Institution: University of Sheffield		
Unit of Assessment: C-17 Business and Management Studies		
Title of case study: Translating environmental sustainable supply chains into global resource efficient systems in China		
Period when the underpinning research was undertaken: 2011–2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Lenny Koh	**Role(s) (e.g. job title):** Professor	**Period(s) employed by submitting HEI:** 2001–present
Period when the claimed impact occurred: 2014–2019		
Is this case study continued from a case study submitted in 2014? N		

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

Sheffield's Advanced Resource Efficiency Centre (AREC) uses systems theory to examine how decisions informed by a whole supply chain could maximise resource efficiency and productivity. Through strategic engagement with key bodies in China, this research has helped to embed a technological approach to resource efficiency and environmental sustainability in the country's main social, economic and development policies: Made in China 2025, the 13th five-year plan, and Belt and Road. By adopting the AREC model, China's policymakers have made changes to its global supply chains that support economic growth through maximising resource efficiency while minimising negative environmental impacts.

2. Underpinning research (indicative maximum 500 words)

Globally and locally, external pressures on organisations have created an imperative for combined low carbon, low cost operational and organisational solutions. In response, a team from Sheffield University Management School, led by Professor Lenny Koh, has researched and tested theories and methodologies to develop a supply chain resource modelling system to help organisations maximise resource efficiency and reduce carbon footprints, and expand the environmental sustainable supply chains into global resource efficient systems.

In response to user needs and working with public and private sector collaborators, Koh and her team undertook research on green supply chain theory through the study of supply chains in Europe and Asia [R1, R2]. They used systems theory to examine how decisions informed by a whole supply chain or an intra-organisational approach could improve performance across the supply chain. They then focused on low carbon supply chain management, the impact of environmental directives on intra-organisational decisions and establishment of a comprehensive decision support system for carbon management across the supply chain [R1, R2].

The group advanced the theory by advocating a balanced whole supply chain system approach to improve both the understanding of, and decision-making for, carbon accounting across global supply chains [R1, R2]. This applied methodologies to identify areas of greater risk and uncertainty for carbon reduction in the supply chain. Following this, the research advanced to

focus on causality between system interventions and supply chains to evaluate and optimise the effectiveness of the tools that the team has developed.

The theoretical and methodological advances and findings, categorised into four strands of intellectual and novel contributions are:

F1) Koh's circular framework for supply chain resource sustainability (SCRS) provided a robust and novel set of decision rules in which to assess the interconnectedness of environmental, economic, and social capital of supply chain resources from pre-production to post-production [R1].

F2) At a global scale, Koh's research on electronic waste recycling and recovery, the circular economy and toxicology assessments, have found sustainable investment opportunities and new supply and demand governance structures [R3-R5]. Koh found that the toxicology footprint will increase if the economy is thriving and decrease if it is in recession [R3]. Her research recommends that policymakers and governments look at their toxicological footprint carefully and, instead of exporting their emissions, make changes to their current environment that reduce their emissions [R3]. Furthermore, Koh's research found that the current resource efficiency system is ineffective and unsustainable due to the lack of a systematic framework [R5]. To address these weaknesses, there needs to be a specific structure that combines financial and governance frameworks. In-depth analysis by Koh [R4] revealed a huge economic incentive for this kind of market, which also leads to significant CO2 savings, contributing to the circular economy in a way that leads to a wider economic impact.

F3) Koh's combined life cycle approach and sustainability measurement using the integrated resource efficiency (IRE) index of 40 countries including 34 OECD nations. It found China, Australia, Greece, and UK, had varying levels of urgent needs to address their economic, environmental, and social resource efficiencies in order to increase their integrated resource efficiency index [R1, R2]. The life cycle approach recognises selections as one part of a whole system of events. It identifies both opportunities and risks of a product or technology, all the way from raw materials to disposal. By integrating Koh's life cycle methodology into a resource efficient model Koh's research suggests that these economic systems and their industries will gain significant improvement in their sustainability performance.

F4) Koh's research found that digital technological approaches such as blockchain, big data, artificial intelligence (AI) and Industry 4.0 have the potential to enable improved resource efficiency and productivity while reducing waste. Blockchain implementation in the supply chain, for example, eliminates the need for an intermediary by building trust directly between stakeholders [R1, R6].

These findings have been incorporated into a suite of software tools developed by Koh with Microsoft called the Supply Chain Environmental Analysis Tools (SCEnAT). SCEnAT, and its cloud-based versions, are an important tool for policymakers and industry to apply green supply chain theory.

3. References to the research (indicative maximum of six references)

R1. Koh, S. C. L., Gunasekaran, A., Morris, J., Obayi, R., & Ebrahimi, S. M. (2017). Conceptualizing a circular framework of supply chain resource sustainability. *International Journal of Operations & Production Management*, *37*(10), 1520–1540. https://doi.org/10.1108/ijopm-02-2016-0078

R2. Koh, S. C. L., Morris, J., Ebrahimi, S. M., & Obayi, R. (2016). Integrated resource efficiency: measurement and management. *International Journal of Operations & Production Management*, *36*(11), 1576–1600. https://doi.org/10.1108/ijopm-05-2015-0266

R3. Koh, S. C. L., Ibn-Mohammed, T., Acquaye, A., Feng, K., Reaney, I. M., Hubacek, K., Fujii, H., & Khatab, K. (2016). Drivers of U.S. toxicological footprints trajectory 1998–2013. *Scientific Reports*, *6*(1), 39514. https://doi.org/10.1038/srep39514

R4. Cucchiella, F., D'Adamo, I., Lenny Koh, S. C., & Rosa, P. (2015). Recycling of WEEEs: An economic assessment of present and future e-waste streams. *Renewable and Sustainable Energy Reviews*, *51*, 263–272. https://doi.org/10.1016/j.rser.2015.06.010. Elsevier Atlas Award winning paper.

R5. Awasthi, A. K., Li, J., Koh, L., & Ogunseitan, O. A. (2019). Circular economy and electronic waste. *Nature Electronics*, *2*(3), 86–89. https://doi.org/10.1038/s41928-019-0225-2

R6. Koh, S. C. L., Genovese, A., Acquaye, A. A., Barratt, P., Rana, N., Kuylenstierna, J., & Gibbs, D. (2013). Decarbonising product supply chains: design and development of an integrated evidence-based decision support system – the supply chain environmental analysis tool (SCEnAT). *International Journal of Production Research*, *51*(7), 2092–2109. https://doi.org/10.1080/00207543.2012.705042

4. Details of the impact (indicative maximum 750 words)

The AREC model identifies how to reduce environmental impacts and maximise productivity and resource efficiency within the supply chain. It does this by making use of the software tool based on Koh's research [R6, F1-4], the Supply Chain Environmental Analysis Tool (SCEnAT), which uses data from the supply chain to reveal the points of highest carbon consumption and recommends interventions that have the most cost-effective impact on the carbon footprint.

Koh's research has influenced the implementation of three of the highest-profile social, economic and development policies that China has launched: The 13th five-year plan; The Belt and Road initiative; and Made in China 2025. Since 2018, Koh has collaborated with Chinese organisations working on these three policies. By making use of her research, policymakers in China have strengthened the sustainability and resource efficiency of current supply chains. The AREC model provided a framework of recommendations targeting the maximum benefit for users instead of narrow changes without regard for the larger context, which was common practice prior to implementing AREC. Having a set of actions that are connected to each other enables a higher level of systems achievement overall throughout the supply chain. Implementing the AREC model enabled the impacts described below.

A. Embedding technological approaches to supply chain sustainability in the implementation of China's Made in China 2025 and other key national policies.

The Made in China 2025 policy aims to upgrade the manufacturing capabilities of Chinese industries from labour-intensive factories into a more technology-intensive powerhouse. This transition required a technological approach to supply chain sustainability and resource efficient systems strategy globally. [Text removed for publication].

Koh recommended that blockchain, big data, AI and industry 4.0 technology should be embedded in China's policies to enable the improvement of resource efficiency and productivity while at the same time reducing waste [F4]. [Text removed for publication], this recommendation

was fed into the economic, industrial, science and innovation policies as well as the Made in China 2025 policy [S1]. [Text removed for publication] implemented Koh's recommendation of introducing blockchain in its development and industrial policies [S1], to reduce reliance on intermediaries and build trust directly between stakeholders [F4]. This has resulted in direct impacts on companies and workers.

For example, in Shanxi, China, using Koh's proposals, blockchain was embedded in seven key companies in the agri-food supply chains, turning them into resource efficient systems. All farmers in that area can now directly access the market without reliance on an intermediary. This improved their economic status in the value chain by 31% [S1], and developed more sustainable agricultural practices [F3]. These led to a 26% reduction in CO2 emissions and a 27% improvement in the utilisation of their natural resources [S1].

DRTT's technological approach accomplished with blockchain, Cloud technology and Koh's SCEnAT platforms [F4, R6] has improved connectivity between rural and urban operations. Koh recommended this technology to be more widely offered to the poorer population on a regional level, such as farmers. The farmers are now able to share these resources amongst themselves and through them earn more money. This led to significantly improved quality of life for the 37% of the 900,000 people living in poverty in Shanxi, China [S1].

B. Improving the resource efficiency of China's USD 670 billion Belt and Road initiative.

China's Belt and Road initiative (BRI) policy connects global supply chains for global economic and social development through investment, trade, and cooperation in major infrastructure such as transport and energy. In 2013, [Text removed for publication] the AREC model was adopted to maximise the resource efficiency in BRI and optimise sustainable development. Since then, China's trade with countries along the Belt and Road expanded 11.3% year on year to 4.57 trillion yuan in the first seven months in 2018 [S2]. [Text removed for publication].

The adoption of Koh's findings [F1-4] resulted in a reduced carbon footprint in the Belt and Road supply chains and improved resource efficiency in the BRI. For example, AREC was considered to have made a meaningful contribution to the Belt and Road's expansion of 2.7% above China's overall trade increase, achieving USD 672.1 billion in trade in the first seven months in 2018 [S3].

C. Influencing sustainability strategy in the implementation of China's national development and reform policy and in support of China's 13th five-year plan.

[Text removed for publication]. Koh prepared a confidential report [Text removed for publication] which provided short-, medium- and long-term actions. Koh's research is credited with improving its development and reform policy planning, which is a key pillar in delivering China's 13th five-year plan (2016-2020) [S2]. They also designed the actions into their overall system, so the wider supply chains follow these requirements as well [S2].

As a direct result, Koh's research was used to help transform social, economic, and environmental development in Ningbo, China. The environmental sustainability of Ningbo's transport infrastructure, also connected to the Belt and Road initiative, has been improved by including environmental criteria as a requirement in public procurement contracts [S2].

[Text removed for publication]. Through workshops and sustained engagement with key stakeholders and senior policy makers, Koh has successfully incorporated the AREC model into economic, social, and environmental strategies and policies. By implementing her model and

using the tools in it (such as SCEnAT), [Text removed for publication] reported that they have achieved “energy consumption per unit of GDP falling by 3.1% and decreasing the rural poor population by 13.86 million people” [S4].

5. Sources to corroborate the impact (indicative maximum of 10 references)

S1. [Text removed for publication]

S2. [Text removed for publication]

S3. [Text removed for publication]

S4. [Text removed for publication]