Designing and manufacturing for sustainability

SCEnAT Lifecycle Platform

(Keynote)

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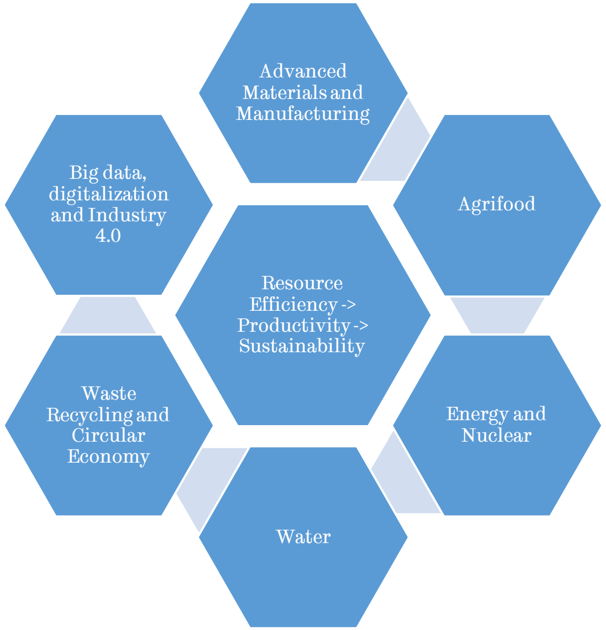
Advanced Resource Efficiency Centre (AREC)

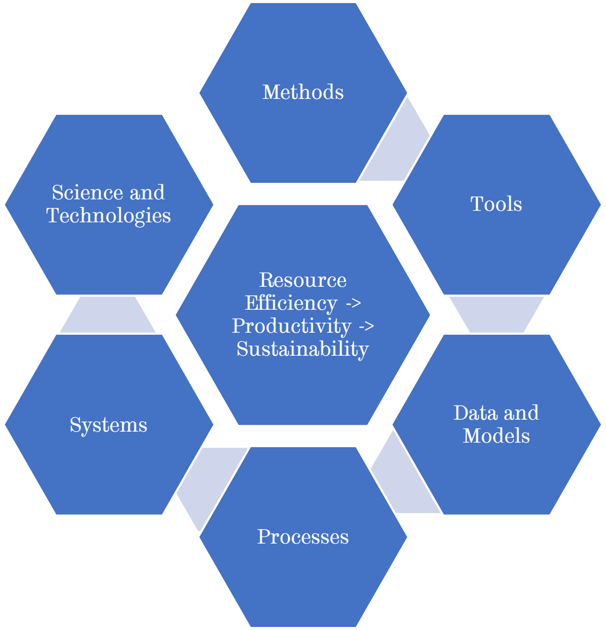


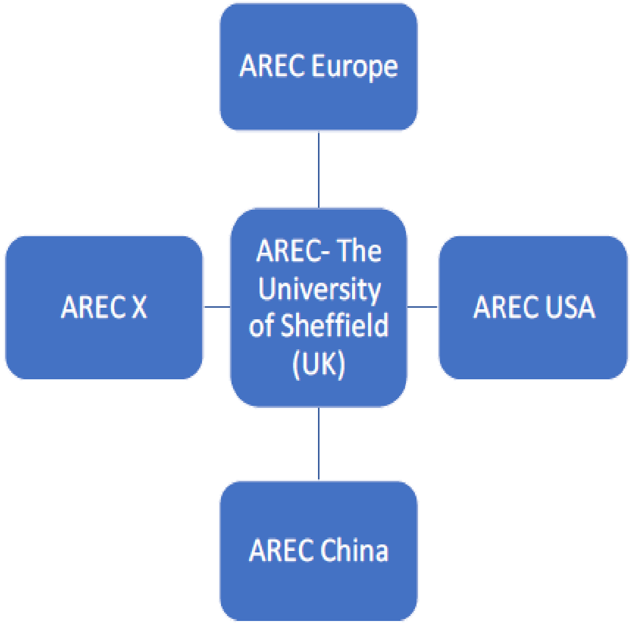
Multi-modal transport

Construction

Infrastructure

Smart system, AI and blockchain





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Energy Institute

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Research Pillars

Electrical energy storage

The Energy Institute carries out energy research across a wide spectrum of fields, including renewable, nuclear
And conventional energy generation, energy storage, energy use and carbon capture, utilisation and energy technology. Our Multi- and interdisciplinary research teams work with industry and government on sustainable solutions.

Nuclear

Wind

Circular economy

Conventional power

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Framework

- Global challenges and goals
- Strategy and policy (e.g. UK)
- **Physical** resources
- **Digital** resources
- **Autonomous** resources

Future industry

Future supply chain

Sustainability

Materials, Energy, Food, Water, Transport

Smart/Intelligent and Future Technology

AI, Blockchain, Robotic, New Manufacturing, New Recycling, New Energy, New Materials, 5G+, AR/MR, Industry 4.0+, IoT+, Edge and Cloud

Hybrid Methodology

LCA, I-O, TEA, OR, ML, DL

Future Government

Future society

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What really matters?

Image source: Pixabay

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UK Industrial Strategy

Our five foundations align to our vision for a transformed economy

5 foundations of productivity

- **Ideas** – the world's most innovative economy
- **People** – good jobs and greater earning power for all
- **Infrastructure** – a major upgrade to the UK's infrastructure
- **Business environment** – the best place to start and grow a business
- **Places** – prosperous communities across the UK

Four Grand Challenges to put the UK at the forefront of the industries of the future:

AI & Data Economy
We will put the UK at the forefront of the artificial intelligence and data revolution

Clean Growth
We will maximise the advantages for UK industry from the global shift to clean growth

Future of Mobility
We will become a world leader in the way people, goods and services move

Ageing Society
We will harness the power of innovation to help meet the needs of an ageing society

INDUSTRIAL STRATEGY

Source: UK Industrial Strategy

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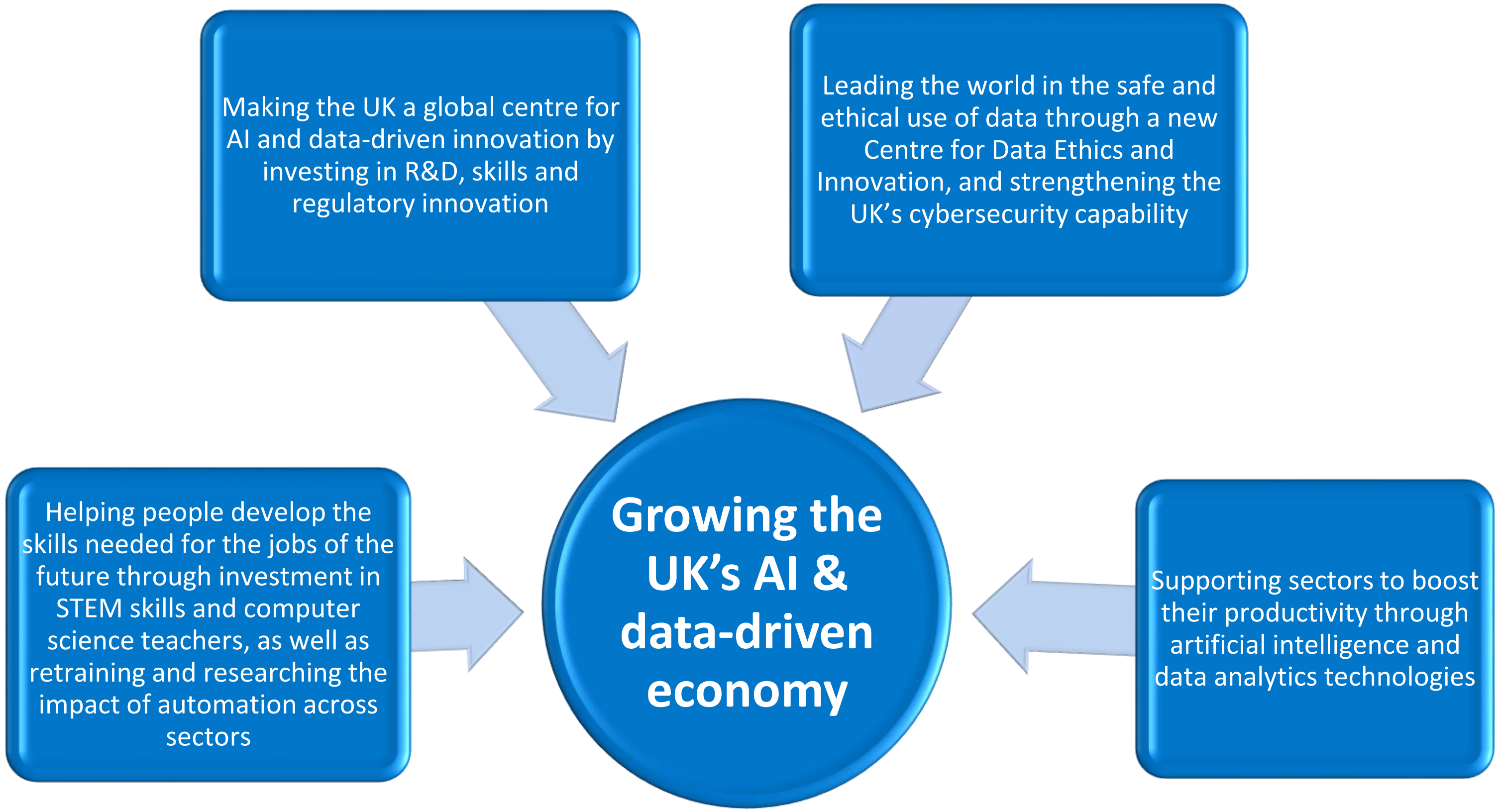
UK AI Sector Deal



Source: UK AI Sector Deal

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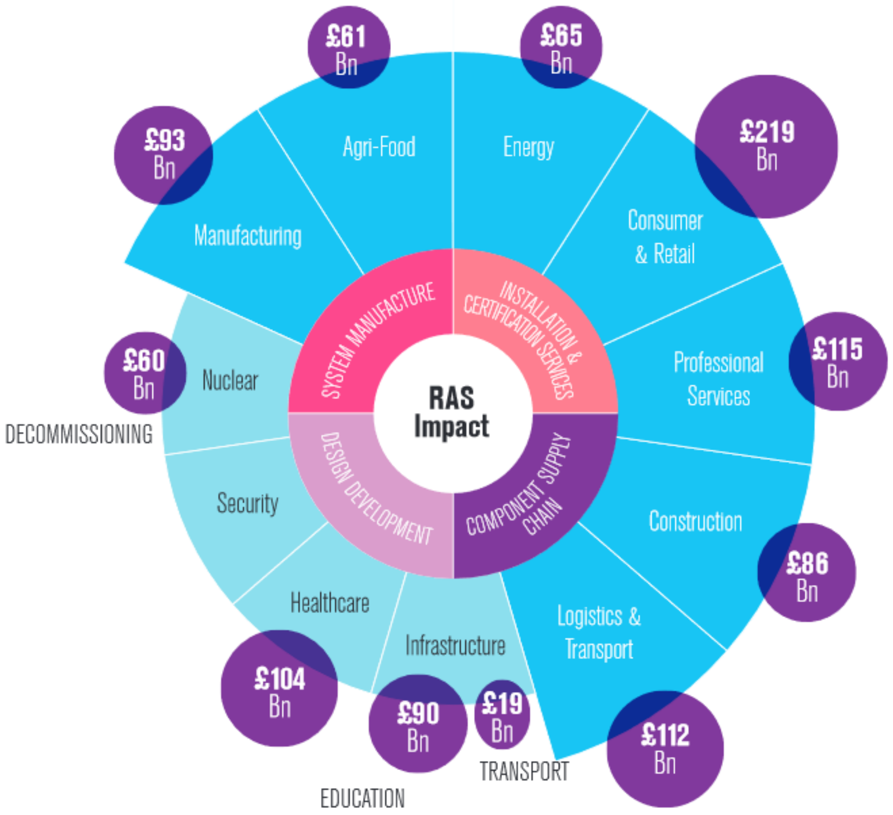
RAS 2020

Five interwoven strategic strands:

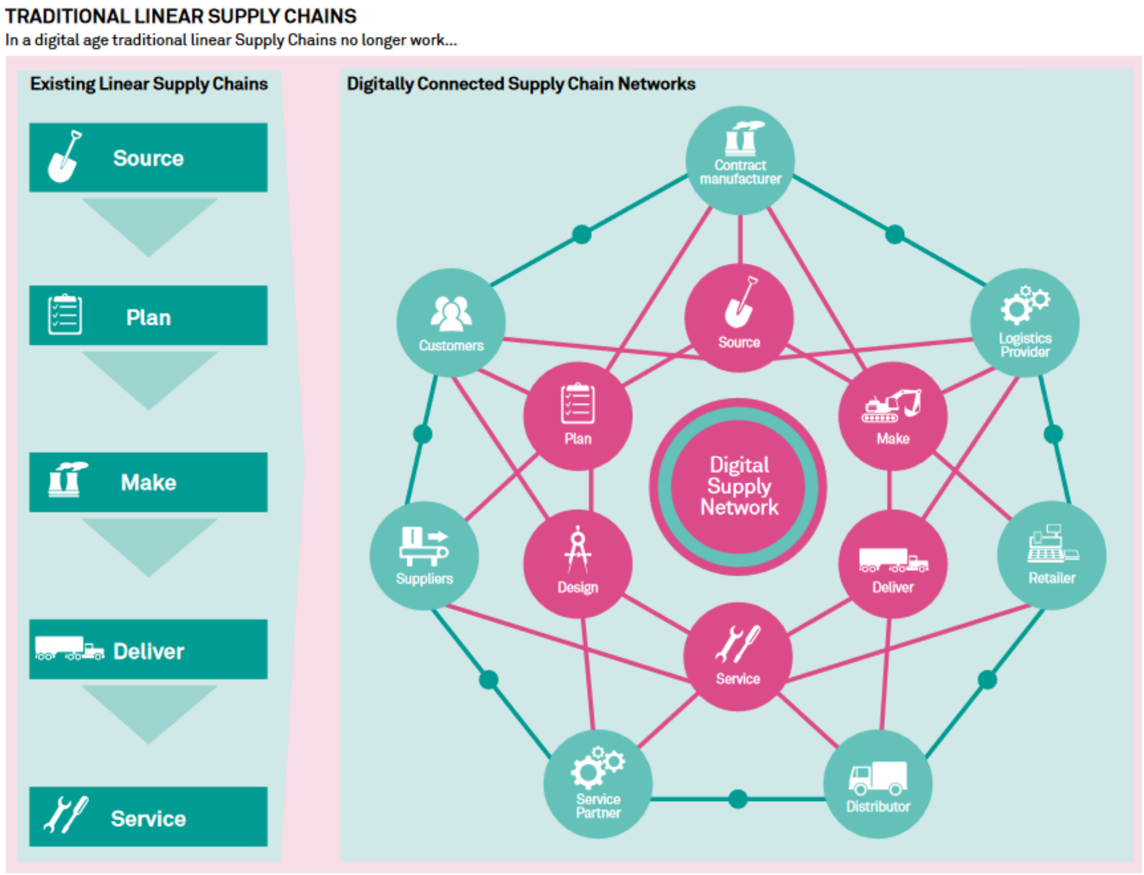
1. **RAS COORDINATION**
   Aligning the instruments of investment in research, business and regulation so that UK efforts form a cohesive, coherent innovation pipeline, shaping a common and competitive approach in different sectors.
1. **RAS ASSETS**
   Developing tangible and intangible assets from demonstration sites in farms, factories, oil and gas plants, nuclear facilities, roads, airports, homes and hospitals, to a flexible legal and regulatory environment, pervasive software skills and a willingness to try new ideas. These will make UK the RAS destination of choice for international research, innovation and market exploration.
1. **RAS GRAND CHALLENGES**
   Focusing competitions on real scenarios in vertical markets that "stimulate collaboration, identify the possibilities, and excite the public". Using the RAS Assets as staging grounds for a series of Grand Challenges will widen engagement and establish regulation ahead of the market.
1. **RAS CLUSTERS**
   Investing in locations to stimulate cross fertilisation and linkage between elements of the RAS supply chain. These clusters will bring together industry, academia, finance and innovators into ecosystems creating a gearing effect for success and establishing an innovation pipeline.
1. **RAS SKILLS**
   Developing the skills base and explaining the benefits of RAS technology is an inherent and essential part of achieving success.
   Implementation of this strategy requires a breadth of engagement between industry, academia, government and the investment community to capture the vision, enthusiasm and proposals that are essential to create a RAS industry in the UK.

Fig 1: represents the market sizes affected or disrupted by the introduction of new RAS products and services. The larger sectors in dark blue represent those market sectors where RAS will have an impact, whereas the smaller sectors in light blue represent areas where government expenditure will be impacted by RAS.



Source: RAS UK Strategy

Made Smarter



In bringing about this transition, a number of key technologies will be critical:

- Sensors, smart packaging, cloud-based storage and 5G. These will support the introduction of the IoT in supply chains, and will facilitate data collection, traceability and the development of a detailed understanding of a supply chain. Specifically, a network of connected sensors across plants and supply chains will enable asset tracking, condition monitoring, predictive maintenance and anti-counterfeiting solutions.
- Predictive analytics and PLM software. These will support data analysis, and provide flexibility and responsiveness within supply chains.
- Virtual reality, mobile and tablet technology and visualisation tools. These will support more active interaction with data and the real-time operations of a supply chain.
- Cybersecurity, digital trust tools and Blockchain. These will help provide the necessary assurance that connected supply networks are secure.

Source: Made Smarter, Review 2017

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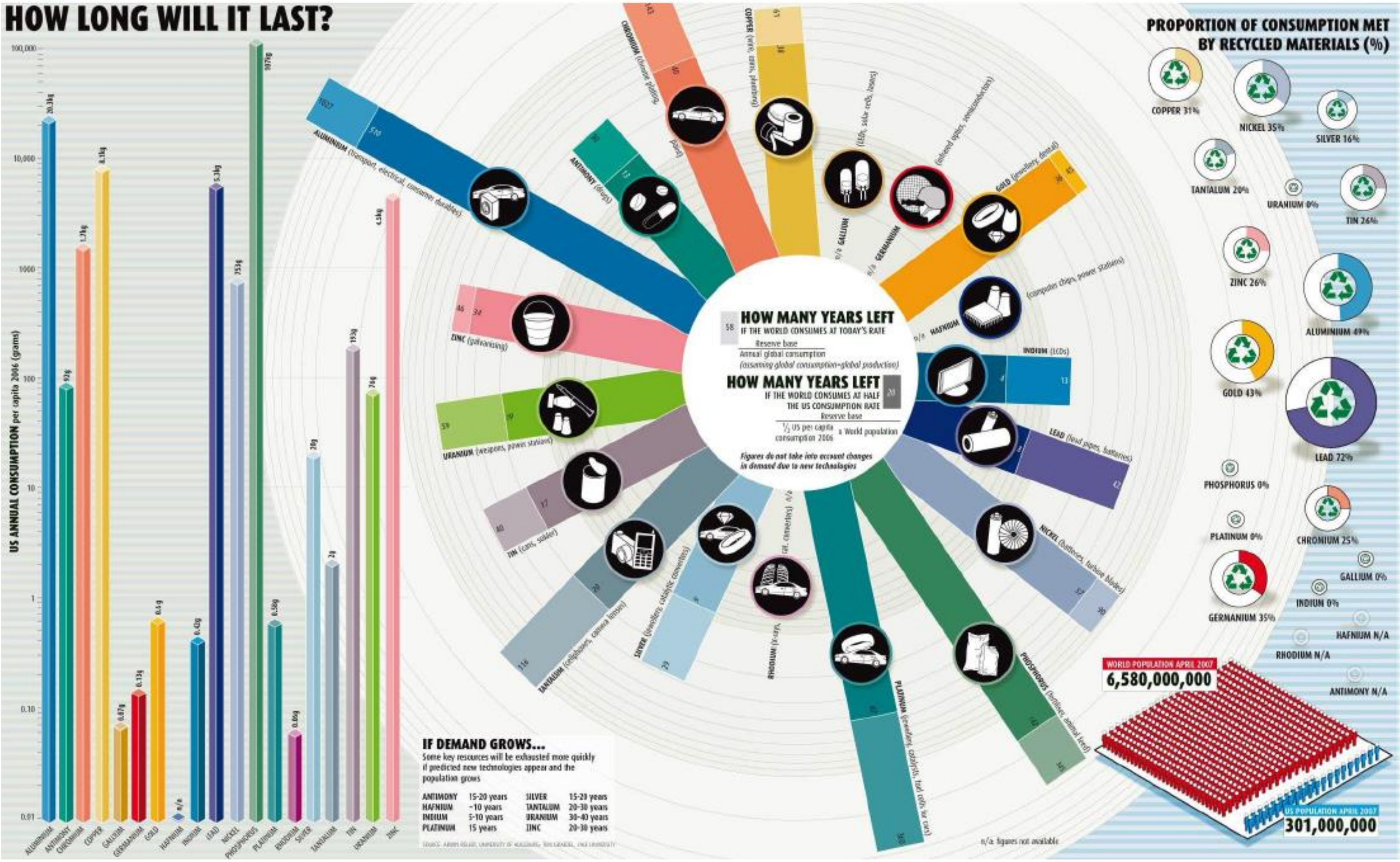
Physical


HOW LONG WILL IT LAST?
US ANNUAL CONSUMPTION per capita 2006 (grams)
HOW MANY YEARS LEFT
IF THE WORLD CONSUMES AT TODAY'S RATE
Reserve base / Annual global consumption (assuming global consumption=global production)
HOW MANY YEARS LEFT
IF THE WORLD CONSUMES AT HALF THE US CONSUMPTION RATE
Reserve base / ½ US per capita consumption 2006 x World population
Figures do not take into account changes in demand due to new technologies
PROPORTION OF CONSUMPTION MET BY RECYCLED MATERIALS (%)
COPPER 31%
NICKEL 35%
SILVER 16%
TANTALUM 20%
URANIUM 0%
TIN 26%
ZINC 26%
ALUMINIUM 49%
GOLD 43%
LEAD 72%
PHOSPHORUS 0%
PLATINUM 0%
CHROMIUM 25%
GALLIUM 0%
INDIUM 0%
GERMANIUM 35%
HAFNIUM N/A
RHODIUM N/A
ANTIMONY N/A
WORLD POPULATION APRIL 2007
6,580,000,000
US POPULATION APRIL 2007
301,000,000
IF DEMAND GROWS...
Some key resources will be exhausted more quickly if predicted new technologies appear and the population grows
ANTIMONY 15-20 years
HAFNIUM ~10 years
INDIUM 5-10 years
PLATINUM 15 years
SILVER 15-20 years
TANTALUM 20-30 years
URANIUM 30-40 years
ZINC 20-30 years
n/a figures not available

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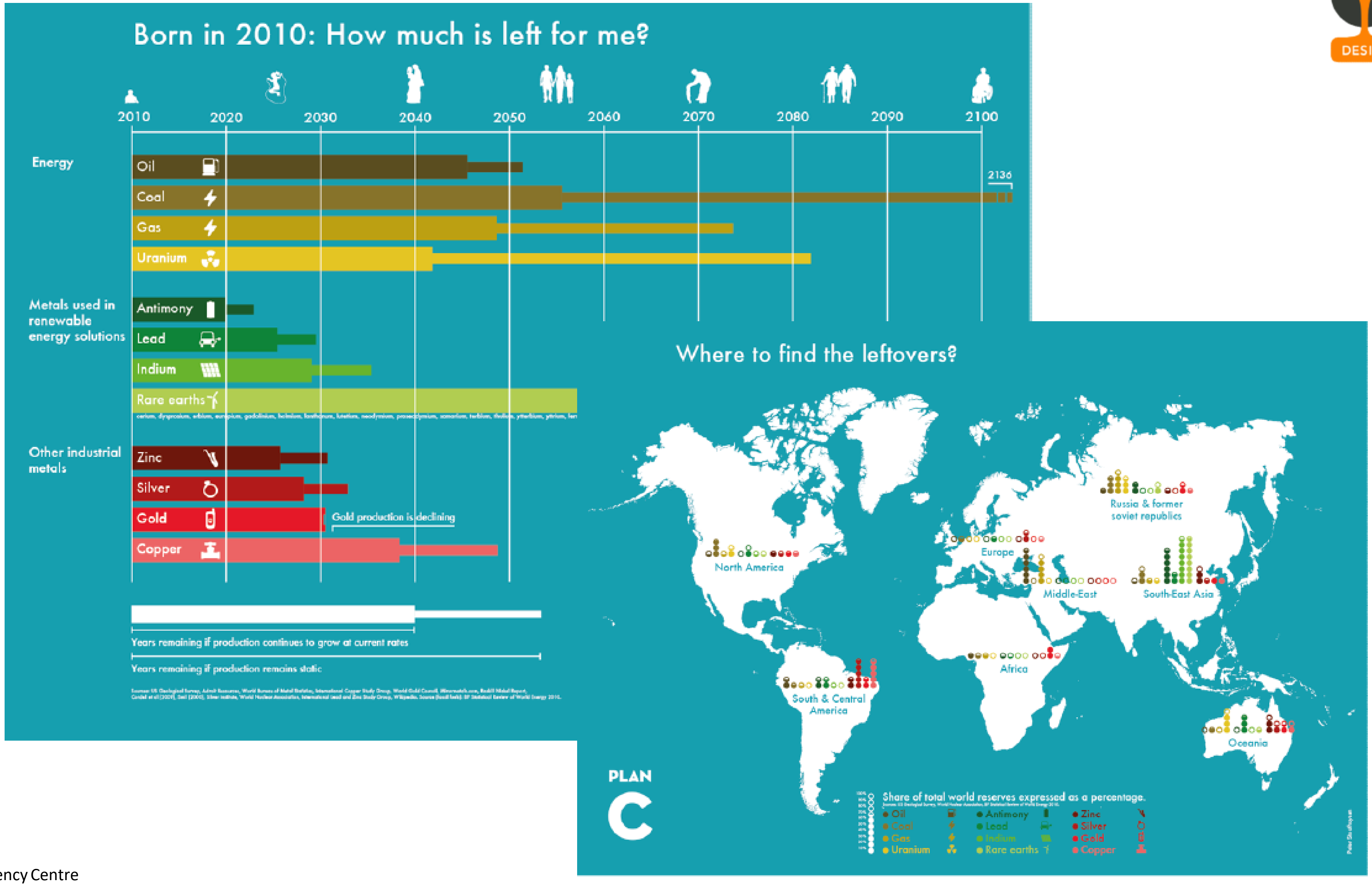
DARE
DESIGNING ALLOYS for RESOURCE EFFICIENCY



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www.nature.com/scientificreports

SCIENTIFIC REPORTS

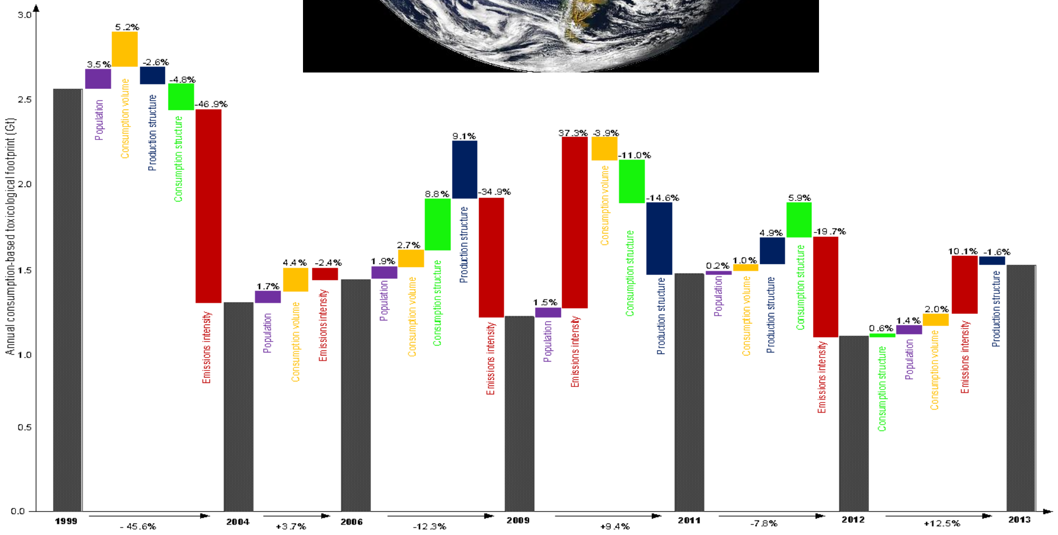
OPEN

Drivers of U.S. toxicological footprints trajectory 1998–2013

S. C. L. Koh[1,2], T. Ibn-Mohammed[1,2], A. Acquaye[3], K. Feng[4], I. M. Reaney[5], K. Hubacek[4,6], H. Fujii[7] & K. Khatab[8]

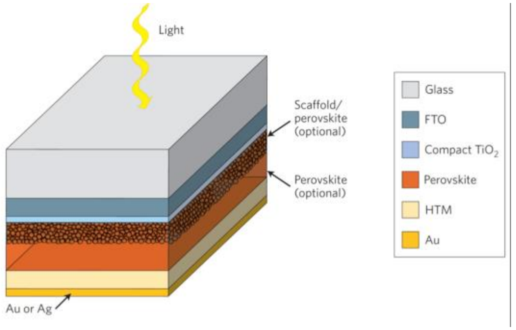
Received: 21 June 2016
Accepted: 24 November 2016
Published: 21 December 2016

By exploiting data from the Toxic Release Inventory of the United States, we have established that the toxicological footprint (TF) increased by 3.3% (88.4 Mt) between 1998 and 1999 and decreased by 39% (1088.5 Mt) between 1999 and 2013. From 1999 to 2006, the decreasing TF was driven by improvements in emissions intensity (i.e. gains in production efficiency) through toxic chemical management options: cleaner production; end of pipe treatment; transfer for further waste management; and production scale. In particular, the mining sector reduced its TF through outsourcing processes. Between 2006 and 2009, decreasing TF was due to decrease in consumption volume triggered by economic recession. Since 2009, the economic recovery increased TF, overwhelming the influence of improved emissions intensity through population growth, consumption and production structures. Accordingly, attaining a less-toxic

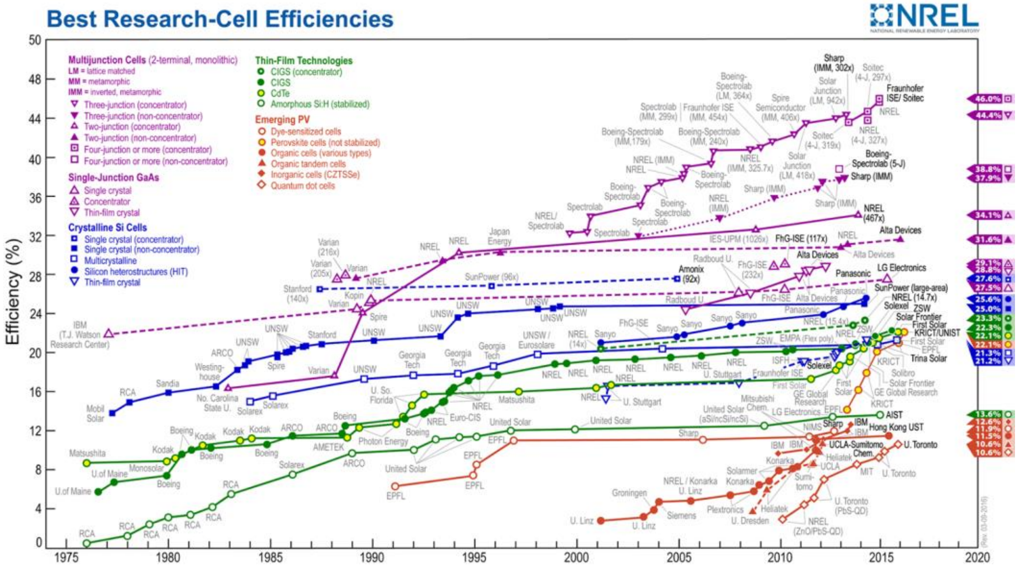


Renewable and Sustainable Energy Reviews

- Perovskite Solar Cells: An Integrated Hybrid Lifecycle Assessment and Review in Comparison with other Photovoltaic Technologies (2015)
- A comparison of environmental and energetic performance of European countries: A sustainability index (2016)
- WEEE and e waste recycling worth 3.7 billions euro (2015)



Materials	% Revenues
Gold	50.4
Copper	13.9
Palladium	9.5
Plastics	9.2
Silver	3.6
Aluminium	2.5
Tin	2.0
Barium	1.8
Platinum	1.7
Cobalt	1.6



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Circular economy and electronic waste recycling

Circular economy and electronic waste

Electronic waste is the fastest growing category of hazardous solid waste in the world. Addressing the problem will require international collaboration, economic incentives that protect labour, and management approaches that minimize adverse impacts on the environment and human health.

Abhishek Kumar Awasthi, Jinhui Li, Lenny Koh and Oladele A. Ogunseitan

The quantity of hazardous electronic waste (e-waste) circulating in the world is now estimated to be more than 6 kg per person, totalling 44.7 million metric tonnes in 2016[1]. Despite international policies designed to restrict transboundary movement of hazardous wastes, the problem of global e-waste is exacerbated by illegal trade and 'informal' rudimentary recycling[2]. Rudimentary processing of e-waste occurs in many parts of the world, especially in emerging market economy countries such as China, Ghana, India and Nigeria, and the process generates toxic residues and emissions to air, soil and water[3] (Fig. 1). The United Nation's Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (known as the Basel Convention) has been influential in framing the debate on e-waste management. For example, the first international recognition of e-waste as a high-priority waste stream was developed with the UN's guidance in 2002[4], and the Solving the E-waste Problem (StEP)

Fig. 1 | **Approaches to electronic waste dismantling. a–e**, There is a marked difference between formal e-waste dismantling, such as Apple's Daisy robot (**a**), and manual dismantling, such as that in the Agbogbloshie market sector in Accra, Ghana (**b**). Informal e-waste resource recovery leads to environmental pollution (**c**), while stockpiles of e-waste awaiting recycling in government-approved facilities on the outskirts of Beijing, China, continue to grow (**d**,**e**), requiring urgent solutions. Credit: photograph in panel **a** courtesy of Apple, Inc.; photographs in panels **b**–**e** taken on location by O.A.O.

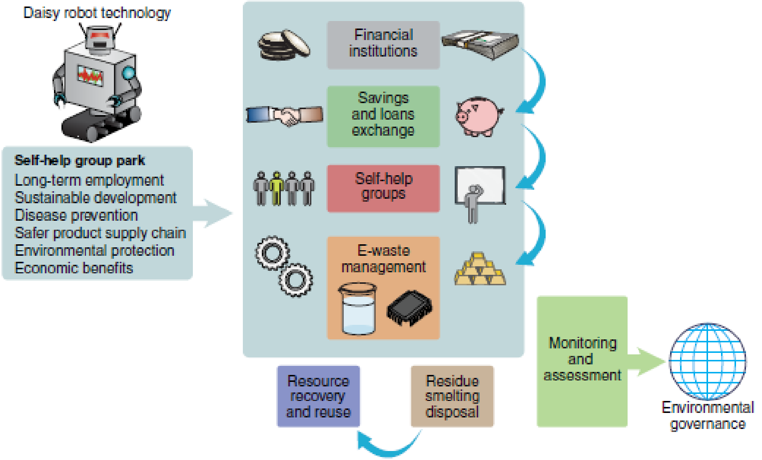

Fig. 2 | **Illustration of a simplified self-help group park.** The park could use Apple's Daisy robot, or similar technical assistance, and financial infrastructure as a model for supplementing a circular economy on e-waste management in developing countries. The motivation for establishing self-help groups (SHGs), depicted in the box under robotic technology, include benefits to labour, public health, environmental protection, economic productivity and boosts for sustainable development. In order to scale up to support e-waste management at the national level in developing countries these SHG parks need support either through the microfinancial systems of the banks offering initial financial provisions, or through corporate social responsibility funding by involving experienced institutions/organizations to promote the SHG formation — and this must be implemented under the umbrella of the environmental regulatory authority of the country. Closing the current gaps in the circular economy framework for electronic waste will also require continuous monitoring and assessment to support the shift from waste disposal to recycling and resource recovery.

EPR should begin with a collective 'superfund' mechanism through which all electronic product manufacturers contribute financially, and manufacturers should be compensated for the adoption of green chemistry or eco-design principles that avoid the use of hazardous materials, which endanger environmental quality and human health anywhere in the life cycle of their products[4]. To be effective, the EPR superfund must also include end-of-life recovery of used products and reuse of recovered materials, whereby manufacturers contribute funds proportionate to the number of products sold, and an independent agency designs and implements strategies for the collecting, sorting and recycling of defunct electronic products worldwide. This CE model may be more attainable for large, easily marked and tracked electronic products for which technical knowledge of repairing or refurbishing them is not widely available to the workforce engaged in resource recovery in emerging market economies. For this category of e-waste, prevention of unsafe and unprincipled rudimentary recycling is a priority for integration into the proposed EPR superfund and CE framework.

Designing effective EPR for most high-volume electronic products, such as mobile phones, laptop computers and televisions, which dominate the e-waste stream, will require engaging local entrepreneurial stakeholders with minimally restrictive regulatory and policy instruments.

Advanced Resource Efficiency Centre

editorial

The road to recovery

Electronic waste is a global problem that requires global action.

Between April and September of 2017, the environmental watchdog Basel Action Network (BAN) attached GPS trackers to various pieces of old electronic equipment and left them at recycling centres across Europe[1]. Of the 314 discarded devices, which included liquid-crystal displays, cathode-ray tube monitors, desktop computers and printers, 19 were found to have been exported out of the country they had been left in. The exported items travelled a combined distance of 78,408 kilometres and 11 of them ended up in developing countries, including Nigeria, Ghana, Pakistan and Thailand — exports that are likely to have been illegal.

Under the Basel Convention — an international treaty that concerns the movement of hazardous waste between nations and aims to prevent the dumping of waste in developing countries — all of the tagged electronics would be classified as

Manual electronic waste dismantling at the Agbogbloshie market sector in Accra, Ghana. Credit: Oladele A. Ogunseitan

Published online: 15 March 2019
https://doi.org/10.1038/s41928-019-0231-4

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EPSRC: Redefining Single Use Plastic

The University of Sheffield's 'Plastics - Redefining Single Use' project, looks at single-use plastics in food and fast-moving consumer goods packaging, as well as their plastic ingredients and medical products.
Four cross-disciplinary teams will address the circular plastic economy from a technological perspective to understand how societal behaviour adapts to increased environmental understanding, regulatory nudges, intervention, and new product development.

The project is funded via the £20 million Plastics Research and Innovation Fund, managed by UK Research and Innovation, the Fund is engaging Britain's best scientists and innovators to help move the country towards more circular economic and sustainable approaches to plastics.

UK Research and Innovation

https://epsrc.ukri.org/newsevents/multimedia/plastics-redefining-single-use/

ReTraCE: Realising the Transition towards the Circular Economy

€4 million research project to train a new cohort of thought leaders to drive the transition towards a more sustainable mode of production and consumption in Europe over the coming decades. This is part of the AREC Waste recycling and Circular Economy research theme.

Realising the Transition to the Circular Economy (ReTraCE) is a research project funded by Horizon 2020 EU's Marie Skłodowska-Curie Innovative Training Networks and will support the implementation of the European Commission's Circular Economy strategy.

The University of Sheffield (UK), The University of Kassel (Germany), Parthenope University of Naples (Italy), Olympia Electronics S.A (Greece), Tata Steel (UK), University of Kent (UK), ABIS - Academy of Business in Society (Belgium), Dalarna University (Sweden), Rotterdam School of Management, Erasmus University (Netherlands), and SEERC - The South-East European Research Centre (Greece).

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Digital

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scenat

Microsoft

SCEnAT 4.0

Power BI

Azure

SCEnAT AI

SCEnAT GIS

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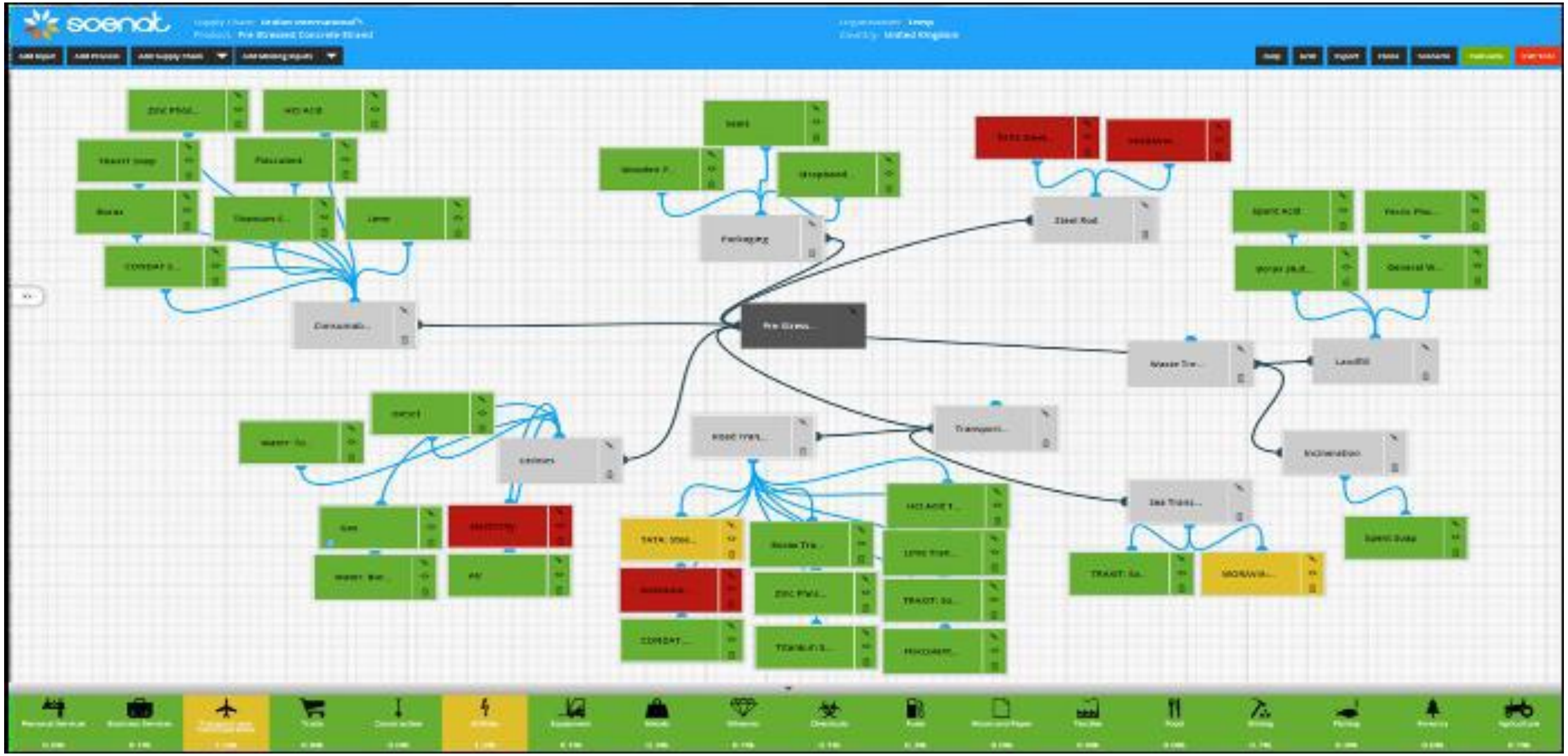
Example SCEnAT Suites



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Example SCEnAt Suites Digital Dashboard

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ARECCreating the Supply Chain of the Future.

SCEnAT 4.0

SCEnAT 4.0 is the most advanced edition of the SCEnAT Cloud based suites. It is designed to serve the Industry 4.0 era by converging the digital, AI and Azure Cloud capabilities of Microsoft with the research of The University of Sheffield Advanced Resource Efficiency Centre on sustainable resources to predict and understand future resources impact on economic, environment and social on the planet and society.

Open Databases:

THE WORLD BANK IBRD • IDA

Google Earth Engine

NASA

FAO Statistics

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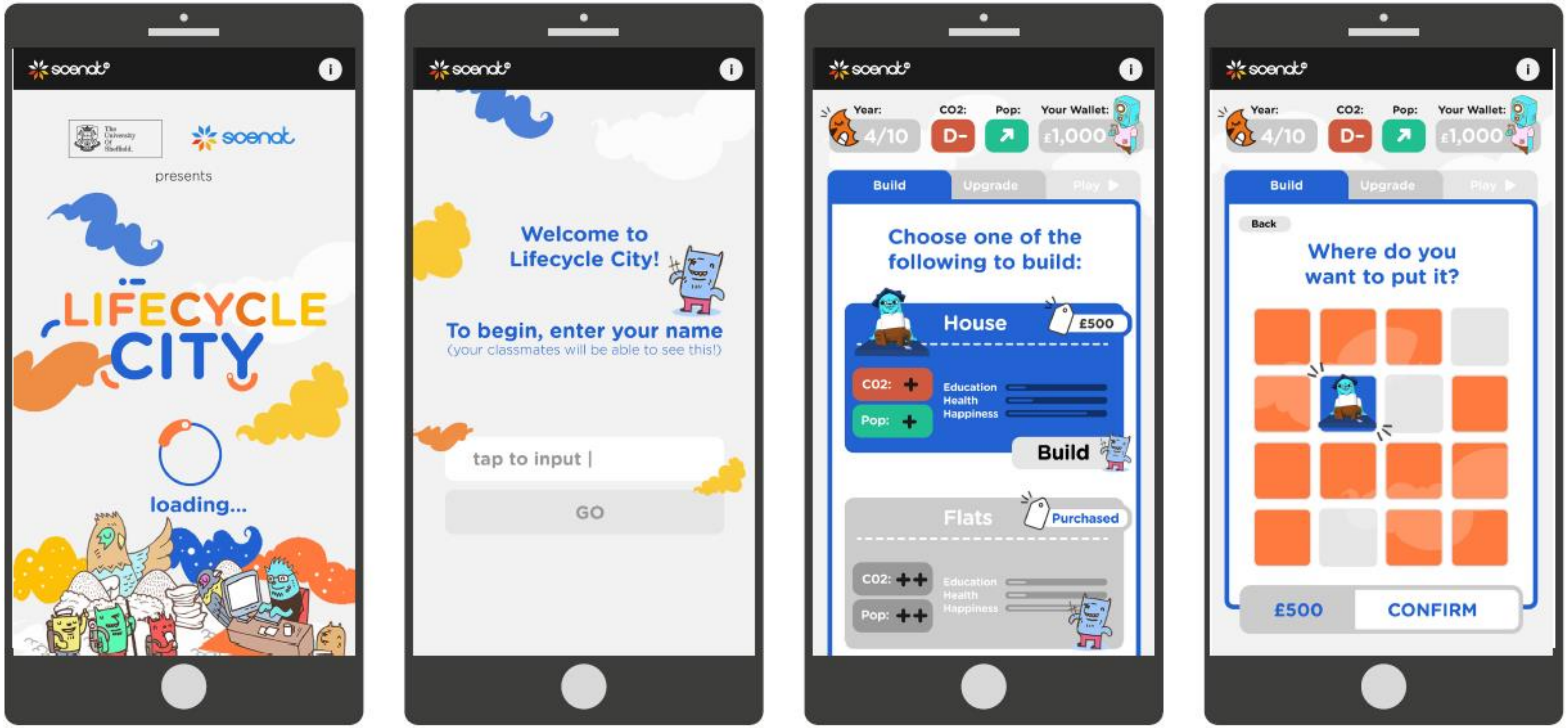
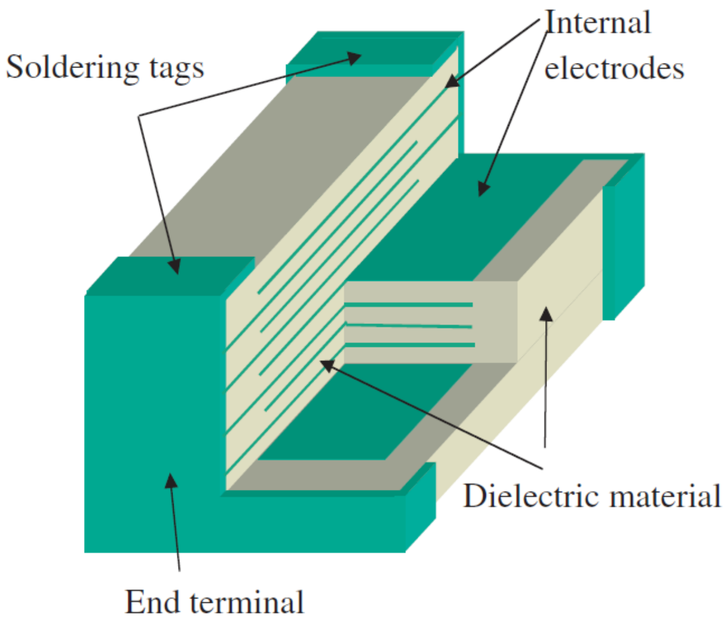
SCEnAT*AR* Lifecycle City Game

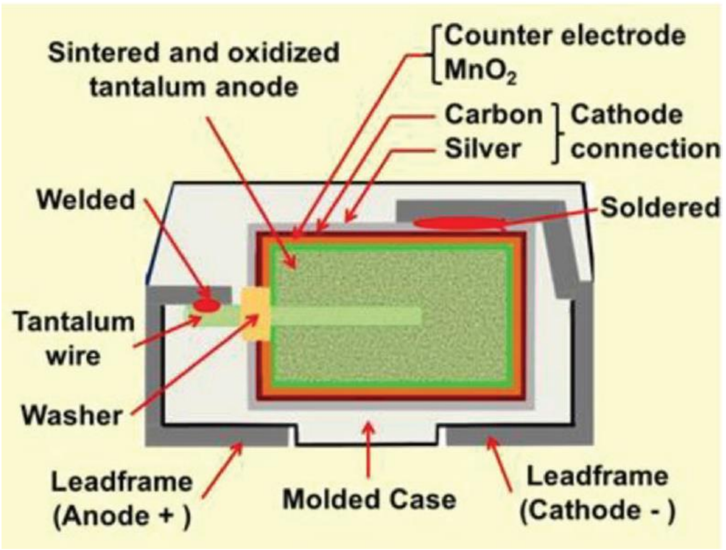


Hybrid LCA of Capacitors



Internal view of MLCC

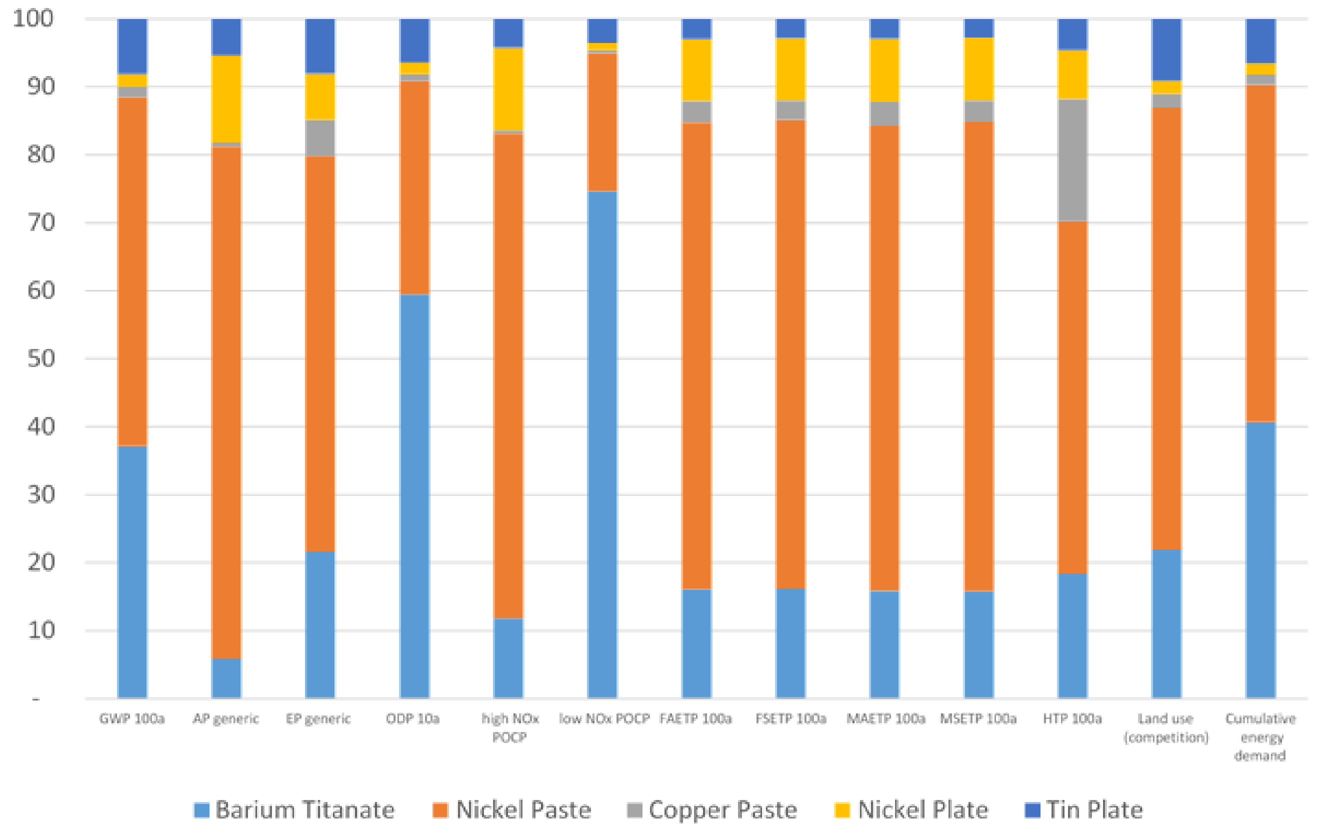
Hiroshi Kishi et al 2003 Jpn. J. Appl. Phys. 42, 1



Internal view of TEC

Both, J 2016 IEEE Electrical Insulation Magazine, 32, 2

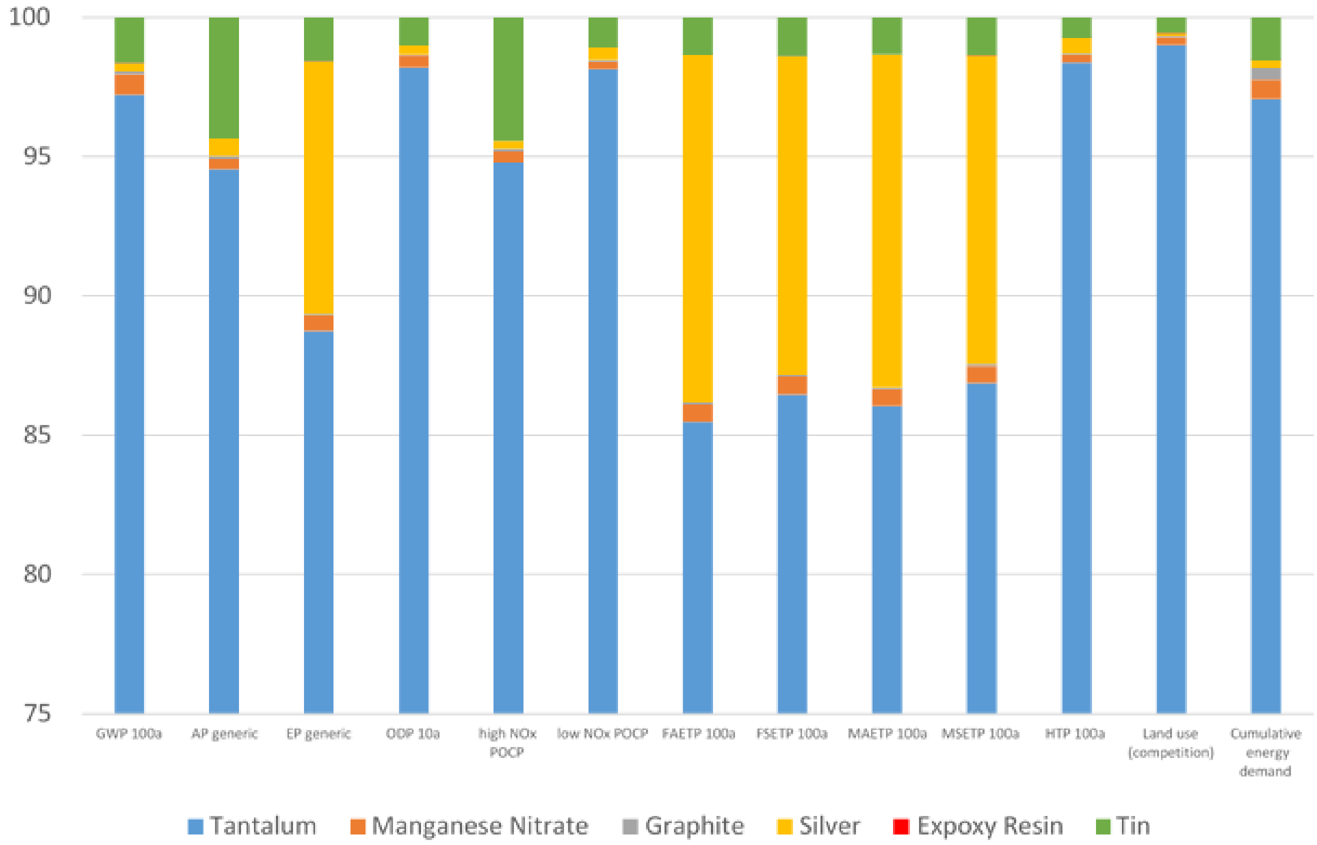
Hybrid LCA of MLCCs



Percentage contribution of each MLCC manufacturing component for the environmental impacts investigated.

Smith. L et al., Applied Energy, 220 (2018) 496-513

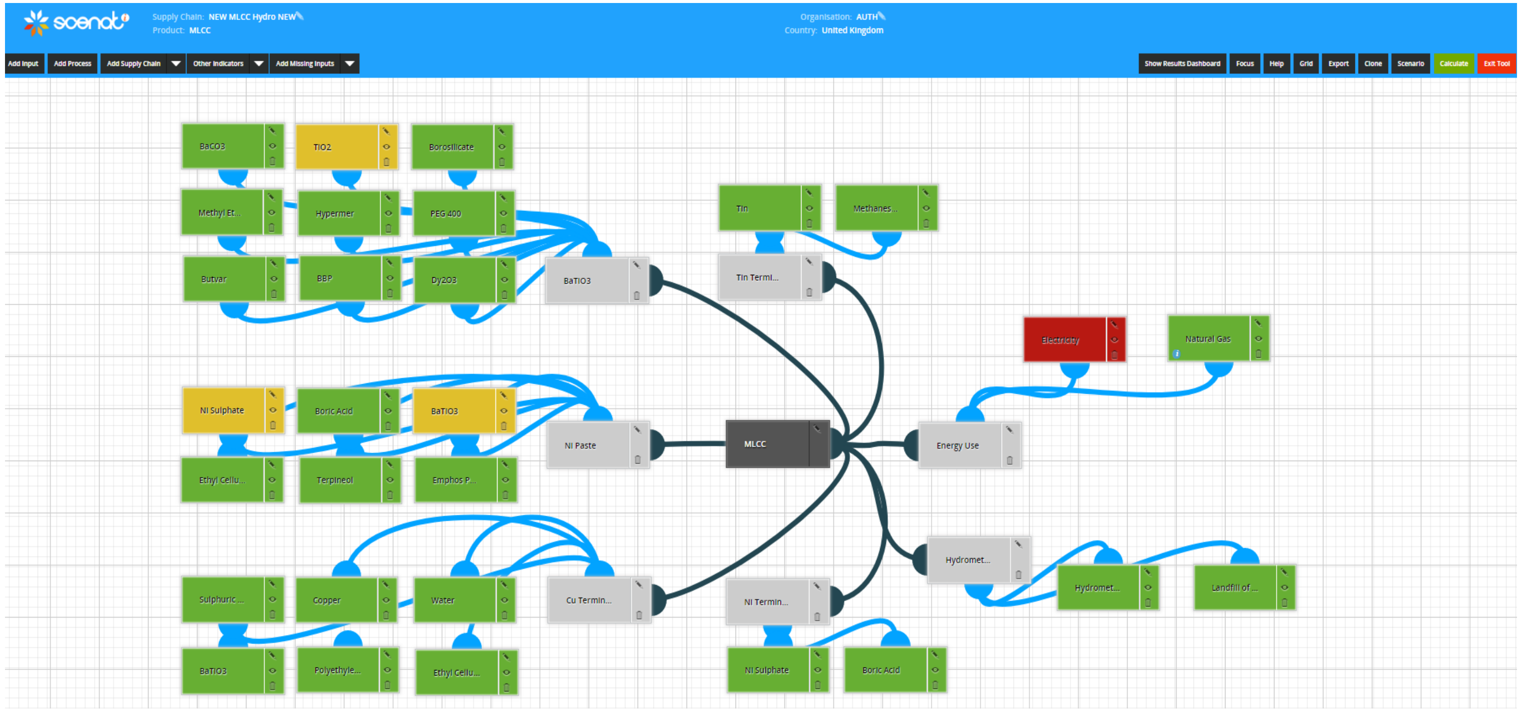
Hybrid LCA of TECs



Percentage contribution of each TEC manufacturing component for the environmental impacts investigated.

Smith. L et al., Applied Energy, 220 (2018) 496-513

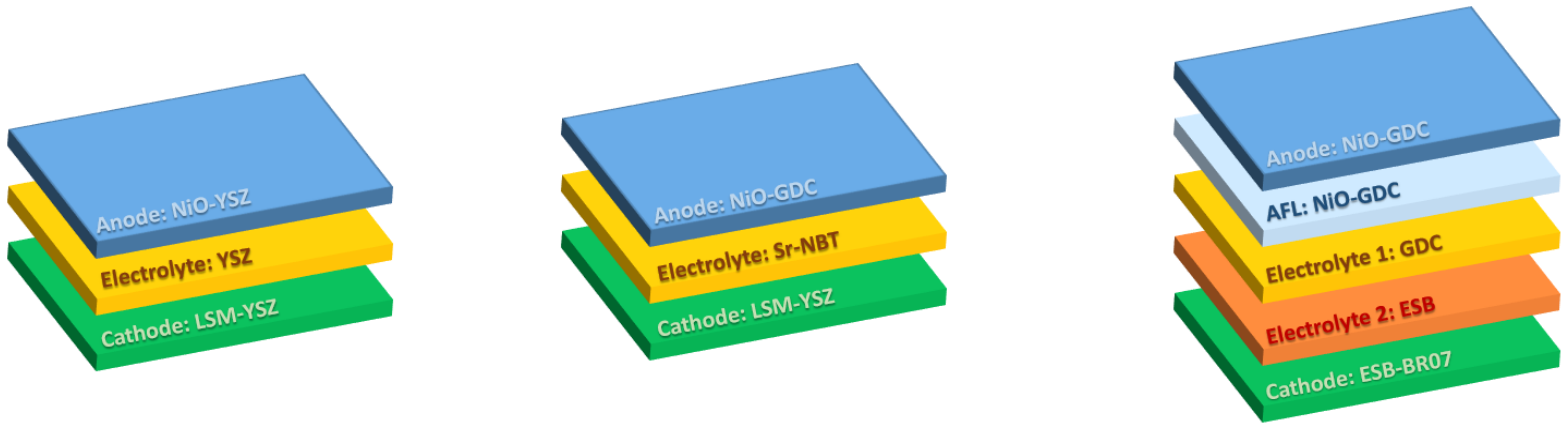
Hybrid LCA of TECs



SCEnAT*i* supply chain map for a MLCC showing the carbon hotspots

Smith. L et al., Applied Energy, 220 (2018) 496-513

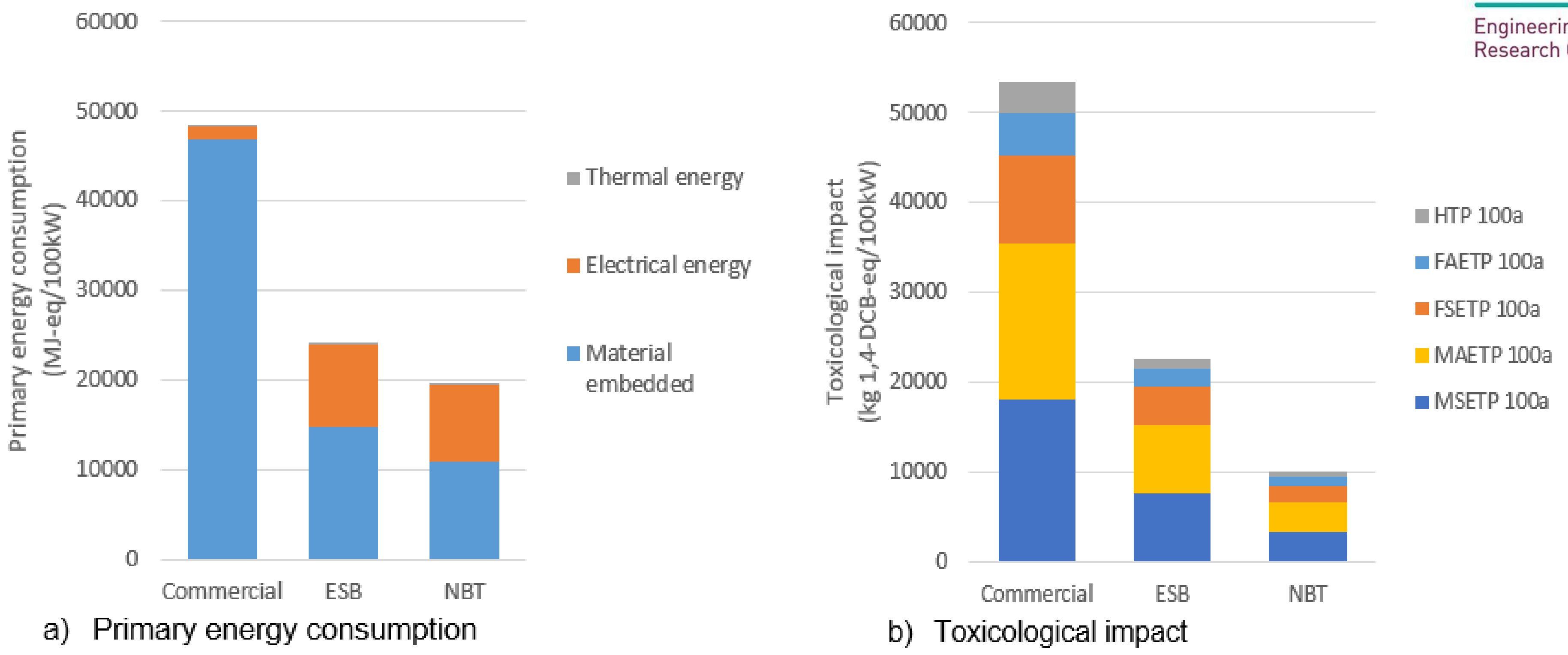
Hybrid LCA of SOFCs



Schematic of the three SOFC architectures studied in this article; from left to right: The Commercial HT-SOFC; the IT-SOFC with NBT electrolyte; the IT-SOFC with ESB electrolyte.

Smith. L et al., Applied Energy, 235 (2019) 1300-1313

Hybrid LCA of SOFCs



The comparison of the Commercial, NBT and ESB SOFC material structures for a) primary energy demand and b) toxicological footprint.

Smith. L et al., Applied Energy, 235 (2019) 1300-1313

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Energy & Environmental Science

ROYAL SOCIETY OF CHEMISTRY

ANALYSIS

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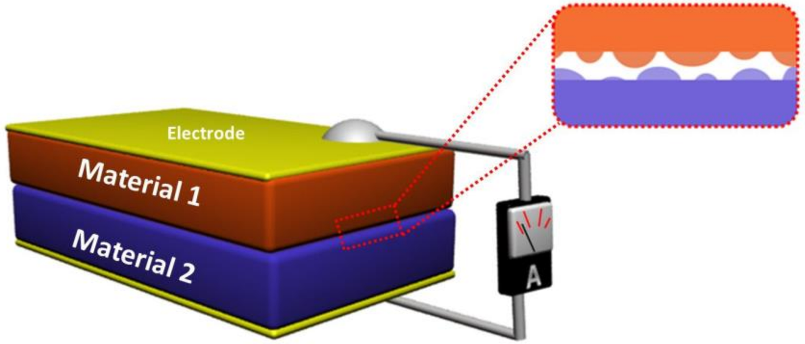
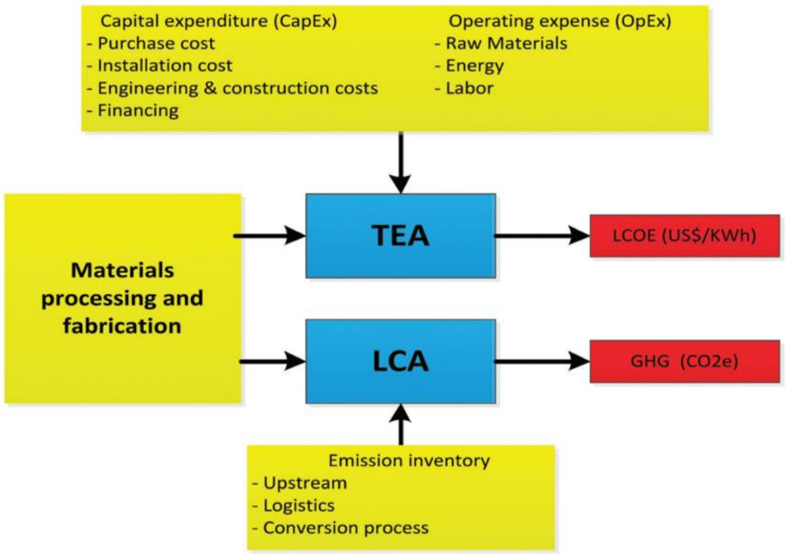
Cite this: DOI: 10.1039/c7ee00158d

Environmental life cycle assessment and techno-economic analysis of triboelectric nanogenerators†

Abdelsalam Ahmed,‡[ab] Islam Hassan,‡[bc] Taofeeq Ibn-Mohammed,‡[de] Hassan Mostafa,[fg] Ian M. Reaney,[h] Lenny S. C. Koh,[de] Jean Zu[b] and Zhong Lin Wang*[ai]

As the world economy grows and industrialization of the developing countries increases, the demand for energy continues to rise. Triboelectric nanogenerators (TENGs) have been touted as having great potential for low-carbon, non-fossil fuel energy generation. Mechanical energies from, amongst others, body motion, vibration, wind and waves are captured and converted by TENGs to harvest electricity, thereby minimizing global fossil fuel consumption. However, only by ascertaining performance efficiency along with low material and manufacturing costs as well as a favorable environmental profile in comparison with other energy harvesting technologies, can the true potential of TENGs be established. This paper presents a detailed techno-economic lifecycle assessment of two representative examples of TENG modules, one with a high performance efficiency (Module A) and the other with a lower efficiency





EPSRC
Engineering and Physical Sciences Research Council

The University Of Sheffield.

Issue 11, 2016

Previous Article | Next Article

From the journal:
Energy & Environmental Science

Integrated hybrid life cycle assessment and supply chain environmental profile evaluations of lead-based (lead zirconate titanate) *versus* lead-free (potassium sodium niobate) piezoelectric ceramics

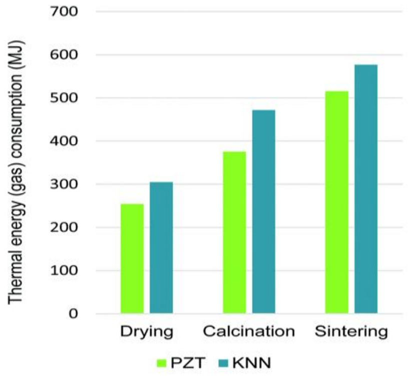
Check for updates

T. Ibn-Mohammed,*[ab] S. C. L. Koh,[ab] I. M. Reaney,[c] A. Acquaye,[d] D. Wang,[c] S. Taylor[e] and A. Genovese[f]

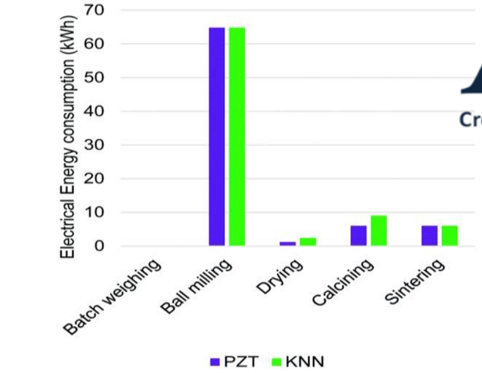
Author affiliations

Abstract

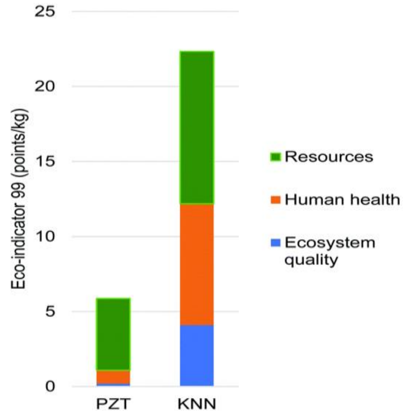
The increasing awareness of the environmental and health threats of lead as well as environmental legislation, both in the EU and around the world targeted at decreasing the use of hazardous substances in electrical appliances and products has reinvigorated the race to develop lead-free alternatives to lead zirconate titanate (PZT), which presently dominates the market for piezoelectric materials. Emphasis has been placed on one of the most likely piezoelectric materials, potassium sodium niobate (KNN), as a lead-free replacement for PZT. KNN has been speculated to have better environmental credentials and is considered as a "greener" replacement to PZT. However, a comparative environmental impact assessment of the life cycle phases of KNN *versus* PZT piezoelectric materials has not been carried out. Such a life cycle assessment is crucial before any valid claims of "greenness" or environmental viability of one material over the other can be made and is the focus of this paper. Against this backdrop, a methodologically robust life cycle supply chain assessment based on integrated hybrid life cycle framework is undertaken within the context of the two piezoelectric materials. Results show that the presence of niobium in KNN constitutes far greater impact across all the 16 categories considered in comparison with PZT. The increased environmental impact of KNN occurs in the early stages of the LCA due to raw material extraction and processing. As a result, the environmental damage has already occurred before its use in piezoelectric applications during which it doesn't constitute any threat. As such, the use of the term "environmentally friendly" for the description of KNN should be avoided. Cost-benefit analysis of



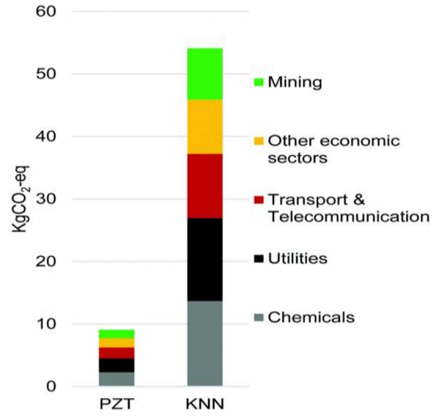
(a) Thermal energy comparison



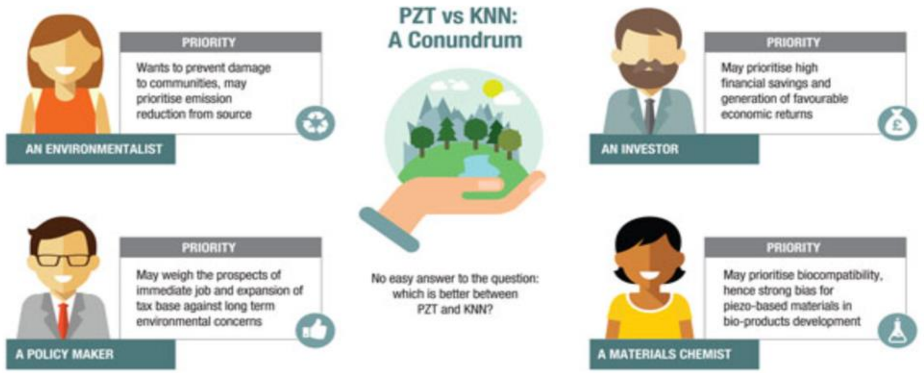
(b) Electrical energy comparison



(c) Eco-indicator comparison



(d) IO upstream GHG comparison



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EPSRC
Engineering and Physical Sciences Research Council

Autonomous

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4th Industrial Revolution

Industry 1.0

Mechanical

- The mechanical weaving loom
- Water power
- Steam power

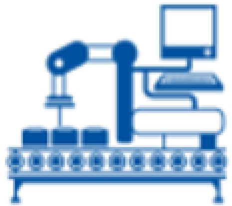
1760-1840

Industry 2.0

Electrical

- First production line
- Mass production using electrical energy

1830s-1915



Industry 3.0

Internet

- Nuclear energy
- Programmable logic controller (PLC)
- Use of electronics and IT for further automation

1969-2010s

Industry 4.0

Digital

- Digitization/Integration of value chains
- Digitization of product and service offerings
- Digital business models and customer access

Today

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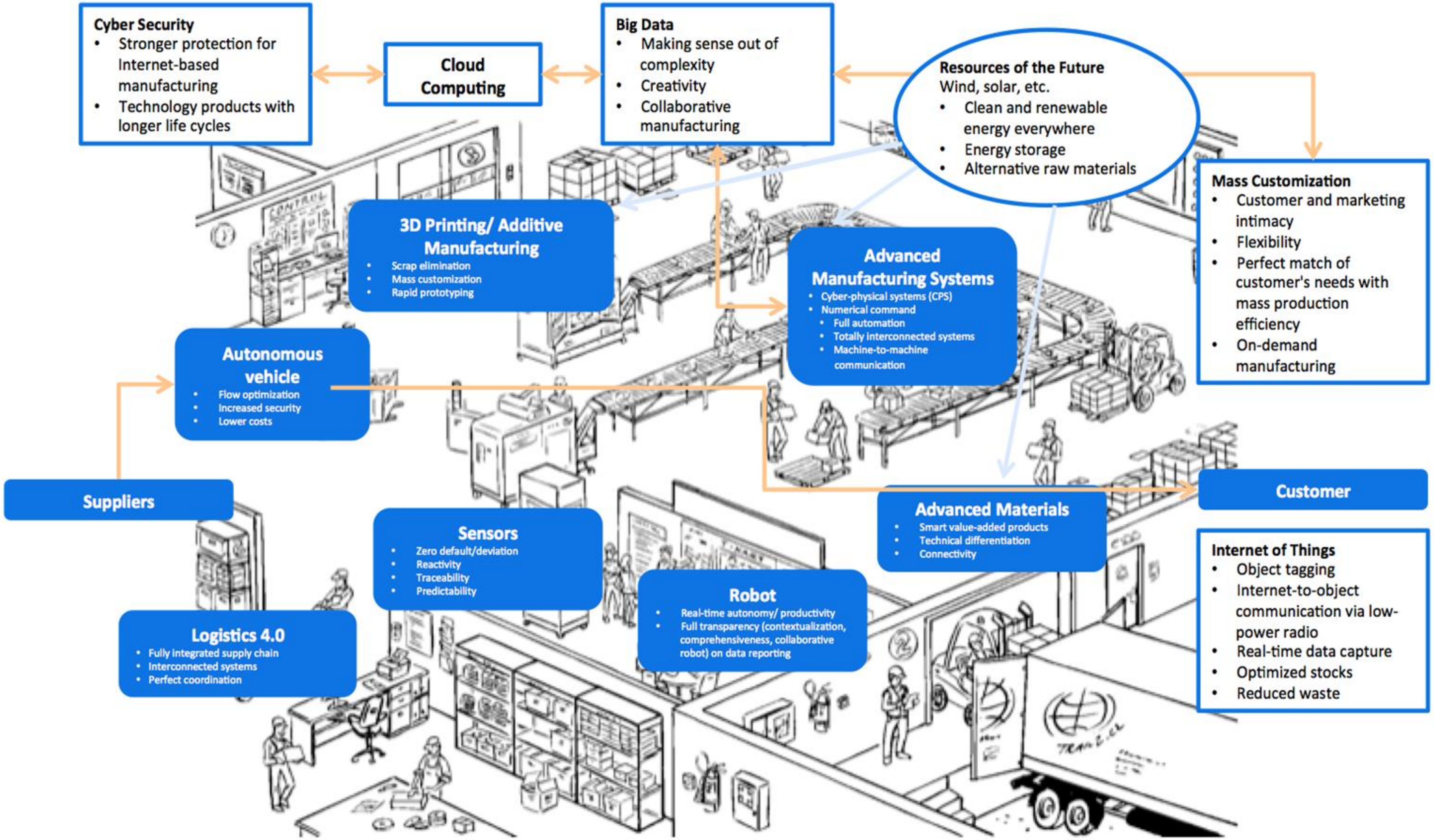
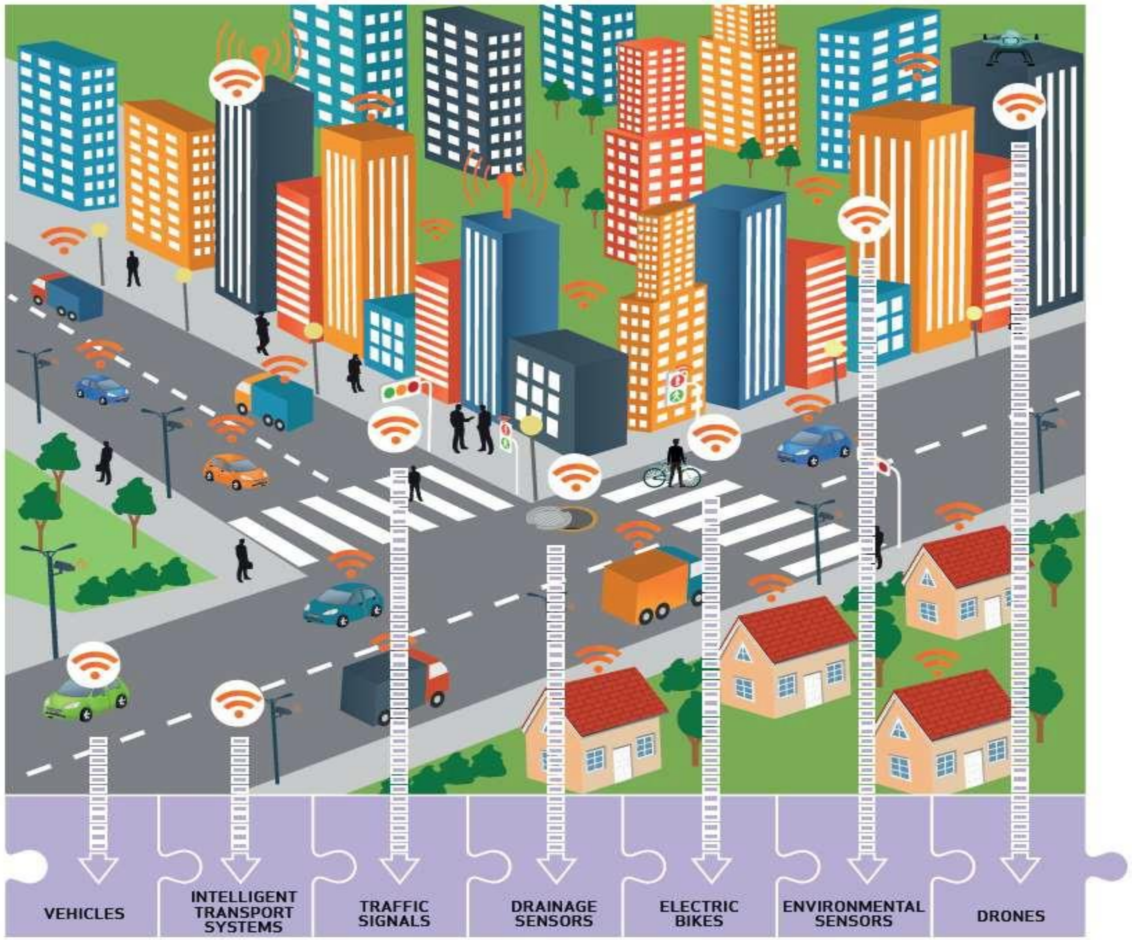
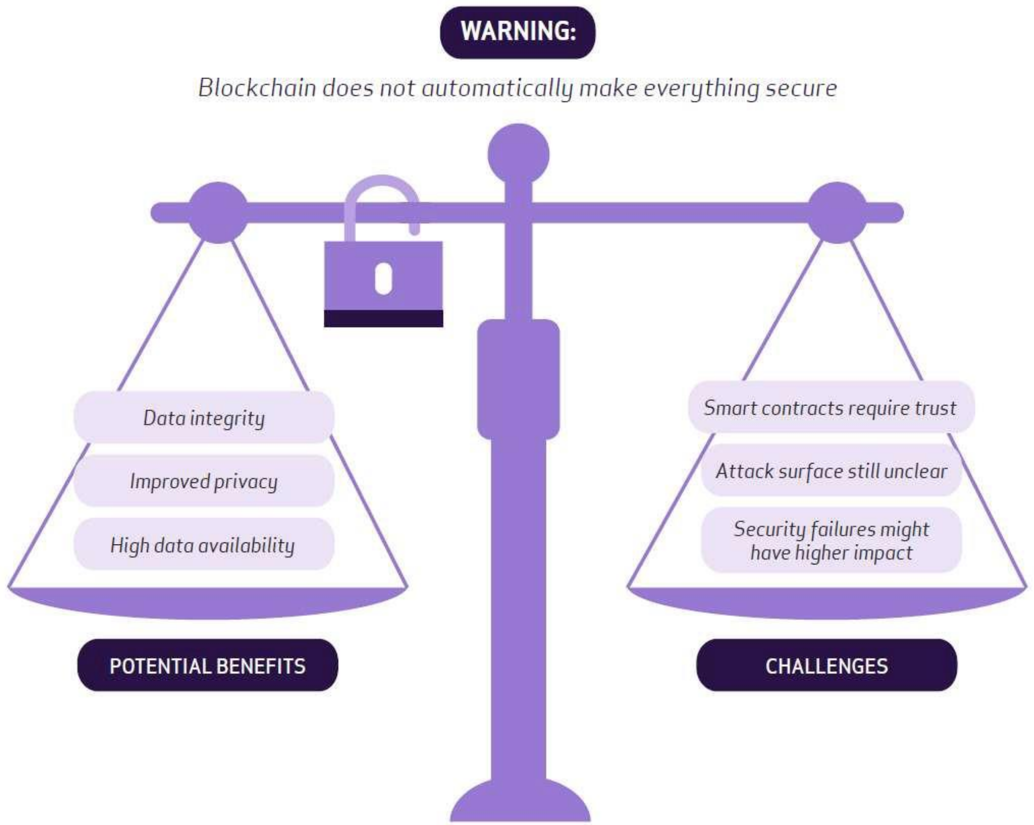


What will be important?

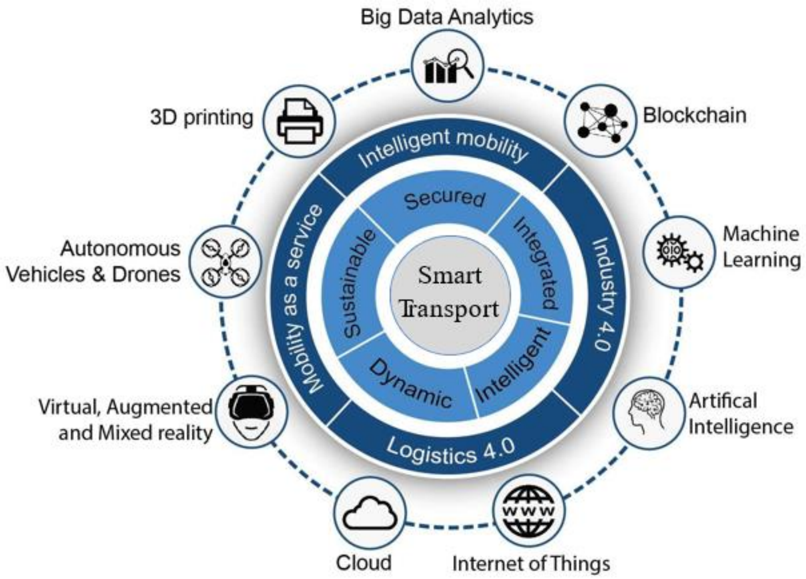
Ledger of Things



Potential security benefits and challenges of blockchain technology

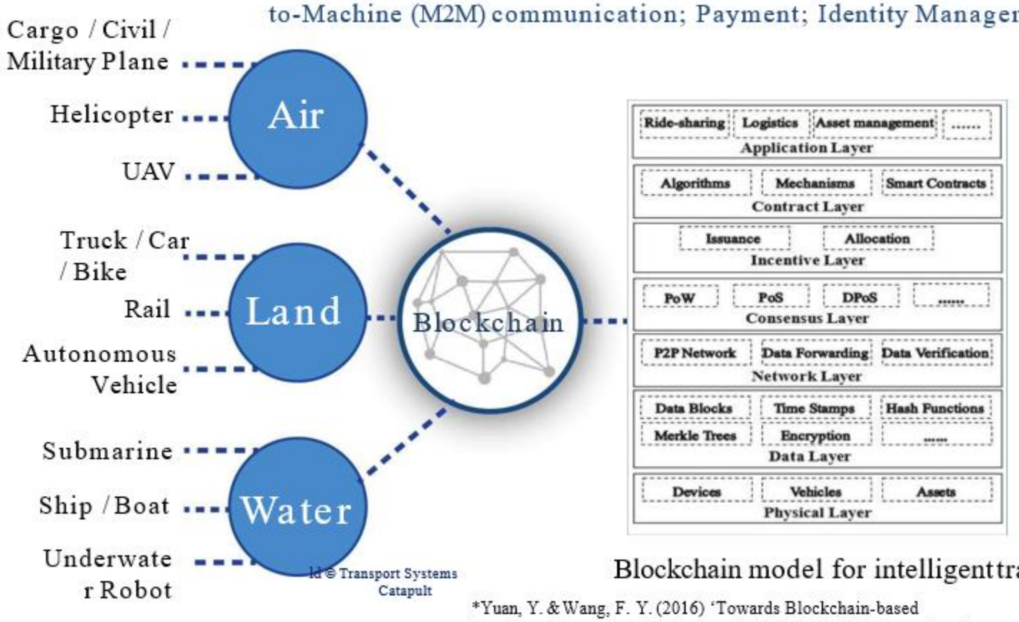


Smart transport future and its multi-modality



The University of Sheffield © Transport Systems Catapult

Key Application for Blockchain in Transport: Trust layer for Machine-to-Machine (M2M) communication; Payment; Identity Management



Blockchain model for intelligent transport*

*Yuan, Y. & Wang, F. Y. (2016) 'Towards Blockchain-based Intelligent Transportation Systems', 2016 IEEE19th International Conference on Intelligent Transportation Systems, pp. 2663–2668.

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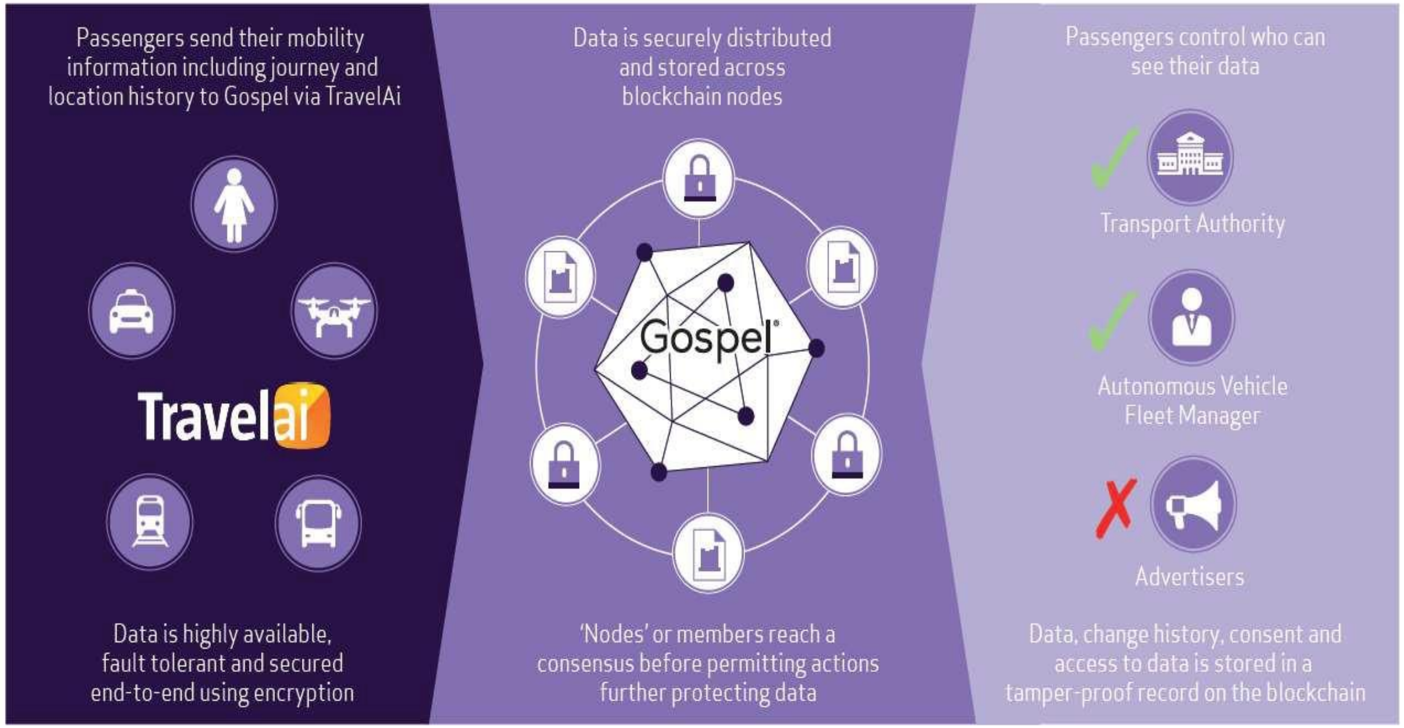
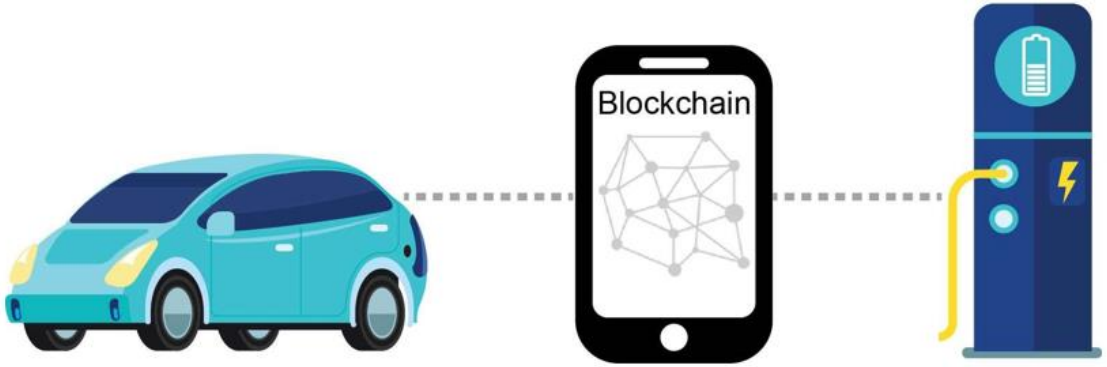
Personal Transport Data Sharing using Blockchain

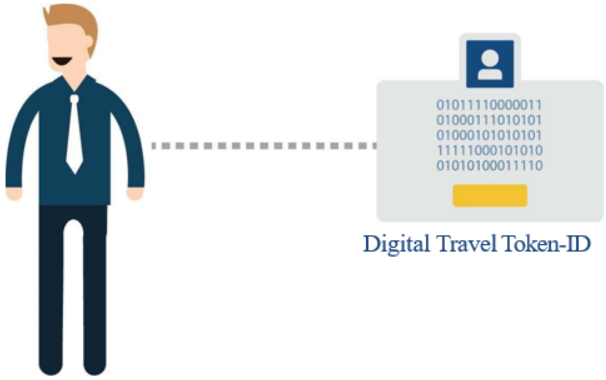


EV charging and civil aviation services using Blockchain

Share&Charge a Blockchain-based peer-to-peer mobile sharing of EV charging network and payments.



SITA Lab is evaluating Blockchain for a single reusable global digital travel token



"By 2020, we are going to see many industry verticals, including airlines, delivering high value to both themselves and their ecosystem of partners and suppliers using blockchain technology."

– Casey Kuhlman, CEO, Monax*

*https://www.sita.aero/air-transport-it-review/articles/the-promised-world-of-blockchain

Technology and Human Needs

- Robotics innovation from a basic 6 degree of freedom robot that is normally deployed in a factory to a flexible, autonomous, reconfigurable robot that can be deployed for multiple functions.
- Nano technology and miniaturisation have started to make robot for daily use.
- This opens up a whole new way of how human and robot should interact.
- Though the above have started to emerge in advanced R&I laboratories, and to some extent in small scale commercial, special purpose and service deployment, it is still far from widely accepted as a standard for human living.
- In difficult circumstances, such as those in humanitarian environment, UAVs are not simply a luxury gadget, but a survival tool.
- In commercial circumstances, such as those in business delivery, UAVs are not simply a luxury gadget, but a potential efficient tool that may help advance customer personalisation delivery or to meet key customer requirement that need high value services.

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Framework

- Global challenges and goals
- Strategy and policy (e.g. UK)
- **Physical** resources
- **Digital** resources
- **Autonomous** resources
- ***Resource sustainability***
- ***Machine economy***

Future industry

Future supply chain

Physical resources **Digital** resources **Autonomous** resources

Resource sustainability
Machine economy

Sustainability
Materials, Energy, Food, Water, Transport

Smart/Intelligent and Future Technology
AI, Blockchain, Robotic, New Manufacturing, New Recycling, New Energy, New Materials, 5G+, AR/MR, Industry 4.0+, IoT+, Edge and Cloud

Hybrid Methodology
LCA, I-O, TEA, OR, ML, DL

Future Government

Future society

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Play AREC film.

Blockchain in Transport and Logistics
Special Issue
International Journal of Production Research
Prof. Lenny Koh, The University of Sheffield, UK
Prof. Alexandre Dolgui, IMT Atlantique, France
Prof. Joe Sarkis, Worcester Polytechnic Institute, USA

The Fourth Industrial Revolution (Industry 4.0): Technologies' Disruption on Operations and Supply Chain Management
Special Issue
International Journal of Operations and Production Management
Prof. Lenny Koh, The University of Sheffield, UK
Dr. Guido Orzes, Free University of Bozen-Bolzano, Italy
Prof. Fu (Jeff) Jia, University of York, UK

Towards a circular economy production system: trends and challenges for operations management
Special Issue
International Journal of Production Research
Prof. Ernesto Santibanez Gonzalez, The University of Talca, Chile
Prof. Lenny Koh, The University of Sheffield, UK
Prof. Janny Leung, The Chinese University of Hong Kong, China

Thank you.