed research project

Final remarks

- Engineering education is based on developing skills and knowledge across the areas of science and mathematics as well as engineering analysis, design and practice – But students can benefit from gaining a broader perspective

- Degree programmes include an integral research project, and it is useful to consider the potential impact of the research as well as the possible link to sustainability and the SDGs

- The concept of sustainability and the SDGs as well as related theory (such as the TBL) can be included in traditional lectures combined with exercises, tutorials and reading tasks to reinforce learning (formative assessment)

- An ability to evaluate the research project and identify links to specific SDGs can be examined in the module assignment (summative assessment)

- Ultimately sustainability helps to improve the quality of our lives, protect the ecosystem and preserve natural resources for future generations – so it is vital that we maintain our focus on achieving this goal

Thank you for listening

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