A critical analysis of the impacts of COVID-19 on the global economy and ecosystems and opportunities for circular economy strategies

Ibn-Mohammed, T.[1*], Mustapha K.B.[2], Godsell, J.M.[1], Adamu, Z.[3], Babatunde K. A.[4,5], Akintade, D. D[6]., Acquaye, A.[7], Fujii, H.[8], Ndiaye, M M.[9], Yamoah, F.A.[10], Koh, S.C.L[11]

[1]Warwick Manufacturing Group (WMG), The University of Warwick, Coventry, CV4 7AL, UK
[2]Faculty of Engineering and Science, University of Nottingham (Malaysia Campus), Semenyih 43500, Selangor, Malaysia
[3]School of The Built Environment and Architecture, London South Bank University, SE1 0AA, UK
[4]Faculty of Economics and Management, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[5]Department of Economics, Faculty of Management Sciences, Al-Hikmah University, Ilorin, Nigeria
[6]School of Life Sciences, University of Nottingham, NG7 2UH UK.
[7] Kent Business School, University of Kent, Canterbury, CT2 7PE, UK
[8]Faculty of Economics, Kyushu University 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[9]Department of Industrial Engineering, College of Engineering, American University of Sharjah, Sharjah, UAE
[10]Department of Management, Birkbeck University of London, WC1E 7JL UK
[11]Sheffield University Management School (SUMS), The University of Sheffield, Sheffield, S10 1FL, UK

*Corresponding author's e-mail: t.ibn-mohammed@warwick.ac.uk /taofeeq_m@yahoo.com

Abstract

The World Health Organization declared COVID-19 a global pandemic on the 11th of March 2020, but the world is still reeling from its aftermath. Originating from China, cases quickly spread across the globe, prompting the implementation of stringent measures by world governments in efforts to isolate cases and limit the transmission rate of the virus. These measures have however shattered the core sustaining pillars of the modern world economies as global trade and cooperation succumbed to nationalist focus and competition for scarce supplies. Against this backdrop, this paper presents a critical review of the catalogue of negative and positive impacts of the pandemic and proffers perspectives on how it can be leveraged to steer towards a better, more resilient low-carbon economy. The paper diagnosed the danger of relying on pandemic-driven benefits to achieving sustainable development goals and emphasizes a need for a decisive, fundamental structural change to the dynamics of how we live. It argues for a rethink of the present global economic growth model, shaped by a linear economy system and sustained by profiteering and energy-gulping manufacturing processes, in favour of a more sustainable model recalibrated on circular economy (CE) framework. Building on evidence in support of CE as a vehicle for balancing the complex equation of accomplishing profit with minimal environmental harms, the paper outlines concrete sector-specific recommendations on CE-related solutions as a catalyst for the global economic growth and development in a resilient post-COVID-19 world.

Keywords: *COVID-19, Circular Economy, Sustainability, Sustainable Development, Supply Chain Resilience, Climate Change*

1. Introduction

The world woke up to a perilous reality on the 11th of March, 2020 when the World Health Organization (WHO) declared novel coronavirus (COVID-19) a pandemic (Sohrabi et al., 2020; WHO, 2020a). Originating from Wuhan, China, cases rapidly spread to Japan, South Korea, Europe and the United States as it reached global proportions. Towards the formal pandemic declaration, substantive economic signals from different channels, weeks earlier, indicated the world was leaning towards an unprecedented watershed in our lifetime, if not in human history

(Gopinath, 2020). In series of revelatory reports (Daszak, 2012; Ford et al., 2009; Webster, 1997), experts across professional cadres had long predicted a worldwide pandemic would strain the elements of the global supply chains and demands, thereby igniting a cross-border economic disaster because of the highly interconnected world we now live in. By all accounts, the emerging havoc wrought by the pandemic exceeded the predictions in those commentaries. At the time of writing, the virus has killed over 800,000 people worldwide (JHU, 2020), disrupted means of livelihoods, cost trillions of dollars while global recession looms (Naidoo and Fisher, 2020). In efforts to isolate cases and limit the transmission rate of the virus, while mitigating the pandemic, countries across the globe implemented stringent measures such as mandatory national lockdown and border closures.

These measures have shattered the core sustaining pillars of modern world economies. Currently, the economic shock arising from this pandemic is still being weighed. Data remains in flux, government policies oscillate, and the killer virus seeps through nations, affecting production, disrupting supply chains and unsettling the financial markets (Bachman, 2020; Sarkis et al., 2020). Viewed holistically, the emerging pieces of evidence indicate we are at a most consequential moment in history where a rethink of sustainable pathways for the planet has become pertinent. Despite this, the measures imposed by governments have also led to some "accidental" positive effects on the environment and natural ecosystems. As a result, going forward, a fundamental change to human bio-physical activities on earth now appears on the spectrum of possibility (Anderson et al., 2020). However, as highlighted by Naidoo and Fisher (2020), our reliance on globalization and economic growth as drivers of green investment and sustainable development is no longer realistic. The adoption of circular economy (CE) – an industrial economic model that satisfies the multiple roles of decoupling of economic growth from resource consumption, waste management and wealth creation – has been touted to be a viable solution.

No doubt, addressing the public health consequences of COVID-19 is the top priority, but the nature of the equally crucial economic recovery efforts necessitates some key questions as governments around the world introduce stimulus packages to aid such recovery endeavours: *Should these packages focus on avenues to economic recovery and growth by thrusting business as usual into overdrive or could they be targeted towards constructing a more resilient low-carbon CE?* To answer this question, this paper builds on the extant literature on public health, socio-economic and environmental dimensions of COVID-19 impacts (Gates, 2020b; Guerrieri et al., 2020; Piguillem and Shi, 2020; Sohrabi et al., 2020), and examines its interplay with CE approaches. It argues for the recalibration and rethink of the present global economic growth model, shaped by a linear economy system and sustained by profit-before-planet and energy-intensive manufacturing processes, in favour of CE. Building on evidence in support of CE as a vehicle for balancing the complex equation of accomplishing profit with minimal environmental harms, the paper outlines tangible sector-specific recommendations on CE-related solutions as a catalyst for the global economic boom in a resilient post-COVID-19 world. It is conceived that the "accidental" or the pandemic-induced CE strategies and behavioural changes that ensued during coronavirus crisis can be leveraged or locked in, to provide opportunities for both future resilience and competitiveness.

In light of the above, the paper is structured as follows. In Section 2, the methodological framework, which informed the critical literature review is presented. A brief overview of the historical context of previous epidemics and pandemics is presented in Section 3 as a requisite background on how pandemics have shaped human history and economies and why COVID-19 is different. In Section 4, an overview of the impacts (both negative and positive) of COVID-19 in terms of policy frameworks, global economy, ecosystems and sustainability are presented. The role of the CE as a constructive change driver is detailed in Section 5. In Section 6, opportunities for CE after COVID-19 as well as sector-specific recommendations on strategies and measures for advancing CE is presented, leading to the summary and concluding remarks in Section 7.

2. Methods

A literature review exemplifies a conundrum because an effective one cannot be conducted unless a problem statement is established (Ibn-Mohammed, 2017). Yet, the literature search plays an integral role in establishing many research problems. In this paper, the approach taken to overcome this conundrum involves searching and reviewing the existing literature in the specific area of study (i.e. impacts of COVID-19 on global economy and ecosystems in the context of CE). This was used to develop the theoretical framework from which the current study emerges and adopting this to establish a conceptual framework which then becomes the basis of the current review. The paper adopts the critical literature review (CLR) approach given that it entails the assessment, critique and synthetisation of relevant literature regarding the topic under investigation in a manner that facilitates the emergence of new theoretical frameworks and perspectives from a wide array of different fields (Snyder, 2019). CLR suffers from an inherent weakness in terms of subjectivity towards literature selection (Snyder, 2019), prompting Grant and Booth (2009) to submit that systematic literature review (SLR) could mitigate this bias given its strict criteria in literature selection that facilitates a detailed analysis of a specific line of investigation. However, a number of authors (Morrison et al., 2012; Paez, 2017) have reported that SLR does not allow for effective synthesis of academic and grey literature which are not indexed in popular academic search engines like Google Scholar, Web-of-Science and Scopus. The current review explores the impacts of COVID-19 on the global economy and ecosystems and opportunities for circular economy strategies, rather than investigating a specific aspect of the pandemic. As such, adopting a CLR approach is favoured in realising the goal of the paper, as it allows for the inclusion of a wide range of perspectives and theoretical underpinnings from different sources (Greenhalgh et al., 2018; Snyder, 2019)

Considering the above, this paper employed archival data consisting of journal articles, documented news in the media, expert reports, government and relevant stakeholders' policy documents, published expert interviews and policy feedback literature that are relevant to COVID-19 and the concept of CE. To identify the relevant archival data, we focused on several practical ways of literature searching using appropriate keywords that are relevant to this work including impact (positive and negative) of COVID-19, circular economy, economic resilience, sustainability, supply chain resilience, climate change, etc. After identifying articles and relevant documents, their contents were examined to determine inclusions and exclusions based on their relevance to the topic under investigation. Ideas generated from reading the resulting papers from the search were then used to develop a theoretical framework and a research problem statement, which forms the basis for the CLR. The impact analysis for the study was informed by the $\boldsymbol{I} = \boldsymbol{P} \times \boldsymbol{A} \times \boldsymbol{T}$ model whereby the "impact" (I) of any group or country on the environment is a function of the interaction of its population size (P), per capita affluence (A), expressed in terms of real per capita GDP, as a valid approximation of the availability of goods and services and technology (T) involved in supporting each unit of consumption.

As shown in the methodological framework in **Figure 1**, the paper starts with a brief review of the impacts of historical plagues to shed more light on the link between the past and the unprecedented time, which then led to an overview of the positive and negative impacts of COVID-19. The role of CE as a vehicle for constructive change in the light of COVID-19 was then explored followed by the synthesis, analysis and reflections on the information gathered during the review, leading to sector-specific CE strategy recommendations in a post-COVID-19 world.

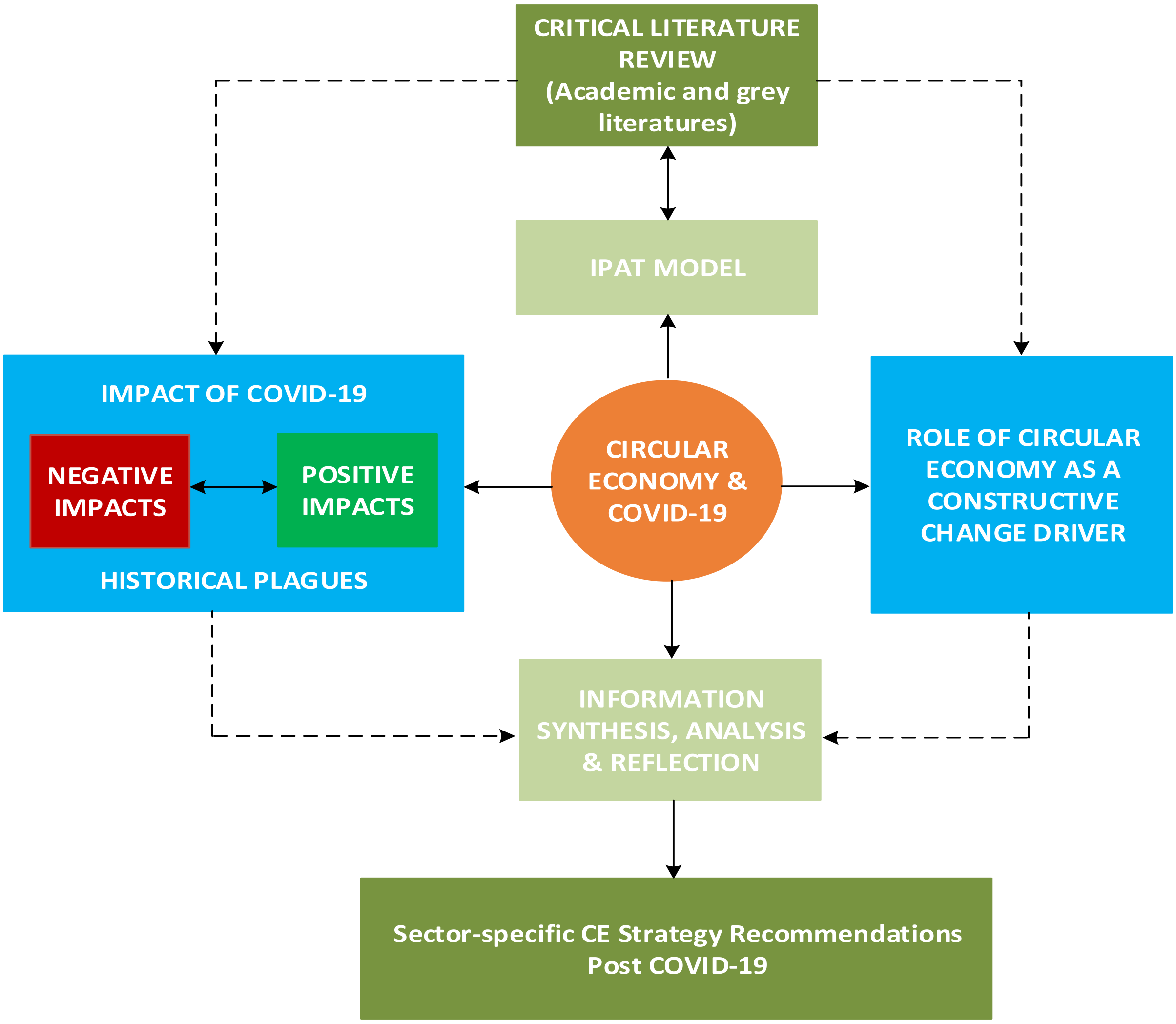


Figure 1: Methodological framework for the critical literature review.

3. A brief account of the socio-economic impacts of historical outbreaks

At a minimum, pandemics result in the twin crisis of stressing the healthcare infrastructure and straining the economic system. However, beyond pandemics, several prior studies have long noted that depending on latency, transmission rate, and geographic spread, any form of communicable disease outbreak is a potent vector of localized economic hazards (Bloom and Cadarette, 2019; Bloom and Canning, 2004; Hotez et al., 2014). History is littered with a catalogue of such outbreaks in the form of endemics, epidemics, plagues and pandemics. In many instances, some of these outbreaks have hastened the collapse of empires, overwhelmed the healthcare infrastructure, brought unrest and triggered economic dislocations and exposed the fragility of the world economy with a knock-on effect on many sectors. Indeed, in the initial few months of COVID-19 pandemic, it has become more evident that natural, accidental or intentional biological threats outbreak in any country now poses an unquantifiable risk to global health and the world economy (Bretscher et al., 2020).

Saunders-Hastings and Krewski (2016) reported that there have been several pandemics over the past 100 years. A short but inexhaustible list of outbreaks of communicable diseases include 'the great plague' (Duncan-Jones, 1996; Littman and Littman, 1973), the Justinian plague (Wagner et al., 2014), the Black Death (Horrox, 2013), the Third Plague pandemic (Bramanti et al., 2019; Tan et al., 2002), the Spanish flu (Gibbs et al., 2001; Trilla et al., 2008), HIV/AIDS (De Cock et al., 2012), SARS (Lee and McKibbin, 2004), dengue (Murray et al., 2013), and Ebola (Baseler et al., 2017), among others. The potency of each of these outbreaks varies. Consequently, their economic implications differ according to numerous retrospective analyses (Bloom and Cadarette, 2019; Bloom and Canning, 2004; Hotez et al., 2014). For instance, the Ebola epidemic of 2013-2016 created socio-economic impact to the tune of $53 billion across West Africa, plummeted Sierra Leone's GDP in 2015 by 20% and that of Liberia by 8% between 2013 and 2014, despite the decline in death rates across the same timeframe (Fernandes, 2020).

As the world slipped into this inflection point, some of the historical lessons from earlier pandemics remain salutary, even if the world we live in now significantly differs from those of earlier period (McKee and Stuckler, 2020). Several factors differentiate the current socio-economic crisis of COVID-19 from the previous ones (Baker et al., 2020), which means direct simple comparisons with past global pandemics are impossible (Fernandes, 2020). Some of the differentiating factors include the fact that COVID-19 is a global pandemic and it is creating knock-on effects across supply chains given that the world has become much more integrated due to globalisation and advancements in technology (McKenzie, 2020). Moreover, the world has witnessed advances in science, medicine and engineering. The modest number of air travellers during past pandemics delayed the global spread of the virus unlike now where global travel has increased tremendously. From an economic impact perspective, interest rates are at record lows and there is a great imbalance between demand and supply of commodities (Fernandes, 2020). More importantly, many of the countries that are hard hit by the current pandemic are not exclusively the usual low-middle income countries, but those at the pinnacle of the pyramid of manufacturing and global supply chains. Against this backdrop, a review of the impact of COVID-19 is presented in the next section.

4. COVID-19: Policy frameworks, global economy, ecosystems and sustainability

4.1 Evaluation of policy frameworks to combat COVID-19

The strategies and policies adopted by different countries to cope with COVID-19 have varied over the evolving severity and lifetime of the pandemic during which resources have been limited (Siow et al., 2020). It is instructive that countries accounting for 65% of global manufacturing and exports (i.e. China, USA, Korea, Japan, France, Italy, and UK) were some of the hardest to be hit by COVID-19 (Baldwin and Evenett, 2020). Given the level of unpreparedness and lack of resilience of hospitals, numerous policy emphases have gone into sourcing for healthcare equipment such as personal protective equipment (PPE) and ventilators (Ranney et al., 2020) due to global shortages. For ventilators, in particular, frameworks for rationing them along with bed spaces have had to be developed to optimise their usage (White and Lo, 2020). Other industries have also been affected, with shocks to their existence, productivity and profitability (Danieli and Olmstead-Rumsey, 2020) including the CE-sensitive materials extraction and mining industries that have been hit by disruption to their operations and global prices of commodities (Laing, 2020).

As highlighted in subsequent sub-sections, one of the psychological impacts of COVID-19 is panic buying (Arafat et al., 2020), which happens due to uncertainties at national levels (e.g. for scarce equipment) and at individual levels (e.g. for everyday consumer products). In both instances, the fragility, profiteering and unsustainability of the existing supply chain model have been exposed (Spash, 2020). In fact, Sarkis et al. (2020) questioned whether the global economy could afford to return to the just-in-time (JIT) supply chain framework favoured by the healthcare sector, given its apparent shortcomings in dealing with much needed supplies. The sub-section that follows examines some of the macro and micro economic ramifications of COVID-19.

4.1.1 Macroeconomic impacts: Global productions, exports, and imports.

One challenge faced by the healthcare industry is that existing best practices, in countries like the USA (e.g. JIT macroeconomic framework), do not incentivise the stockpiling of essential medical equipment (Solomon et al., 2020). Although vast sums were budgeted, some governments (e.g. UK, India and USA) needed to take extraordinary measures to protect their supply chain to the extent that manufacturers like Ford and Dyson ventured into the ventilator design/production market (Iyengar et al., 2020). The US, in particular activated the Defense Production Act to compel car manufacturers to shift focus on ventilator production (American Geriatrics Society, 2020; Solomon et al., 2020) due to the high cost and shortage of this vital equipment. Hospitals and suppliers in the US were also forced to enter the global market due to the chronic shortfall of N95 masks as well as to search for lower priced equipment (Solomon et al., 2020). Interestingly, the global production of these specialist masks is thought to be led by China (Baldwin and Evenett, 2020; Paxton et al., 2020) where COVID-19 broke out, with EU's supply primarily from Malaysia and Japan (Stellinger et al., 2020). Such was the level of shortage that the US was accused of 'pirating' medical equipment supplies from Asian countries intended for EU countries (Aubrecht et al., 2020).

France and Germany followed suit with similar in-ward looking policy and the EU itself imposed restrictions on the exportation of PPEs, putting many hitherto dependent countries at risk (Bown, 2020). Unsurprisingly, China and the EU saw it fit to reduce or waive import tariffs on raw materials and PPE, respectively (Stellinger et al., 2020). Going forward, the life-threatening consequences of logistics failures and misallocation of vital equipment and products could breathe new life and impetus to technologies like Blockchain, RFID and IoT for increased transparency and traceability (Sarkis et al., 2020). Global cooperation and scenario planning will always be needed to complement these technologies. In this regard, the EU developed a joint procurement framework to reduce competition amongst member states, while in the US, where states had complained that federal might was used to interfere with orders, a ventilator exchange program was developed (Aubrecht et al., 2020). However, even with trade agreements and cooperative frameworks, the global supply chain cannot depend on imports – or donations (Evenett, 2020) for critical healthcare equipment and this realisation opens doors for localisation of production with consequences for improvements in environmental and social sustainability (Baldwin and Evenett, 2020). This can be seen in the case of N95 masks which overnight became in such high demand that airfreights by private and commercial planes were used to deliver them as opposed to traditional container shipping (Brown, 2020).

As detailed in forthcoming sections, a significant reduction in emissions linked to traditional shipping was observed, yet there was an increase in use of airfreighting due to desperation and urgency of demand. Nevertheless, several countries are having to rethink their global value chains (**Figure 2**) as a result of realities highlighted by COVID-19 pandemic (Javorcik, 2020). This is primarily because national interests and protectionism have been a by-product of COVID-19 pandemic and also because many eastern European/Mediterranean countries have a relative advantage with respect to Chinese exports. As shown in Figure 2, the global export share which each of these countries has, relative to China's share of the same exports (x-axis) is measured against the economies of countries subscribing to the European Bank for Reconstruction and Development (EBRD) (y-axis). For each product, the ideal is to have a large circle towards the top right-hand corner of the chart.

Figure 2: A summary of how some Eastern European / Mediterranean countries have advantages over China on certain exports – based on the Harmonized Commodity Description and Coding System from 2018, where export volume is represented by dot sizes in millions of USD; Source: Javorcik (2020).

4.1.2 Microeconomic impacts: Consumer behaviour

For long, there has been a mismatch between consumerist tendencies and biophysical realities (Spash, 2020). However, COVID-19 has further exacerbated the need to reflect on the social impacts of individual lifestyles. The behaviour of consumers, in many countries, was at some point alarmist with a lot of panic buying of food and sanitary products (Sim et al., 2020). At a private level, consumer sentiment is also changing. Difficult access to goods and services has forced citizens to re-evaluate purchasing patterns and needs, with focus pinned on the most essential items (Company, 2020; Lyche, 2020). Spash (2020) argued that technological obsolescence of modern products brought about by rapid innovation and individual consumerism is also likely to affect the linear economy model which sees, for instance, mobile phones having an average life time of four years (two years in the US), assuming their manufacture/repair services are constrained by economic shutdown and lockdowns (Schluep, 2009). On the other hand, a sector like healthcare, which could benefit from mass production and consumerism of vital equipment, is plagued by patenting. Most medical equipment are patented and the issue of a 3D printer's patent infringement in Italy led to calls for 'Open Source Ventilators' and 'Good Samaritan Laws' to help deal with global health emergencies like COVID-19 (Pearce, 2020). It is plausible that such initiatives/policies could help address the expensive, scarce, high-skill and material-intensive production of critical equipment, via cottage industry production.

For perspective, it should be noted that production capacity of PPE (even for the ubiquitous facemasks) have been shown by COVID-19 to be limited across many countries (Dargaville et al., 2020) with some countries having to ration facemask production and distribution in factories (San Juan, 2020). Unsurprisingly, the homemade facemask industry has not only emerged for the protection of mass populations as reported by (Livingston et al., 2020), it has become critical for addressing shortages (Rubio-Romero et al., 2020) as well as being part of a post-lockdown exit strategy (Allison et al., 2020). A revival of cottage industry production of equipment and basic but essential items like facemasks could change the landscape of global production for decades, probably leading to an attenuation of consumerist tendencies. This pandemic will also impact on R&D going forward, given the high likelihood that recession will cause companies to take short-term views, and cancel long and medium-term R&D in favour of short-term product development and immediate cash flow/profit as was certainly the case for automotive and aerospace sectors in previous recessions.

4.2 Overview of the negative impacts of COVID-19

The negative effects have ranged from a severe contraction of GDP in many countries to multi-dimensional environmental and social issues across the strata of society. In many respects, socio-economic activities came to a halt as: millions were quarantined; borders were shut; schools were closed; car/airline, manufacturing and travel industries crippled; trade fairs/sporting/entertainment events cancelled, and unemployment claims reached millions while the international tourist locations were deserted; and, nationalism and protectionism re-surfaced (Baker et al., 2020; Basilaia and Kvavadze, 2020; Devakumar et al., 2020; Kraemer et al., 2020;

Thunstrom et al., 2020; Toquero, 2020). In the subsections that follow, an overview of some of these negative impacts on the global economy, environment, and society is presented.

4.2.1 Negative macroeconomic impact of COVID-19

Undoubtedly, COVID-19 first and foremost, constitutes a ferocious pandemic and a human tragedy that swept across the globe, resulting in a massive health crisis (WHO, 2020b), disproportionate social order (UN DESA, 2020), and colossal economic loss (IMF, 2020). It has created a substantial negative impact on the global economy, for which governments, firms and individuals scramble for adjustments (Fernandes, 2020; Pinner et al., 2020; Sarkis et al., 2020; Sohrabi et al., 2020; Van Bavel et al., 2020). Indeed, the COVID-19 pandemic has distorted the world's operating assumptions, revealing the absolute lack of resilience of the dominant economic model to respond to unplanned shocks and crises (Pinner et al., 2020). It has exposed the weakness of over-centralization of the complex global supply and production chains networks and the fragility of global economies, whilst highlighting weak links across industries, (Fernandes, 2020; Guan et al., 2020; Sarkis et al., 2020). This has had a direct impact on employment and heightened the risk of food insecurity for millions due to lockdown and border restrictions (Guerrieri et al., 2020). To some extent, some of the interventional measures introduced by governments across the world have resulted in the flattening of the COVID-19 curve (as shown in **Figure 3)**. This has helped in preventing healthcare systems from getting completely overwhelmed (JHU, 2020), although as at the time of writing this paper, new cases are still being reported in different parts of the globe. Fernandes (2020) and McKibbin and Fernando (2020) reported that the socio-economic impact of COVID-19 will be felt for many months to come.

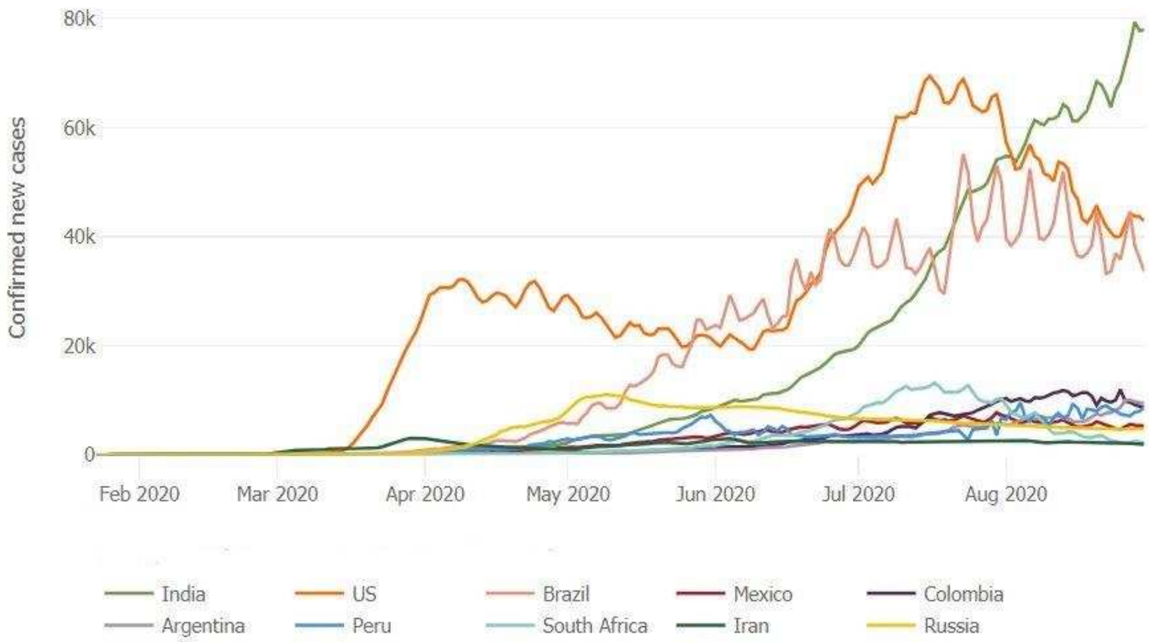


Figure 3: Daily confirmed new COVID-19 cases of the current 10 most affected countries based on a 5-day moving average. Valid as of August 31st, 2020 at 11:46 PM EDT (JHU, 2020).

Guan et al. (2020) submitted that how badly and prolonged the recession rattles the world depends on how well and quickly the depth of the socio-economic implications of the pandemic is understood. IMF (2020) reported that in an unprecedented circumstance (except during the Great Depression), all economies including developed, emerging, and even developing will likely experience recession. In its April World Economic Outlook, IMF (2020) reversed its early global economic growth forecast from 3.3% to -3 %, an unusual downgrade of 6.3% within three months. This makes the pandemic a global economic shock like no other since the Great Depression and it has already surpassed the global financial crisis of 2009 as depicted in **Figure 4.** Economies in the advanced countries are expected to contract by -6.1% while recession in emerging and developing economies is projected (with caution) to be less adverse compared to the developed nations with China and India expected to record positive growth by the end of 2020. The cumulative GDP loss over the next year from COVID-19 could be around $9 trillion (IMF, 2020).

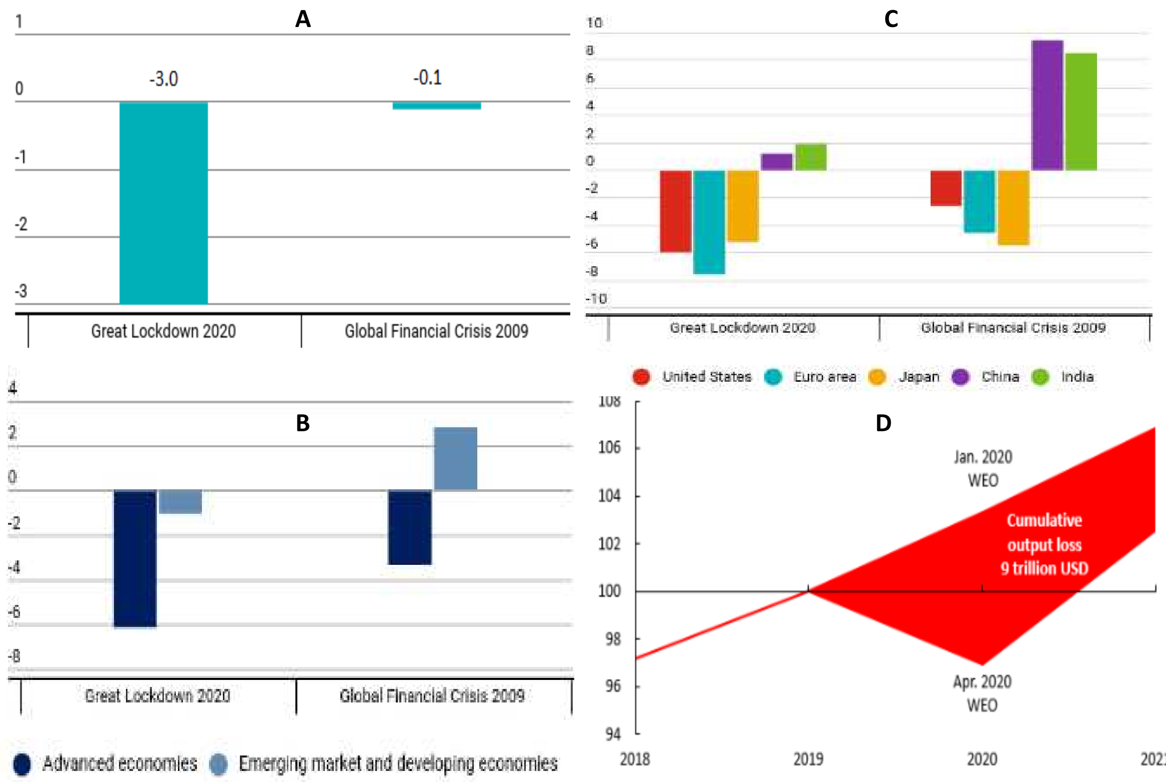


Figure 4. Socioeconomic impact of COVID-19 lockdown: (a) Comparison of global economic recession due to COVID-19 and the 2009 global financial crisis; (b) Advanced economies, emerging and developing economies in recession; (c) the major economies in recession ; (d) the cumulative economic output loss over 2020 and 2021. Note: Real GDP growth is used for economic growth, as year-on-year for per cent change (IMF, 2020).

With massive job loss and excessive income inequality, global poverty is likely to increase for the first time since 1998 (Mahler et al., 2020). It is estimated that around 49 million people could be pushed into extreme poverty due to COVID-19 with Sub-Sahara Africa projected to be hit hardest. The United Nations' Department of Economic and Social Affairs concluded that COVID-19 pandemic may also increase exclusion, inequality, discrimination and global unemployment in the medium and long term, if not properly addressed using the most effective policy instruments (UN DESA, 2020). The adoption of detailed universal social protection systems as a form of automatic stabilizers, can play a long-lasting role in mitigating the prevalence of poverty and protecting workers (UN DESA, 2020).

4.2.2 Impact of COVID-19 on global supply chain and international trade

COVID-19 negatively affects the global economy by reshaping supply chains and sectoral activities. Supply chains naturally suffer from fragmentation and geographical dispersion. However, globalisation has rendered them more complex and interdependent, making them vulnerable to disruptions. Based on an analysis by the U.S. Institute for Supply Management, 75% of companies have reported disruptions in their supply chain (Fernandes, 2020), unleashing crisis that emanated from lack of understanding and flexibility of the several layers of their global supply chains and lack of diversification in their sourcing strategies (McKenzie, 2020). These disruptions will impact both exporting countries (i.e. lack of output for their local firms) and importing countries (i.e. unavailability of raw materials) (Fernandes, 2020). Consequently, this will lead to the creation of momentary "manufacturing deserts" in which the output of a country, region or city drops significantly, turning into a restricted zone to source anything other than essential items like food items and drugs (McKenzie, 2020). This is due to the knock-on effect of China's rising dominance and importance in the global supply chain and economy (McKenzie, 2020). As a consequence of COVID-19, the World Trade Organization (WTO) projected a 32% decline in global trade (Fernandes, 2020). For instance, global trade has witnessed a huge downturn due to reduced Chinese imports and the subsequent fall in global economic activities. This is evident because as of 25th March 2020, global trade fell to over 4% contracting for only the second time since the mid-1980s (McKenzie, 2020). **Figure 5** shows a pictorial representation of impact of pandemics on global supply chains based on different waves and threat levels.

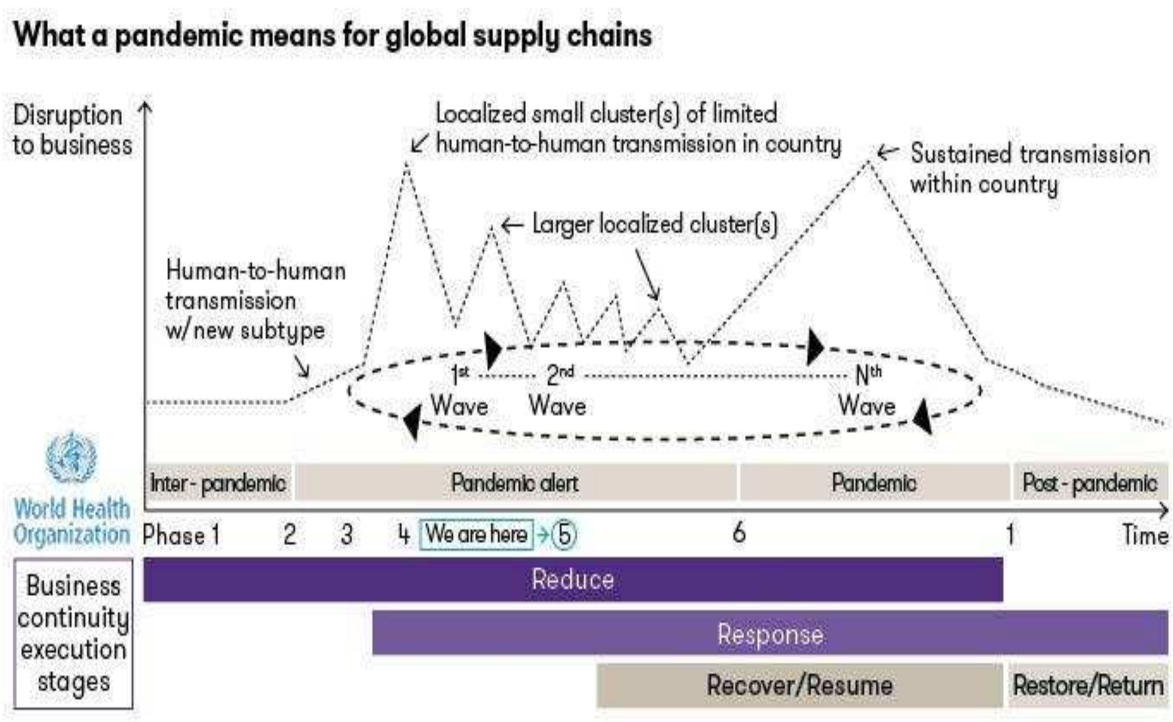


Figure 5: Impact of pandemics on global supply chains. Adapted from Eaton and Connor (2020).

4.2.3 Impact of COVID-19 on the aviation sector

The transportation sector is the hardest hit sector by COVID-19 due to the large-scale restrictions in mobility and aviation activities (IEA, 2020; Le Quéré et al., 2020; Muhammad et al., 2020). In the aviation sector, for example, where revenue generation is a function of traffic levels, the sector has experienced flight cancellations and bans, leading to fewer flights and a corresponding immense loss in aeronautical revenues. This is even compounded by the fact that in comparison to other stakeholders in the aviation industry, when traffic demand declines, airports have limited avenues to reducing costs because the cost of maintaining and operating an airport remains the same and airports cannot relocate terminals and runaways or shutdown (Hockley, 2020). Specifically, in terms of passenger footfalls in airports and planes, the Air Transport Bureau (2020) modelled the impact of COVID-19 on scheduled international passenger traffic for the full year 2020 under two scenarios namely Scenario 1 (the first sign of recovery in late May) and Scenario 2 (restart in the third quarter or later). Under Scenario 1, it estimated an overall reduction of: between 39%-56% of airplane seats; 872-1,303 million passengers, corresponding to a loss of gross operating revenues between ~$153 - $ 231 billion. Under Scenario 2, it predicted an overall drop of: between 49%-72% of airplane seats; 1,124 to 1,540 million passengers, with an equivalent loss of gross operating revenues between ~$198 - $ 273 billion. They concluded that the predicted impacts are a function of the duration and size of the pandemic and containment measures, the confidence level of customers for air travel, economic situations, and the pace of economic recovery (Air Transport Bureau, 2020).

The losses incurred by the aviation industry require context and several other comparison-based predictions within the airline industry have also been reported. For instance, the International Civil Aviation Organization ICAO (2020) predicted an overall decline in international passengers ranging from 44% to 80% in 2020 compared to 2019. Airports Council International, ACI (2020) also forecasted a loss of two-fifths of passenger traffic and >$76 billion in airport revenues in 2020 in comparison to business as usual. Similarly, the International Air Transport Association IATA (2020) forecasted $113 billion in lost revenue and 48% drop in revenue passenger kilometres (RPKs) for both domestic and international routes (Hockley, 2020). For pandemic scenario comparisons, **Figure 6** shows the impact of past disease outbreaks on aviation. As shown, the impact of COVID-19 has already outstripped the 2003 SARS outbreak which had resulted in the reduction of annual RPKs by 8% and $6 billion revenues for Asia/Pacific airlines, for example. The 6-month recovery path of SARS is, therefore, unlikely to be sufficient for the ongoing COVID-19 crisis (Air Transport Bureau, 2020) but gives a backdrop and context for how airlines and their domestic/international markets may be impacted.

Notably, these predictions are bad news for the commercial aspects of air travel (and jobs) but from the carbon/greenhouse gas emission and CE perspective, these reductions are enlightening and should force the airline industry to reflect on more environmentally sustainable models. However, the onus is also on the aviation industry to emphasise R&D on solutions that are CE-friendly (e.g. fuel efficiency; better use of catering wastes; end of service recycling of aircraft in sectors such as mass housing, or re-integrating airplane parts into new supply chains) and not merely investigating ways to recoup lost revenue due to COVID-19.

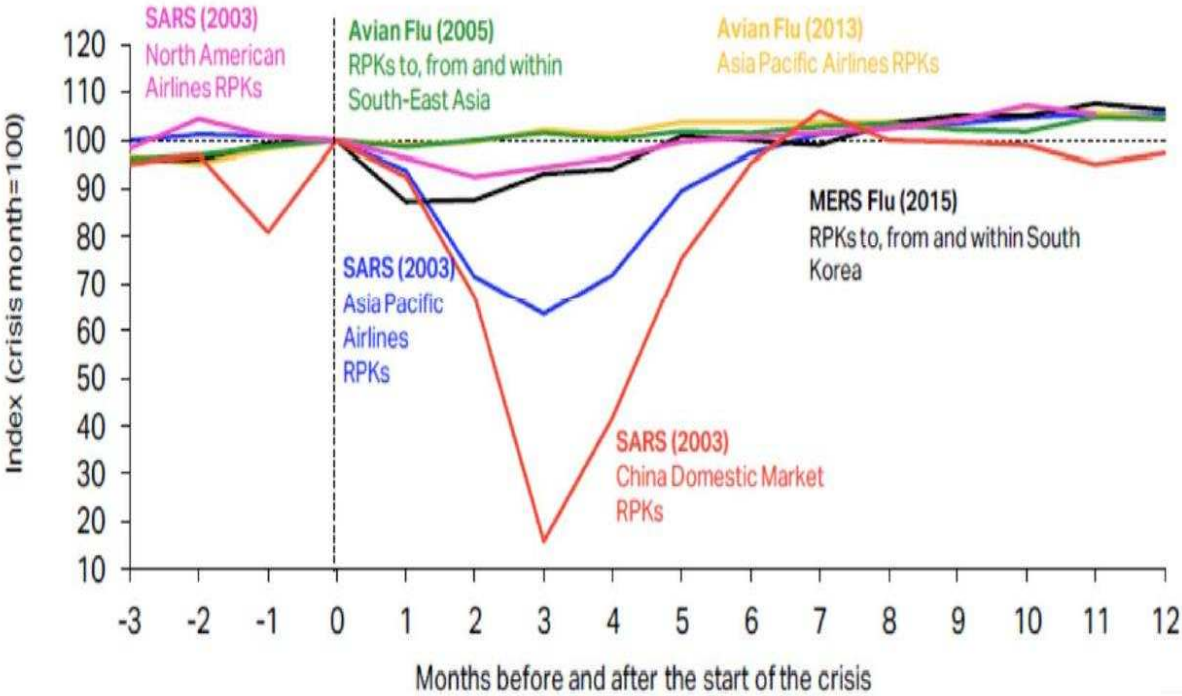


Figure 6: Impact of past disease outbreaks on aviation (Air Transport Bureau, 2020).

4.2.4 Impact of COVID-19 on the tourism industry

Expectedly, the impact of COVID-19 on aviation has led to a knock-on effect on the tourism industry, which is nowadays hugely dependent on air travel. For instance, the United Nation World Tourism Organization UNWTO (2020) reported a 22% fall in international tourism receipts of $80 billion in 2020, corresponding to a loss of 67 million international arrivals. Depending on how long the travel restictions and border closures last, current scenario modelling indicated falls between 58% to 78% in the arrival of international tourists, but the outlook remains hugely uncertain. The continuous existence of the travel restrictions could put between 100 to 120 million direct tourism-related jobs at risk. At the moment, COVID-19 has rendered the sector worst in the historical patterns of international tourism since 1950 with a tendency to halt a 10-year period of sustained growth since the last global economic recession (UNWTO, 2020). It has also been projected that a drop of ~60% in international tourists will be experienced this year, reducing tourism's contribution to global GDP, while affecting countries whose economy relies on this sector (Naidoo and Fisher, 2020). **Figure 7** depicts the impact of COVID-19 on tourism in Q1 of 2020 based on % change in international tourists' arrivals between January and March.

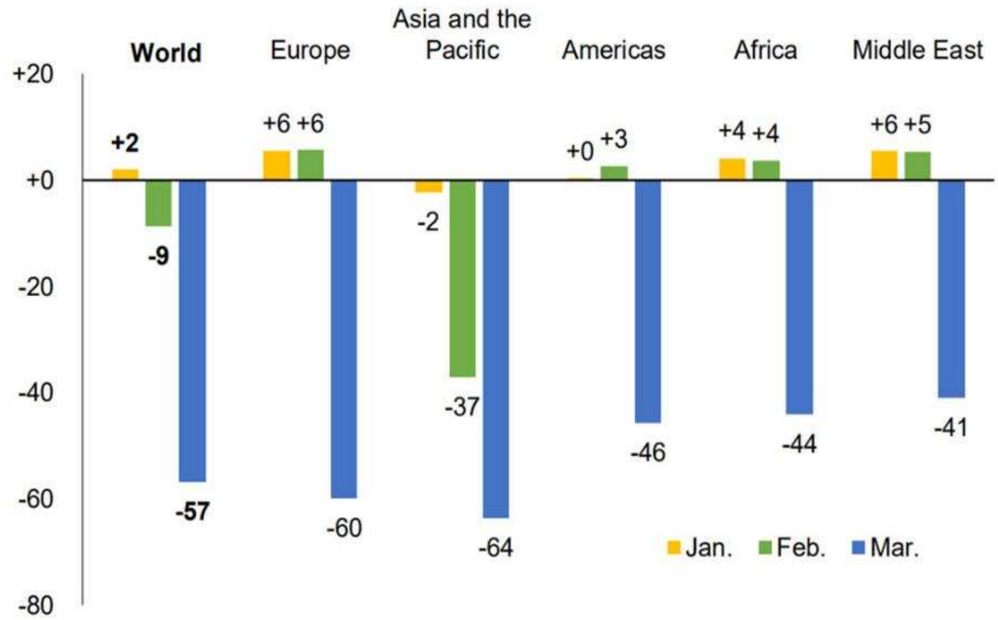


Figure 7: The impact of COVID-19 on tourism in quarter 1of 2020. Provisional data but current as of 31st August 2020 (UNWTO, 2020).

4.2.5 Impact of COVID-19 on sustainable development goals

In 2015, the United Nations adopted 17 Sustainable Development Goals (SDGs) with the view to improve livelihood and the natural world by 2030, making all countries of the world to sign up to it. To succeed, the foundations of the SDGs were premised on two massive assumptions namely globalisation and sustained economic growth. However, COVID-19 has significantly hampered this assumption due to several factors already discussed. Indeed, COVID-19 has brought to the fore the fact that the SDGs as currently designed are not resilient to shocks imposed by pandemics. Prior to COVID-19, progress across the SDGs was slow. Naidoo and Fisher (2020) reported that two-thirds of the 169 targets will not be accomplished by 2030 and some may become counterproductive because they are either under threat due to this pandemic or not in a position to mitigate associated impacts.

4.3 Positive impact of COVID-19

In this section, we discussed some of the positive ramifications of COVID-19. Despite the many detrimental effects, COVID-19 has provoked some natural changes in behaviour and attitudes with positive influences on the planet. Nonetheless, to the extent that the trends discussed below were imposed by the pandemic, they also underscore a growing momentum for transforming business operations and production towards the ideal of the CE.

4.3.1 Improvements in air quality

Due to the COVID-19-induced lockdown, industrial activities have dropped, causing significant reductions in air pollution from exhaust fumes from cars, power plants and other sources of fuel combustion emissions in most cities across the globe, allowing for improved air quality (Le Quéré et al., 2020; Muhammad et al., 2020). This is evident from the National Aeronautics and Space Administration (NASA, 2020a) and European Space Agency (ESA, 2020) Earth Observatory pollution satellites showing huge reductions in air pollution over China and key cities in Europe as depicted in **Figure 8**. In China, for example, air pollution reduction of between

20-30% was achieved and a 20-year low concentration of airborne particles in India is observed; Rome, Milan, and Madrid experienced a fall of ~45%, with Paris recording a massive reduction of 54% (NASA, 2020b). In the same vein, the National Centre for Atmospheric Science, York University, reported that air pollutants induced by NO_2 fell significantly across large cities in the UK. Although Wang et al. (2020) reported that in certain parts of China, severe air pollution events are not avoided through the reduction in anthropogenic activities partially due to the unfavourable meteorological conditions. Nevertheless, these data are consistent with established accounts linking industrialization and urbanization with the negative alteration of the environment (Rees, 2002).

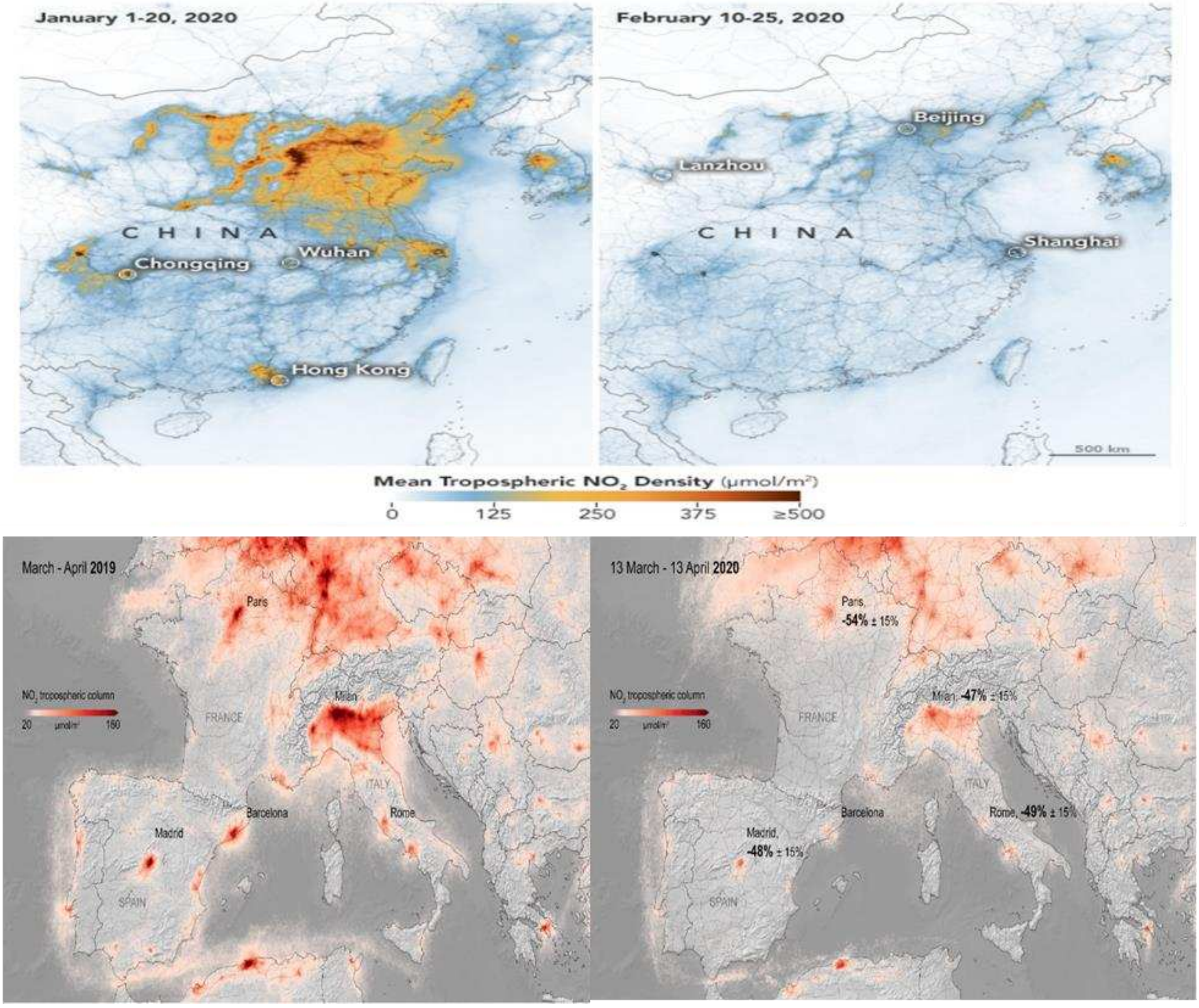


Figure 8: The upper part shows the average nitrogen dioxide (NO_2) concentrations from January 1-20, 2020 to February 10-25, 2020, in China. While the lower half shows NO_2 concentrations over Europe from March 13 to April 13, 2020, compared to the March-April averaged concentrations from 2019 (ESA, 2020; NASA, 2020a).

The scenarios highlighted above reiterates the fact that our current lifestyles and heavy reliance on fossil fuel-based transportation systems have significant consequences on the environment and by extension our wellbeing. It is this pollution that was, over time, responsible for a scourge of respiratory diseases, coronary heart diseases, lung cancer, asthma etc.(Mabahwi et al., 2014), rendering plenty people to be more susceptible to the devastating effects of the coronavirus (Auffhammer et al., 2020). Air pollution constitutes a huge environmental threat to health and wellbeing. In the UK for example, between ~28,000 to ~36,000 deaths/year was linked to long-term exposure to air pollutants (PHE, 2020). However, the reduction in air pollution with the corresponding improvements in air quality over the lockdown period has been reported to have saved more lives than already caused by COVID-19 in China (Auffhammer et al., 2020).

4.3.2 Reduction in environmental noise

Alongside this reduction in air pollutants is a massive reduction in environmental noise. Environmental noise, and in particular road traffic noise, has been identified by the European Environment Agency, EEA (2020) to constitute a huge environmental problem affecting the health and well-being of several millions of people across Europe including distortion in sleep pattern, annoyance, and negative impacts on the metabolic and cardiovascular system as well as cognitive impairment in children. About 20% of Europe's population experiences exposure to long-term noise levels that are detrimental to their health. The EEA (2020) submitted that 48000 new cases of ischaemic heart disease/year and ~12000 premature deaths are attributed to environmental noise pollution. Additionally, they reported that ~22 million people suffer chronic high annoyance alongside ~6.5 million people who experience extreme high sleep disturbance. In terms of noise from aircraft, ~12500 schoolchildren were estimated to suffer from reading impairment in school. The impact of noise has long been underestimated, and although more premature deaths are associated with air pollution in comparison to noise, however noise constitutes a bigger impact on indicators of the quality of life and mental health (EEA, 2020).

A recent study on the aftereffect of COVID-19 pandemic on exercise rates across the globe concluded that reduced traffic congestions and by extension reduced noise and pollution has increased the rate at which people exercise as they leveraged the ensued pleasant atmosphere. Average, moderate, and passive (i.e. people who exercised once a week before COVID-19) athletes have seen the frequency of their exercise increased by 88%, 38%, and 156% respectively (Snider-Mcgrath, 2020).

4.3.3 Increased cleanliness of beaches

Beaches constitute the interface between land and ocean, offering coastal protection from marine storms and cyclones (Temmerman et al., 2013), and are an integral part of natural capital assets found in coastal areas (Zambrano-Monserrate et al., 2018). They provide services (e.g. tourism, recreation) that are crucial for the survival of coastal communities and possess essential values that must be prevented against overexploitation (Lucrezi et al., 2016; Vousdoukas et al., 2020). Questionable use to which most beaches have been subjected have rendered them pollution ridden (Partelow et al., 2015). However, due to COVID-19-induced measures, notable changes in terms of the physical appearance of numerous beaches across the globe have been observed (Zambrano-Monserrate et al., 2020).

4.3.4 Decline in primary energy use

Global energy demand during the first quarter of 2020 fell by ~3.8% compared to the first quarter of 2019, with a significant effect noticeable in March as control efforts heightened in North America and Europe (IEA, 2020). The International Energy Agency (IEA) submitted that if curtailment measures in the form of restricted movement continue for long and economic recoveries are slow across different parts of the globe, as is progressively likely, annual energy demand will plummet by up to 6%, erasing the last five years energy demand growth. As illustrated in **Figure 9,** if IEA's projections become the reality, the world could experience a plunge in global energy use to a level not recorded in the last 70 years. The impact will surpass the effect of the 2008 financial crisis by a factor of more than seven times. On the other hand, if COVID-19 is contained earlier than anticipated and there is an early re-start of the economy at a successful rate, the fall in energy could be constrained to <4% (IEA, 2020). However, a rough re-start of the economy characterised by supply chain disruptions and a second wave of infections in the second half of the year could further impede growth (IEA, 2020).

Coal was reported to have been hit the hardest by ~8% in comparison to the first quarter of 2019 due to the impact of COVID-19 in China whose economy is driven by coal, reduced gas costs, continued growth in renewables, and mild weather conditions. Oil demand was also strongly affected, plummeting by ~5% in the first quarter driven mainly by restrictions in mobility and aviation activities which constitute ~60% of global oil demand (IEA, 2020). For instance, global road transport and aviation activities were respectively ~50% and 60% below the 2019 average. Global electricity demand declined by >20% during full lockdown restrictions, with a corresponding spill over effect on the energy mix. Accordingly, the share of renewable energy sources across the energy supply increased due to priority dispatch boosted by larger installed capacity and the fact that their outputs are largely unconstrained by demand (IEA, 2020). However, there was a decline for all other sources of electricity including gas, coal and nuclear power (IEA, 2020).

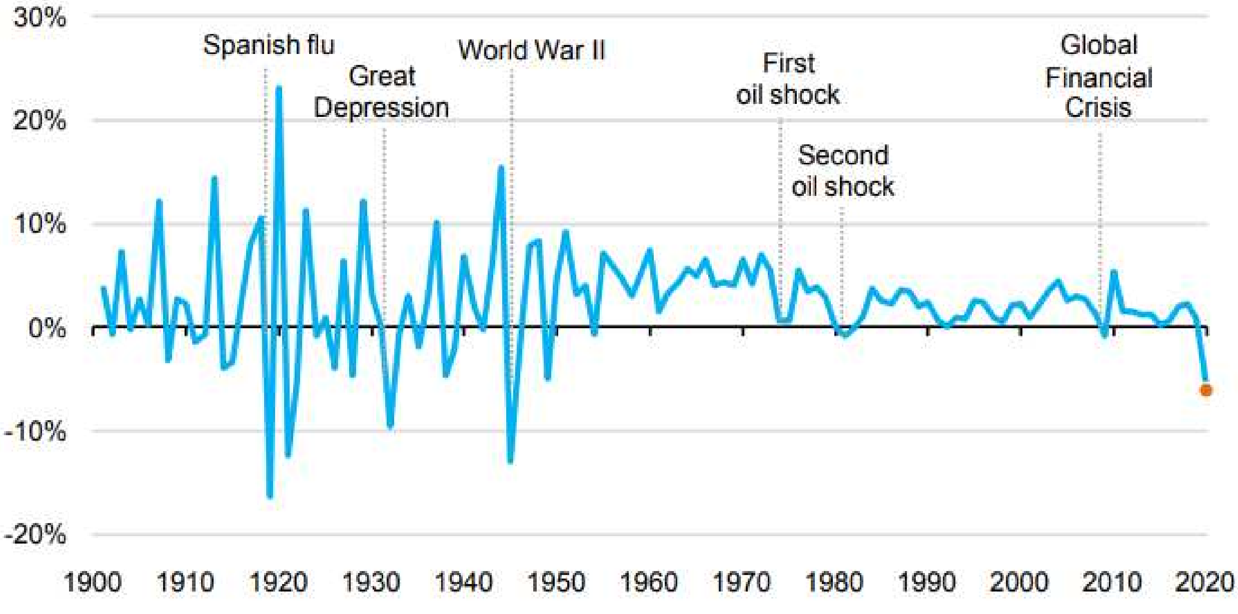


Figure 9: Annual rate of change in primary energy demand, since 1900, with key events impacting energy demand highlighted (IEA, 2020).

4.3.5 Record low CO_2 emissions

Unprecedented reduction in global CO_2 emissions is another positive effect that can be attributed to the COVID-19 pandemic. The massive fall in energy demand induced by COVID-19 accounted for the dramatic decline in global GHG emissions. The annual CO_2 emissions have not only been projected to fall at a rate never seen before, but the fall is also envisioned to be the biggest in a single year outstripping the fall experienced from the largest recessions of the past five decades combined (IEA, 2020). The global CO_2 emissions are projected to decline by ~8% (2.6 GCO_2) to the levels of the last decade. If achieved, this 8% emissions reduction will result in the most substantial reduction ever recorded as it is expected to be six times larger than the milestone recorded during the 2009 financial crisis, (**Figure 10**). Characteristically, after an economic meltdown, the surge in emissions may eclipse the decline, unless intervention options to set the economy into recovery mode is based on cleaner and more resilient energy infrastructure (IEA, 2020).

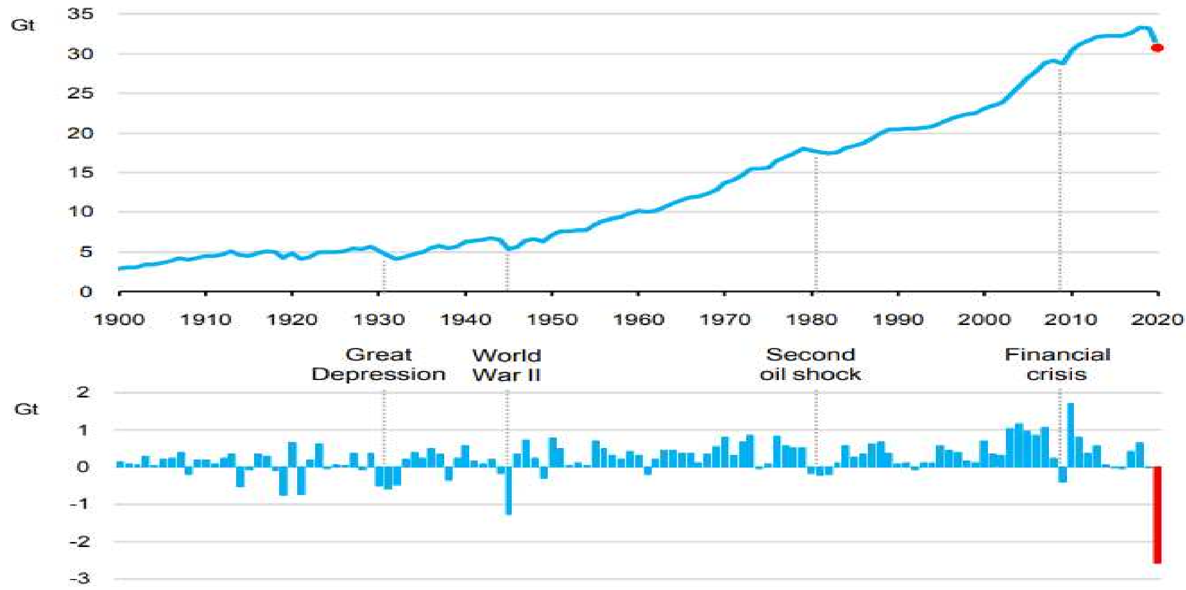


Figure 10: Global energy-related emissions (top) and annual change (bottom) in $GtCO_2$, with projected 2020 levels highlighted in red. Other major events are indicated to provide a sense of scale (IEA, 2020).

4.3.6 Boost in digitalisation

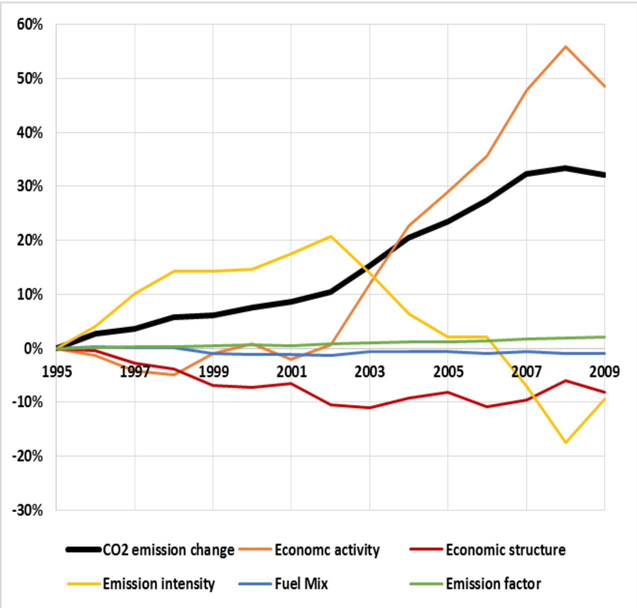
The COVID-19 pandemic has been described as an opportunity to further entrench digital transformation without the 'digitalism' which is an extreme and adverse form of connectedness (Bayram et al., 2020). Protecting patients from unnecessary exposure was a driver for telemedicine (Moazzami et al., 2020) and virtual care would become the new reality (Wosik et al., 2020). The necessity for social distancing under lockdown circumstances has also highlighted the importance (and need) for remote working (Dingel and Neiman, 2020; Omary et al., 2020), which has had implications for broadband connectivity (Allan et al., 2020) as well as reductions in transportation-related pollution levels (Spash, 2020). The impact of COVID-19 on remote working and digitalisation of work is expected to constitute long-term implications for reduced fossil fuel consumption due to mobility and commuting (Kanda and Kivimaa, 2020). Besides, the survival and thriving of many small business restaurants during the lockdown period depended on whether they had a digital resilience, via online platforms, through which they could exploit the home delivery market via Uber Eats (Raj et al., 2020). For consumers, the pandemic has seen a noticeable increase in online orders for food in many countries such as: Taiwan (Chang and Meyerhoefer, 2020); Malaysia (Hasanat et al., 2020); Germany (Dannenberg et al., 2020) as well as Canada (Hobbs, 2020).

4.4 Unsustainability of current economic and business models amidst COVID-19

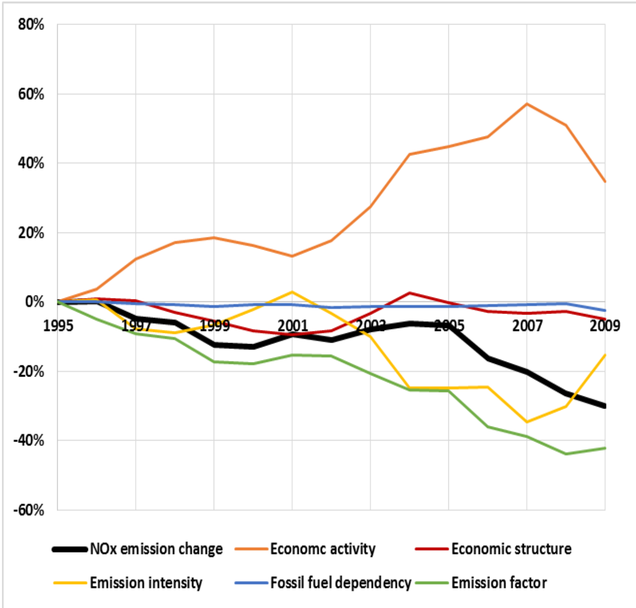
It is interesting to observe that while COVID-19 has led to a very steep reduction in air pollution in advanced economies due to reduced economic activity imposed by the lockdown, this pandemic-driven positive impact is only temporary as they do not reflect changes in economic structures of the global economy (Le Quéré et al., 2020). The changes are not due to the right decisions from governments in terms of climate breakdown policies and therefore should not be misconstrued as a climate triumph. More importantly, life in lockdown will not linger on forever as economies will need to rebuild and we can expect a surge in emissions again. To drive home the point, we conducted a decomposition analysis of key drivers (accelerators or retardants) of four global air pollutants using Logarithmic Mean Divisia Index (LMDI) framework (Ang, 2005; Fujii et al., 2013), with the results shown in **Figure 11**. The drivers of the pollutants considered based on the production side of an economy include: (i) *economic activity* effect, given that emissions can increase or decrease as a result of changes in the activity level of the entire economy; (ii) *industrial economy structure* effect, based on the fact that the growth in emissions is a function of the changes in the industrial activity composition; (iii) *emissions intensity* effect, which can be improvements or deteriorations at the sectoral level, depending on the energy efficiency (e.g. cleaner production processes) of the sector; (iv) *fuel mix or fuel dependency* effect, given that its composition influences the amount of emissions; and (v) *emission factors* effect, because these factors, for different fuel types, changes over time due to switching from fossil fuels to renewables, for example.

As shown in Figure 11a, for example, between 1995 and 2009, global change in CO_2 emission was 32%, where economic activity (+48%) and emission factor (+2%) acted as accelerators, while economic structure (-8%), emission intensity (-9%) and fuel mix (-1%) acted as retardants, of the global CO_2 emission dynamics and trajectory. This implies that although economic activities, as expected, alongside emission factor drove up emissions, however, the upward effect of both drivers was offset by the combined improvements of other driving factors namely economic structure, emission intensity, and fuel mix. Indeed, cutting back on flying or driving less as we have experienced due to COVID-19 contributed to ~8% in emission reduction, however, zero-emissions cannot be attained based on these acts alone. Simply put, emissions reduction cannot be sustained until an optimal balance across the aforementioned drivers informed by structural changes in the economy is attained. As Gates (2020a) rightly stated – the world should be using more energy, not less, provided it is clean.

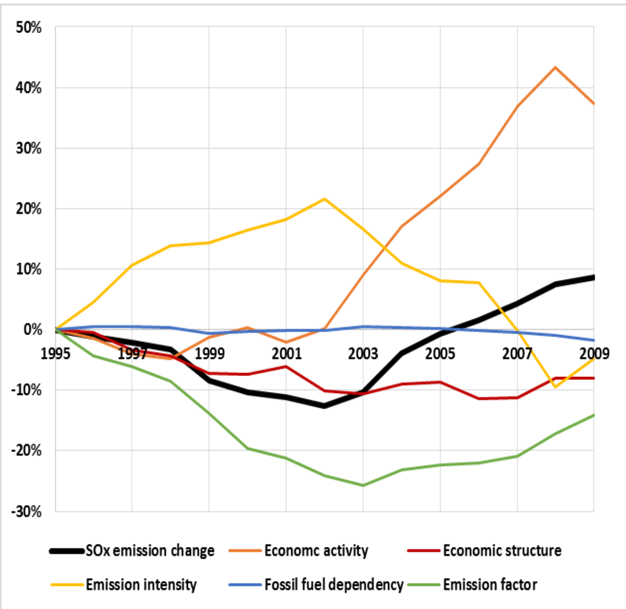
Characteristically, after an economic meltdown, like the global recession in 2008, there is a surge in emissions (Feng et al., 2015; Koh et al., 2016). The current social trauma of lockdown and associated behavioural changes tends to modify the future trajectory unpredictably. However, social responses would not drive the profound and sustained reduction required to attain a low-carbon economy (Le Quéré et al., 2020). This is evident given that we live on a planet interlinked by networked product supply chains, multidimensional production technologies, and non-linear consumption patterns (Acquaye et al., 2017; Ibn-Mohammed et al., 2018; Koh et al., 2016). Additionally, post COVID-19, the society may suffer from green bounce back – there appears to be an increasing awareness of climate change and air pollution because of this pandemic (though the linkages are non-causal). On the one hand this might promote greener choices on behalf of consumers, but on the other it may result in increased car ownership (at the expense of mass transit), driving up emissions. As such, establishing approaches that ensure an optimal balance between quality of life and the environmental burden the planet can bear is pertinent, if the boundaries of environmental sustainability informed by the principles of low-carbon CE are to be extended. In the next section, the role of the CE as a potential strategy for combating pandemics such as COVID-19 is discussed.



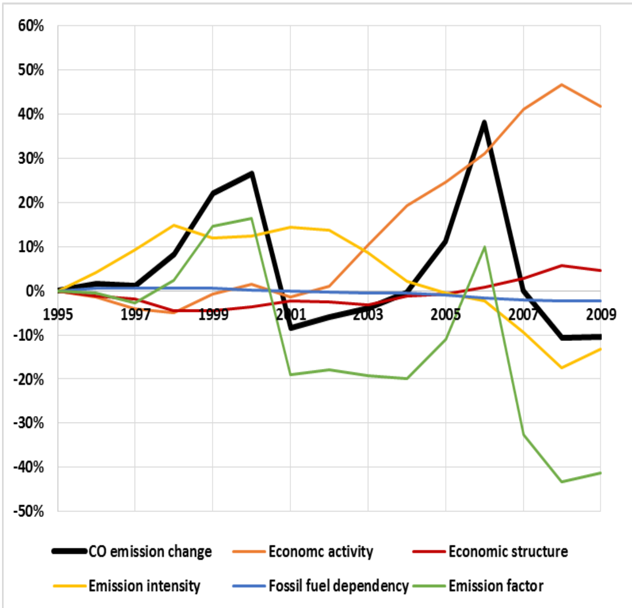
a. Drivers of CO_2 emissions



b. Drivers of NO_x emissions



c. Drivers of SO_x emissions



d. Drivers of CO emissions

Figure 11: Drivers of representative four (4) global pollutants: a) CO_2 emissions; b) NO_x emissions; c) SO_x emissions; d) CO emissions. All data for the decomposition analysis of the four pollutants were obtained from the WIOD database (Timmer et al., 2012).

5. The role of circular economy

For long, the central idea of the industrial economy rests on the traditional linear economic system of taking resources, making products from them, and disposing of the product at the end of life. Experts referred to this as "extract-produce-use-dump", "take-make-waste", or "take-make-dispose" energy flow model of industrial practice (Geissdoerfer et al., 2017; Kirchherr et al., 2017; MacArthur, 2013). However, the unlimited use of natural resources with no concern for sustainability jeopardizes the elastic limit of the planet's resource supply. For instance, Girling (2011) submitted that ~90% of the raw materials used in manufacturing become waste before the final product leaves the production plant while ~80% of products manufactured are disposed of within the first 6 months of their life. Similarly, Hoornweg and Bhada-Tata (2012) reported that ~1.3 billion tonnes of solid waste with a corresponding cost implication of $205.4 billion/year is generated by cities across the globe and that such waste might grow to ~2.2 billion tonnes by 2025, with a corresponding rate of $375.5 billion. This is further compounded by the fact that at the global level, the demand for resources is forecasted to double by 2050 (Ekins et al., 2016).

Against this backdrop, the search for an industrial economic model that satisfies the multiple roles of decoupling of economic growth from resource consumption, waste management and wealth creation, has heightened interests in concepts about circular economy (Ekins et al., 2016; MacArthur, 2013). In theory, CE framework hinges on three principles: designing out waste, keeping products and materials in use and regenerating the natural systems (MacArthur, 2013). Practically, CE is aimed at: (i) emphasizing environmentally-conscious manufacturing and product recovery (Gungor and Gupta, 1999); (ii) promoting the avoidance of unintended ecological degradation in symbiotic cooperation between corporations, consumers and government (Bauwens et al., 2020); and (iii) shifting the focus to a holistic product value chain and cradle-to-cradle life cycle via promotion of product repair/re-use and waste management (Duflou et al., 2012; Lieder and Rashid, 2016; Rashid et al., 2013).

Given the current COVID-19 pandemic, there has never been a more adequate time to consider how the principles of CE could be translated into reality when the global economy begins to recover. This is pertinent because the pandemic has further exposed the limitations of the current dominant linear economy regarding how it is failing the planet and its inhabitants, and has revealed the global ecosystem's exposure to many risks including climate breakdown, supply chain vulnerabilities and fragility, social inequality and inherent brittleness (Bachman, 2020; Sarkis et al., 2020). The pandemic continues to amplify the global interlinkages of humankind and the interdependencies that link our natural environment, economic, and social systems (Haigh and Bäunker, 2020). In the subsections that follow, the potentials of CE as a tool for: climate change mitigation, crafting a more resilient economy, and facilitating a socially just and inclusive society is briefly discussed.

5.1 Circular economy as a tool for climate breakdown mitigation

As highlighted in section 4.3.5, a CO_2 emission reduction of 8%, which in real terms implies an equivalent of ~172 billion tCO_2 will be released instead of ~187 billion tCO_2, is indeed unprecedented. Nevertheless, the peculiar conclusion from the lockdown is that it still entails emissions of 92% of the initial value while there was restrictions to mobility and other related leisure activities. Measures for mitigating climate change have often been presented dramatically as a "prohibition of the nice things of life", but as shown, a cut-off of such an amount of nice things only delivers an 8% reduction. More importantly, it comes at a heavy cost of between $3,200/tCO_2$ and $5,400/tCO_2$ in the US, for example, based on data from the Rhodium Group (Gates, 2020a). In other words, the shutdown is reducing emissions at a cost between 32 and 54 times the $100/tCO_2$ deemed a reasonable carbon price by economists (Gates, 2020a). This suggests that a completely different approach to tackling climate issue is required.

Accordingly, there is the need for a system that calls for greater adoption of a more resilient low-carbon CE model, given the predictions by experts that climate breakdown and not COVID-19 will constitute the biggest threat to global health (Hussey and Arku, 2020; Watts et al., 2018a; Watts et al., 2018b). International bodies and country-level environmental policies have highlighted the fact that a significant reduction in GHG emissions cannot be achieved by transitioning to renewables alone but with augmentation with CE strategies. The demands side CE strategies such as *(i) material recirculation* (more high-value recycling, less primary material production, lower emissions per tonne of material); *(ii) product material efficiency* (improved production process, reuse of components and designing products with fewer materials); *(iii) circular business models* (higher utilisation and longer lifetime of products through design for durability and disassembly, utilisation of long-lasting materials, improved maintenance and remanufacturing), could reduce emissions whilst contributing to climate change mitigation (Enkvist et al., 2018). CE principles, when adopted in a holistic manner provide credible solutions to the majority of the structural weaknesses exposed by COVID-19, offering considerable opportunities in competitiveness and long-term reduced GHG emissions across value chains. Investments in climate-resilient infrastructure and the move towards circular and low-carbon economy future can play the dual role of job creation while enhancing environmental and economic benefits.

5.2 Circular economy as a vehicle for crafting more resilient economies

Haigh and Bäunker (2020) reported that if we muddle through every new crisis based on the current economic model, using short-term solutions to mitigate the impact, future shocks will continue to surpass capacities. It is, therefore, necessary to devise long-term risk-mitigation and sustainable fiscal thinking with the view to shift away from the current focus on profits and disproportionate economic growth. Resilience in the context of the CE largely pertains to having optimized cycles (i.e. products are designed for longevity and optimized for a cycle of disassembly and reuse that renders them easier to handle and transform). Some cycles can be better by being closed locally (e.g. many food items), and for other cycles, a global value chain could be a better option (e.g. rare earth elements). Due to globalization, all cycles have become organized at the global level, diminishing resilience. COVID-19 has further shown how some particular cycles had the wrong scale level, as such, the adoption of CE can be seen as an invitation to reconsider the optimal size of cycles.

Sustainability through resilience thinking would have a positive and lasting impact as reported by the Stockholm Resilience Centre (2016), which concluded that prosperity and sustainability cannot be accomplished without building "*resilient systems that promote radical innovation in economic policy, corporate strategy, and in social systems and public governance*". It calls for sustainability through resilience thinking to become an overarching policy driver and encourages the application of the principles of resilience thinking to enhance social innovation. Haigh and Bäunker (2020) concluded that when resilience thinking is employed as a guide, all innovations emanating from circular thinking would extend beyond focusing mainly on boosting the market and competitiveness and recognise the general well-being of the populace as an equal goal. As the global economy recovers from COVID-19, it has become more apparent that there is a strong sense of interconnectedness between environmental, economic and social sustainability (Bauwens et al., 2020).

5.3 Circular economy as a facilitator of a socially just and inclusive society

Advanced economies have mainly focused on maintaining the purchasing power of households through the establishment of the furlough scheme (in the UK, for example). Most developing countries have also adopted a similar approach through the integration of containment measures with a huge increase in social protection spending. However, these intervention strategies in response to the pandemic have further revealed the social injustice and inequality between countries and communities given that the deployment of such strategy in advanced economies could devastate developing countries and communities (Ahmed et al., 2020; Haigh and Bäunker, 2020). Guan and Hallegatte (2020) revealed that developing and underdeveloped economies face tougher and more challenging situation in comparison to their developed counterparts, because even under the assumption that social protection systems could fully replace income and shield businesses from bankruptcy, maintaining access to essential commodities is impossible if the country is lacking in production capabilities in the first place. Furthermore, in the underdeveloped world, the idea of working from home is very difficult due to the lack of infrastructure and access to health facilities is severely cumbersome. As such, short-term fixes adopted by governments cannot adequately address deep-rooted inequality and social injustice.

Accordingly, Preston et al. (2019) submitted that CE has the potential to minimise prevailing pressures and struggles regarding conflicts due to imbalanced distribution of resources, through participatory forms of governance that entails the inclusion of local stakeholders in resource management initiatives. This can be achieved through the adoption of CE strategy such as closed-loop value chains where wastes are transformed into resources with the view to not only reduce pollution but to simultaneously aid the pursuance of social inclusion objectives. A number of companies are already embracing this idea. For instance, under the Food Forward SA initiative, "*the world of excess is connected with the world of need*" through the recovery of edible surplus food from the consumer goods supply chain and gets redistributed to the local community. This ensures loops are closed and the needy receive nourishment (Haigh and Bäunker, 2020). With sufficient investment in the CE, developing countries can leapfrog their developed counterparts in digital and materials innovation to integrate sustainable production and consumption and low-carbon developments at the core of their economies. Additionally, Stahel (2016) reported that another benefit of the CE as a facilitator of a socially just and inclusive society is that it is likely to be more labour-intensive due to the variety of end-of-life products and the high cost of automating their processing compared to manual work. As such, CE can enable the creation of local jobs and "reindustrialisation of regions" (Stahel, 2019) through the substitution of: manpower for energy, materials for (local) labour, and local workshops for centralised factories (Stahel, 2019), while boosting the repair economy and local micro industries. Of course, not everybody will see this as a benefit, and many would like to see more automation, not less. However, this is a political/economic argument, not an engineering or scientific one. In the next section, barriers to CE in general and in the context of COVID-19 is discussed.

5.4 Barriers to CE in the context of COVID-19

On the surface, the benefits of CE should be obvious as it strives for three wins in the three dimensions of social, economic and environment impacts through a symbiotic vision of reduced material usage, reduced waste generation, extending value retention in products and designing products for durability. However, limiting barriers obviating the success of CE have existed around technical implementation, behavioural change, financial and intellectual investments, policy and regulations, market dynamics, socio-cultural considerations as well as operational cost of transforming from the linear economy to one based on circularity (Friant et al., 2020). In more concrete terms, the barriers dwell within the ecosystem of actors (and the interactions within the actors) involved in the move towards CE (Lieder and Rashid, 2016).

Pre-COVID-19, Korhonen et al. (2018) enumerated six fundamental factors hindering the promise of CE: (i) thermodynamic factors (limit imposed by material and energy combustion in recycling/re-manufacturing); (ii) complexity of spatial and temporal boundaries (material and energy footprints for a product cannot be easily reduced to a point in space and time for an in-depth analysis of environmental impacts); (iii) interlink of governance and nation's economy; (iv) consumer and organizational inertia (reluctance to embrace new way of doing things due to uncertainty about the success of business models as well as fuzziness around organizational culture and management models that rely on CE); (v) fragile industrial ecosystems (featuring the difficulty of establishing and managing intra-/inter-organizational collaboration along with local/regional authorities); and (vi) lack of consensus on what the many Rs (re-use, recycle, recover, repurpose, repair, refurbish, remanufacture) embedded in CE framework really means (Kirchherr et al., 2017). Challenges in data sharing between product end points and stakeholders, complexity in the supply chain with unclear details of product biography over time, and prohibitive start-up investment costs have also been identified as CE barrier in other climes (Jaeger and Upadhyay, 2020; Manninen et al., 2018). Other issues along similar lines were captured in the work by several other authors including Galvão et al. (2020), Kirchherr et al. (2018), Govindan and Hasanagic (2018), De Jesus and Mendonça (2018) and many more.

The paradox of COVID-19 is grounded on creating a once in a lifetime opportunity to re-examine the difficulty of some of these barriers, but it also unveiled a new set of challenges. For instance, the sharing economy models that have been hitherto hailed as exemplars of CE strategy is now perceived differently by many urban dwellers because of the behavioural change embedded in "social distancing", which is necessary to limit the spread of the virus. Although if concepts such as "access over ownership" or "pay for performance" service have become fully operational, they could have constituted a significant solution to offer flexibility. Additionally, it has been argued that COVID-19 will 'disrupt some disruptors' peer-to-peer (P2P) providers such as Airbnb, which has reported a 4.16% drop in local bookings for every doubling new COVID-19 cases (Hu and Lee, 2020). In transportation, demand from ride-sharing modes could increase due to commuters wanting to minimise exposure to COVID-19 in mass transport systems like buses and trains (Chandra, 2020). However, the risks of human-to-human transmission of COVID-19 for passengers not wearing facemask have been noted (Liu and Zhang, 2020), including when either passengers or drivers in ride-hailing and car-sharing disruptors like Uber do not wear facemasks (Wong et al., 2020).

Reducing emissions, in the long run, requires large investments, from both the public and private sectors, in low-carbon technologies and infrastructure in terms of both innovation and diffusion (OECD, 2018). Given the downturn of the global economy due to COVID-19, the prospects of significant low-carbon investments from the private sector have significantly reduced compared to pre-COVID-19. This view is not just limited to the private sector, but also to the public sector, as echoed by Naidoo and Fisher (2020). Hence, post COVID-19, accelerating progress towards CE still requires: (i) decisive legal and financial championships from local, regional and national authorities; (ii) innovation across multiple domains (product design, production technologies, business models, financing and consumer behaviours); (iii) governments to promote green logistics and waste management regulations with reasonable incentives to aid producers and manufacturers in minimizing loss while maximizing value. It is therefore recommended that governments provide the much-needed policy framework that will eliminate some of aforementioned barriers to facilitate the urgent transition to CE. Doing this will build resilience for community response to future pandemic and it also aligns with some of the existing roadmaps for resource efficiency (European Commission, 2011).

6. Opportunities for circular economy post COVID-19

COVID-19 has instigated a focus on vibrant local manufacturing as an enabler of resilient economy and job creation; fostered behavioural change in consumers; triggered the need for diversification and circularity of supply chains, and evinced the power of public policy for tackling urgent socio-economic crises. As we rise to the challenges imposed by COVID-19, the question is no longer should we build back better, but how. Consequently, going forward, crafting a roadmap for a sustainable future is as much about the governmental will to forge a new path to socio-economic growth as it is about local businesses joining forces with the consumers to enable the transition to CE. As already documented in the earlier sections of this paper, governments around the world have deployed many financial policy instruments to combat the short-term consequences of COVID-19 pandemic. Still, in the long-term, the adoption of circular economic principles across various technological frontiers holds the promise to bring about a desired technical and behavioural change that will benefit many nations around the world.

Specifically, adopting the CE principle will alleviate some of the detrimental effects of COVID-19 pandemic in the future. To mention just a few: (i) a national-level adoption of CE will reduce the over-reliance on one country as the manufacturing hub of the world; (ii) a systematic shift away from the traditional polluting, energy-intensive, manufacturing-driven economy to a CE, based on renewable energy, smart materials, smart re-manufacturing, and digital technology will strengthen the fight against pollution; and (iii) the transition to CE will also spur local job creation along several of the axes of societal needs (e.g. built environment, mobility, health, consumables, etc.). Accordingly, in the subsections that follow, an overview of recommendations as well as policy measures, incentives, and regulatory support for advancing sector-specific CE strategies in a post-COVID-19 world is presented.

6.1 Local manufacturing and re-manufacturing of essential medical accessories

Disruptions due to COVID-19 has been attributed to unprecedented demand, panic buying, and intentional hoarding of essential medical goods for profit (Bradsher and Alderman, 2020; Fischer et al., 2020). The shortage of many items was so dire in many countries that the principle of CE, such as re-use, is already been unwittingly recommended (Gondi et al., 2020), by respectable bodies such as the US Centres for Disease Control and Prevention (CDC) (Ranney et al., 2020). However, designed and produced from non-CE compliant processes, medical accessories such as PPE cannot be easily refurbished for re-use without leading to severe degradation in their efficiencies, as noticed for example, in the case of particulate respirators (Liao et al., 2020). Accordingly, it is recommended that companies strive to establish competencies in eco-design and environmentally beneficial innovation to facilitate product re-use in the long run. Some of the desired competencies centre on design strategies for closing resource loops (e.g. designing for technological and biological cycles) as pioneered by McDonough and Braungart (2010).

A detailed discussion of these competencies is also enunciated by Braungart et al. (2007), where the authors differentiated between eco-efficiency (less desirable) and eco-effectiveness (the desired dream of CE) for companies to be compliant with the CE framework. Meanwhile, a starting point for companies to shift to eco-effectiveness at the product design level, which will facilitate product re-use, is to follow the five-step framework enumerated by Braungart et al. (2007) or to adopt the analytical framework to explore some of the key dimensions in eco-design innovations developed by Carrillo-Hermosilla et al. (2010). During implementation, the preceding steps comport with the idea of eco-factories that take pride in design for effortless end-of-life product re-use and design for "upcycling" and remanufacturing (Bocken et al., 2016; Herrmann et al., 2014; Ijomah, 2010), all of which falls under the umbrella of CE.

Another emerging evidence in favour of CE, also adopted inadvertently during this pandemic, is the ease with which several manufacturers have pivoted their factory floors to make different products in response to the shortage of medical accessories. Few examples of these companies in the UK include, but not limited to: AE Aerospace, which retooled its factory floor to produce milled parts for ventilators; Alloy Wire International re-purposed its machinery to make springs for ventilators; AMTICO (flooring manufacture) re-configured to make visors for front line workers; BAE Systems deployed its factory resources to produce and distribute over 40000 face shields; and BARBOUR (a clothing company) re-purposed to produce PPE for nurses (Williamson, 2020).

6.2 CE strategies for managing hospital medical and general waste

Wastes generated by the healthcare industry (HCI) normally arouse concerns about operational, public, and environmental safety as a result of the awareness of the corrosive, hazardous, infectious, reactive, possibly radioactive, and toxic nature of the wastes' composition (Lee et al., 1991; Prüss-Üstün et al., 1999). Consequently, the management of the different categories of healthcare waste far removed from the traditional municipal wastes, falls under stringent national or local regulatory frameworks. Pre-COVID-19, the staggering scale of HCI waste is reported to reach into millions of tonnes per year and there have been many studies of national-level attempts at managing these wastes (Da Silva et al., 2005; Insa et al., 2010; Lee et al., 1991; Oweis et al., 2005; Tudor et al., 2005). However, this problem is expected to worsen with the tremendous surge, in the last few months, in the volume of disposable medical hardware (PPE, masks, gloves, disposable gears worn by healthcare workers and sanitation workers as well as those contaminated by contacts with COVID-19 patients). Another allied problem is the troubling shift among consumers who now prioritize concerns for hygiene by leaning towards plastic packaging (e.g. in food delivery and grocery shopping) during this pandemic at the expense of environmental impacts (Prata et al., 2020). Most of these products are derived from non-biodegradable plastics, and their disposal has not been given much thought. As a result, the management of these wastes has raised understandable angst in several quarters (Klemeš et al., 2020; Xiao and Torok, 2020). Frustratingly, there is much less that can be done at the moment apart from devising judicious waste management policy for these potentially hazardous wastes.

The traditional steps concerning the treatment of HCI wastes (such as collection and separation, storage, transportation to landfill, and decontamination/disposal) suffer from many complications that make the management a challenging undertaking (Windfeld and Brooks, 2015). To alleviate the complexity, the characterization of the physicochemical composition of HCI waste has become an important tool in devising crucial steps for setting up waste minimization and recycling programs (Kaiser et al., 2001). This aligns with the objective of circular economy (CE), which prioritizes the prevention of waste, failing which it proposes the re-use/recyclability of materials from waste to close the loop.

Wong et al. (1994) reported that hospital wastes involve different types of materials: plastics (tubes, gloves, syringes, blood bags), metals (basins, aluminium cans), papers (towel papers, toilet papers, newspapers), cotton/textiles (drapes, table covers, diapers, pads, bandages), glass (bottles) etc. With this categorization in mind, a CE product design consideration that looks promising in the near future, as a way to avert some of the dangers that can be triggered by events such as COVID-19 is to increase the volume of recyclable materials and biodegradable bioplastics in the production of medical accessories. However, the reality is that not all medical gears and products can be derived from bio-plastics or recyclable materials, and some will inevitably continue to be fabricated with materials that need further downstream processing. Yet, the application of CE to the healthcare industry (HCI) remains a touchy subject. Understandably, health and safety concerns, as well as requirements to meet stringent regulations, tend to override the environmental gain from the 4R practice promoted by CE (Kane et al., 2018). On the other hand, the benefits of CE are starting to catch on in the HCI as a means of optimizing hospital supply chains and reduce overhead cost, all the while creating environmental benefits in the course of saving human lives.

Principally, the applications of CE in HCI, like in other fields, are tied to materials flow and an examination of the nature of wastes. Pioneering studies on hospital wastes characterizations (Diaz et al., 2008; Eleyan et al., 2013; Özkan, 2013; Wong et al., 1994), revealed that close to 80% of the wastes can be classified as general wastes, while the remaining 20% falls under the infectious waste category (WHO, 1998). A prevalent method of dealing with the two HCI waste categories has been incineration (Wong et al., 1994). Although suitable for large volumes, incineration produces toxic pollutants such as heavy metals, dioxins, acid gases, and hydrogen chloride (Yang et al., 2009). Consequently, pre-COVID-19, besides incineration, reducing or preventing the volume of wastes in both categories is also shaped by the adoption of green purchasing practices (Wormer et al., 2013). While this may help in the short term, a holistic approach to confronting this problem is the adoption of CE, which can facilitate the shift towards eco-efficient HCI, starting with lifecycle evaluations of medical products to the proposal for re-usable medical instruments (Cimprich et al., 2019; De Soete et al., 2017; Penn et al., 2012). Numerous CE strategies for healthcare waste management are detailed by Kane et al. (2018) and Voudrias (2018). Undoubtedly, with COVID-19, there is an uptick in the percentage of waste under the infectious category due to hospitals taking various precautions to facilitate control of the pandemic (Peng et al., 2020). Nevertheless, by subjecting the general waste category to proper sterilization procedure via any of thermal, microwave, bio-chemical sterilization, the huge potential from upcycling of the retrieved materials will edge towards fulfilling the promise of CE within the sector (Yang et al., 2009).

6.3 Embracing resource efficiency in the construction and built environment

As with other economic sectors, COVID-19 has exposed the shortcomings of the built and natural environment's business-as-usual practices, highlighting the prevalence of poor-quality buildings, issues regarding affordability of decent housing and rigidity of the current building stock (EMF, 2020b). Living in poor-quality houses and in small constricted energy inefficient homes, led to the in-house transmission of the virus (Clair, 2020). This is particularly the case in poorer countries where inadequate access to sanitation amenities have prevented people from adopting best practices necessary for halting the transmission (Andrew et al., 2020). These issues alongside the growing concern and awareness regarding the resource-wasting nature of the sector, present a strong case for rethinking it. The CE is well positioned to offer potential solutions to these problems.

CE can help balance behavioural challenges and opportunities from occupancy requirements. Humans spend up to 90% of their time indoors (Marques et al., 2018; Pitarma et al., 2017). The pandemic has led to people spending more time at 'home' than at work, leading to massively underutilised office and business spaces, which is likely to increase due to on-going social distancing constraints (Feber et al., 2020) or perhaps due to more organisation discovering the cost benefits of remote working. It is also plausible that upgrading of existing (or design of new) office and commercial spaces would require making them flexible and adaptable to cope with changing needs (e.g. occupant density, social distancing, ventilation, etc.) by using movable walls (Carra and Magdani, 2017). Insufficient ventilation can increase the risk of infection to healthcare workers and susceptible patients in healthcare buildings, especially makeshift hospitals (Chen and Zhao, 2020). The impact of these engineering measures on energy consumption of typical buildings and healthcare facilities needs to be considered because of social distancing measures, which may require a decrease in occupant density but an increase in ventilation rates. So, although energy recovery is high on the agenda for CE in the built environment (Eberhardt et al., 2019), the additional requirement of more mechanical ventilation for less people will stretch the energy consumed by buildings. Some researchers have argued for buildings to avoid recirculation (essential for energy savings) and use 100% fresh outdoor air for mechanical ventilation systems (Pinheiro and Luís, 2020). Such scenarios are likely to increase the adoption of renewable energy sources to support acceptable indoor air quality (IAQ).

The adoption of CE strategies such as material reuse and development of recycling infrastructure can facilitate value circulation and efficient use of resources within the built and natural environment, ensuring a more competitive and cost-effective post-COVID-19 recovery, while contributing to GHG emissions reduction and creating job opportunities (EMF, 2020b). For instance, a study by ARUP estimated that designing for steel reuse has the potential of generating savings of 6-27% and 9-43% for a warehouse and an office respectively, whilst constituting up to 25% savings on material costs (SYSTEMIQ, 2017). The EU is leading in policy direction that would make it a legal requirement to introduce recycled content (i.e. material looping) in specific construction products, after the functionality and safety have been vetted (European Commission, 2020). Such initiatives will encourage designers and researchers to incorporate material looping into their overall design strategy across the value chain to ensure they are fit for circulation (Deloitte, 2020). This material looping has been shown to reduce disposal fees and generate new income streams from the secondary materials market (Rios et al., 2015). It is an approach that would help reduce construction waste, which accounts for a third of all solid wastes in countries like India (EMF, 2016). The adoption of digital material passports that supports end-to-end tracking of building materials has been reported by SYSTEMIQ (2017) to aid the identification of materials for reuse as they approach their end of first life, thereby allowing the longevity and encouraging tighter material looping.

COVID-19 in the context of CE will encourage prefabrication, design thinking and renovation. As the building industry moves towards the industrialisation of construction via prefabrication/offsite production, seven strategies have been suggested by Minunno et al. (2018) out of which the principle of designing for eventual disassembly and reuse is critical. With a combined smart and industrialised prefabrication (SAIP) process (Abbas Elmualim et al., 2018), the intelligent performance and circularity of buildings can be boosted by advanced smart technologies (Windapo and Moghayedi, 2020). The building of 1,000 bed Huoshenshan Hospital in Wuhan covering 34,000m^2 in ten days using modular pre-fabricated components, which can be disassembled and reused (Zhou et al., 2020) has demonstrated the capability of the construction industry to deliver adaptable buildings in record time. But it is perhaps in the sphere of refurbishment and renovation that CE in the built environment would mostly be felt. A CE strategy that promotes repair and refurbishment is preferable to one which encourages recycling since the economic and environmental value of a product is retained better by the former (Sauerwein et al., 2019).

Renovation helps achieve carbon reduction targets while contributing to economic stimulation (Ibn-Mohammed et al., 2013) . Retrofitting, refurbishing or repairing existing buildings leads to lower emission facilities, is less resource-intensive and more cost-effective than demolition or new construction (Ardente et al., 2011; Ibn-Mohammed et al., 2014). Nevertheless, circular renovation of buildings must align with circular design thinking – as alluded to above, in terms of re-integrating materials back into the value chain – as well as the need to enhance material/product durability and energy efficiency (Pomponi and Moncaster, 2017). In Europe, renovation of buildings decreases the residential sector's GHG emissions by 63%, with a reduction of up to 73% in the non-residential sector (Artola et al., 2016). In meeting the emerging needs of the renovation sub-sector, digital infrastructure technologies (such as thermographic and infrared surveys, photogrammetry and 3D laser scanning, as well as BIM and Digital Twinning) will play a crucial role in ensuring the low carbon and energy-efficient future of the built environment (ARUP, 2020).

6.4 Bio-cycle economy and the food sector

COVID-19 or not, the food sector is generally wasteful (Dilkes-Hoffman et al., 2018), contributes to environmental degradation (Beretta and Hellweg, 2019), disrupts nutrient flows due to the current linear nature of its value chain, thereby diminishing the nutritional quality of food (Castañé and Antón, 2017). To address these issues, as part of a future resilience in the food sector, a number of CE levers applicable to the sector is highlighted: (i) closing nutrient loops through the adoption of regenerative agriculture (Rhodes, 2017). The organic content of soil reflects its healthiness and propensity to produce nutritious crops. The adoption of regenerative agriculture can facilitate the preservation of soil health through returning organic matter to the soil in the form of food waste or composted by-products or digestates from treatment plants (Sherwood and Uphoff, 2000); (ii) value recovery from organic nutrients through the adoption of anaerobic digestion facilities (De Gioannis et al., 2017; Huang et al., 2017), which is related to controlled biogas production for onward injection into natural gas network or conversion to electrical energy (Atelge et al., 2020; Monlau et al., 2015). This has the potential to transform ensuing methane from food waste into carbon-neutral energy; and (iii) the embrace of urban and peri-urban agriculture (Ayambire et al., 2019; Lwasa et al., 2014; Opitz et al., 2016; Thebo et al., 2014), which entails the "*cultivation of crops and rearing of animals for food and other uses within and surrounding the boundaries of cities, including fisheries and forestry*"(EPRS, 2014). Indeed, by cultivating food in proximity to where it will be consumed, carbon footprint can be mitigated in numerous ways. For instance, through the adoption of urban agriculture, Lee et al. (2015) demonstrated GHG reduction of 11,668 t yr^{-1} in the transportation sector. The popularity of local farms has severely increased as a direct consequence of COVID-19, whereby people could experience the power of local food cycles and could avoid perceived contamination risks in supermarkets. This will further bolster urban and peri-urban agriculture.

All the above-mentioned CE strategies will contribute towards the establishment of a better and more resilient future food system. However, in the context of COVID-19, transitioning to regenerative agricultural production processes and expanding food collection, redistribution and volarisation facilities constitute an integral part of a more resilient and healthy food system that allows greater food security and less wastage post COVID-19 (EMF, 2020a). Investments towards accelerating regenerative agriculture offer economic benefits facilitated by reforms in food, land, and ocean use (World Economic Forum, 2020). It also offer environmental benefits by supporting biologically active ecosystems (EMF, 2020a) and through numerous farming mechanisms including no-till farming, adoption of cover crops; crop rotations and diversification (Ranganatha et al., 2020) as well as managed grazing for regenerative livestock rearing (Fast Company, 2019). Similarly, expanding food collection, redistribution and volarisation facilities offers both economic and environmental benefits for the food system (EMF, 2020a). However, realising these benefits will require investment in: (i) physical infrastructure like cold chains that support the storage, processing, and supply of edible food, especially in low-income countries, and (ii) processing infrastructure for the collection and volarisation of waste food (EMF, 2020a). This will facilitate door-to-door waste food collection, offering avenues for municipal organic waste volarisation.

6.5 Opportunities for CE in the transport and mobility sector

Facilitating the movement of people, products and materials, transportation infrastructures is imperative to the success of circularity in the shift towards sustainable cities given its impact on the quality of life, the local environment and resource consumption (Van Buren et al., 2016). As noted in an earlier section, the transport sector was one of the most heavily impacted sectors by COVID-19. Going forward, many CE strategies could be adopted as part of building a resilient transport sector. Development of compact city for effective mobility given their attributes in terms of being dense with mixed-use neighbourhoods and transit-oriented (EMF, 2019), creating an enabling environment for both shared mobility options (e.g. trams, buses, ride-shares) and active mobility options (e.g. bicycling, walking) (Chi et al., 2020; Shaheen and Cohen, 2020). This will help to re-organize urban fabric and promote intelligent use of transportation infrastructures (Marcucci et al., 2017). However, the behavioural change embedded in "social distancing", which is necessary to limit the contagion may affect the perception of many urban dwellers about this. On the other hand, less compact cities require increased mobility infrastructure with a corresponding increase in operational vehicle use, leading to more traffic congestion, energy and resource depletion and pollution (UN Habitat, 2013).

The use of urban freight strategies for effective reverse logistics and resource flows is also a viable CE strategy for the transport sector (EMF, 2019) as it enables the provision of services in a manner that also supports similar priorities for economic growth, air quality, environmental noise and waste management (Akgün et al., 2019; Kiba-Janiak, 2019). Beyond vehicles and infrastructure, the adoption of these strategies can enable the development of new technologies and practices such as virtualisation of products, digital manufacturing, waste collection, and sorting systems. Interestingly, innovative environmentally-friendly logistics solutions resting on the backbone of the CE framework are already materializing and being trialled in various capacities, including: urban consolidation centre (UCC) (Johansson and Björklund, 2017), crowshipping (Buldeo Rai et al., 2017a; Rai et al., 2018) and off-hour delivery (Gatta et al., 2019). UCC stresses the use of logistics facilities in city suburbs to ease good deliveries to customers (Browne et al., 2005), while crowshipping is a collaborative measure that employs the use of free mobility resources to perform deliveries (Buldeo Rai et al., 2017b).

The availability of rich transport data (e.g. impacts of events on transport, commuter habits) and AI-enabled complex data processing technologies can be leveraged to inform the planning, management, and operations of transport networks over time. Real-time data can also be adopted for monitoring and for instant regulations of traffic flow based on route planning, dynamic pricing and parking space allocation. Noticeably, many of these innovative CE-related initiatives still need an efficient governance mechanism (Janné and Fredriksson, 2019). However, coupling them with the deployment of environmentally efficient vehicles and superior technical solutions hinging on the internet-of-things will bring many nations closer to reaping the benefits of CE. Given that urban planning is most often within the remit of governmental agencies, they must therefore develop integrated pathways and strategies for urban mobility to ensure effective logistics and resource flows. Stakeholder engagements within the transport sector can also facilitate innovative solutions that enable better use of assets and big data solutions.

6.6 Sustaining improvements in air quality

Improvements in air quality is one of the positives recorded due to the COVID-19-imposed lockdown as transportation and industrial activities halted. To sustain such improvements, there is the need to facilitate a step change by ramping up the uptake of low emission vehicles through setting more ambitious targets for the embrace of electric vehicles, constructing more electric car charging points as well as encouraging low emissions fuels. This entails heightening investments in cleaner means of public transportation as well as foot and cycle paths for health improvements; redesigning of cities to ensure no proximity to highly polluting roads and the populace as well as preventing highly polluting vehicles from accessing populated areas using classifications such as clear air or low emission zones (PHE, 2020).

Batteries constitute an integral part towards the decarbonisation of road transportation and support the move to a renewable energy system (World Economic Forum, 2019). As such, it is important to establish a battery value chain that is circular, responsible and just, to realise the aforementioned transitions. This entails the identification of the (World Economic Forum, 2019): (i) challenges inhibiting the scaling up of the battery value chain (e.g. battery production processes, risks of raw materials supplies); (ii) levers to mitigate the challenges such as a *circular value chain* (e.g. design for life extension, implementation of V1G and V2G and scaling up of electric shared and pooled mobility, coupling the transport and power sectors); *sustainable business and technology* (e.g. increasing the share of renewables and energy efficiency measures across the value chain, effective regulations and financial incentives to support value creation); and a *responsible and just value chain* based on a balanced view and interplay between environmental, social and economic factors. Indeed, cost-effective and sustainable batteries, as well as an enabling ecosystem for the deployment of battery-enabled renewable energy technologies backed with a dense infrastructure network for charging, will facilitate the transition towards broader acceptance of electric vehicles and by extension guarantees a sustained improvement in air quality (Masiero et al., 2017; PHE, 2020; World Economic Forum, 2019). We recognize that if all cars are simply replaced by electric ones, there will still be the same volume of traffic and an increased need for raw materials, posing significant social, environmental and integrity risks across its value chain. However, CE through the aforementioned levers can address these challenges and support the achievement of a sustainable battery value chain. This will entail lowering emission during manufacturing, eradicating human rights violations, ensuring safe working conditions across the value chain and improving reuse, recycling and remanufacturing (World Economic Forum, 2019).

6.7 Digitalisation for supply chain resilience post COVID-19

Digitalisation of supply chains through leveraging disruptive digital technologies (DDTs) - technologies or tools underpinning smart manufacturing such as the internet of things (IoT), artificial intelligence, big data analytics, cloud computing and 3D printing - constitute an important step for companies to prepare for and mitigate against the disruptions and attain business resilience amidst global pandemics such as COVID-19. Circular supply chain value drivers' entails elongation of useful lifespan and maximisation of asset utilisation. Intelligent assets value drivers entail gathering knowledge regarding the location, condition and availability of assets (Morlet et al., 2016). Paring these drivers could provide a broad range of opportunities, which could change the nature of both products and business models, enabling innovation and value creation (Antikainen et al., 2018; Morlet et al., 2016). For instance, big data analytics, when adopted properly can aid companies in streamlining their supplier selection processes; cloud-computing is currently being used to facilitate and manage supplier relationships; through automation and the IoT, logistics and shipping processes can be greatly enhanced (McKenzie, 2020). Digitalisation enables predictive maintenance, preventing failures while extending the lifespan of a product across the supply chains. It therefore, constitutes an ideal vehicle for circular supply chains transitioning, providing opportunities to close material loops and improve processes (Morlet et al., 2016; Pagoropoulos et al., 2017).

Indeed, COVID-19 has prompted renewed urgency in the adoption of automation and robotics towards mitigating against the disruptive impact on supply chains through restrictions imposed on people's movement. Numerous companies are taking advantage of this to automate their production lines. Prior to COVID-19, momentum towards adopting 5G mobile technology was mounting but delays including anticipated use evaluations, security, competition and radio communications regulatory issues limited progress (McKenzie, 2020). It is highly likely that the experience of COVID-19 may accelerate the provision of regulatory certainty for 5G, which will in turn fast track the deployment of IoT-enabled devices for remote monitoring, to support supply chain resilience post COVID-19.

Despite the benefits of DDTs, tension exists between their potential benefits (i.e. ability to deliver measurable environmental benefits at an affordable cost), and the problems (i.e. heavy burden imposed during manufacturing and disposal phases of their lifecycle) they constitute, creating rebound effects. As such, the tension between the push for increasing digitalisation and the associated energy costs and environmental impacts should be investigated such that they do not exacerbate the existing problems of resource use and pollution caused by rapid obsolescence and disposal of products containing such technologies. This entails identifying, mapping and mitigating unintended consequences across their supply chains, whilst taking into account technological design embedded within green ethical design processes, to identify environmental sustainability hotspots, both in conception and application phases.

6.8 Policy measures, incentives and regulatory support CE transitioning

Becque et al. (2016) in their analysis of the political economy of the CE identified six main types of policy intervention to facilitate, advance and guide the move to a CE by addressing either barriers that aims to fix the market and regulatory failures or encourage market activity. Some of the policy intervention options identified include: (i) *education, information and awareness* that entails the integration of CE and lifecycle systems thinking into educational curricula supported by public communication and information campaigns; (ii) *setting up platforms for collaboration* including public-private partnerships with ventures at the local, regional and national levels, encouraging information sharing as well as value chain and inter-sectoral initiatives, establishing research and development to facilitate breakthroughs in materials science and engineering, biomaterials systems etc.; (iii) introduction of sustainability initiatives in *public procurement and infrastructure*; (iv) *provision of business/financial/technical support schemes* such as initial capital outlay, incentive programs, direct subsidies and financial guarantees as well as technical support, training, advice and demonstration of best practices; (v) *regulatory frameworks* such as regulation of products (including design), extension of warranties and product passports; strategies for waste management including standards and targets for collection and treatments, take-back systems and extended producer responsibility; strategies at the sectoral levels and associated targets for resource productivity and CE; consumer, competition, industry and trade regulations; introduction of standard carbon accounting standards and methodologies; and (vi) fiscal frameworks such as reductions of VAT or excise tax for products and services designed with CE principles.

7. Conclusion

COVID-19 has highlighted the practical and environmental folly of 'extract-produce-use-dump' economic model of material and energy flows. Short-term policies to cope with the urgency of the pandemic are unlikely to be sustainable models in the long run. Nonetheless, they shed light on critical issues that deserve emphases, such as the clear link between environmental pollution and transportation/industrialization. The role of unrestricted air travel in spreading pandemics particularly the viral influenza types (of which COVID-19 is one) is not in doubt, with sectors like tourism and aviation being walloped (some airlines may never recover or return to profitability in a long time) due to reduced passenger volumes. The fallout will re-shape the aviation sector, which like tourism has been among the hardest to be hit economically, albeit with desirable outcomes for the reduction in adverse environmental impacts. Peer-to-peer (P2P) or sharing economy models (e.g. Uber, Airbnb) which have birthed a new generation of service providers and employees are found to be non-resilient to global systemic shocks.

The urgency of supply and demand led to a reduction in cargo shipping in favour of airfreights whose transatlantic cost/kg tripled overnight is matched by job losses, income inequalities, mass increase in global poverty levels and economic shocks across industries and supply chains. The practicability of remote working (once the domain of technology/service industries) has been tried and tested for specific industries/professions with its associated impacts on reduced commuting for workers. Remote healthcare/telemedicine/ and remote working, in general, is no longer viewed as unfeasible because it has been practiced with success over the best part of a four-month global lockdown period. There was a corresponding reduction in primary energy consumption due to the slowing and shutting down of production and economic activities, and the delivery of education remotely is also no longer questioned. The potential of automation, IoT, and robotics in improving manufacturing processes, as well as the use of cloud computing and big data analytics in streamlining supplier selection processes and management of supplier relationships and logistics are better appreciated.

The inadequacies of modern healthcare delivery systems to cope with mass casualties and emergencies are universally acknowledged, primarily due to the incapacity of hospital JIT procurement process to provide essential medical and emergency supplies in vast quantities at short notice. This had deadly consequences with thousands of patients and healthcare workers paying the ultimate price for lack of planning and shortfalls in PPE inventory and critical care equipment. Protectionism and in-ward looking policies on exports and tariff reductions/waivers on the importation of raw materials and critical PPE have emphasized the importance of cooperation to cope with shortages, which evolved in tandem with profiteering, thereby emphasizing the role/need for cottage industries to help meet global production of essentials (facemasks, 3D printed parts/equipment, etc.). The increase in infectious hospital wastes due to the pandemic was necessitated by precautionary measures to control the transmission, but proper/advanced sterilization procedures via thermal, microwave, biochemical processes can help in upcycling discarded or retrieved materials and PPE.

Changes in consumer behaviour with social distancing have necessitated a huge increase in online purchasing, which has benefitted the big players but seriously harmed SMEs who were not exploiting web-based product and service delivery. A CE-based resilience of the consumer food sector was found to require: (i) closing nutrient loops with the use of regenerative agriculture; (ii) value recovery from organic nutrients via anaerobic digestion facilities; (iii) adoption of urban and peri-urban agriculture; and (iv) expanding food collection, redistribution and volarisation facilities. It is believed that CE will facilitate a socially just and inclusive society driven by the need for resilience and sustainability goals, which could see a rise in bio-economy and sharing economy (SE). The consequences of these would be felt in terms of global cooperation and mutual interests; long-term planning as well as the need to strike a more excellent balance between dependence outsourcing/importation and local manufacturing/productivity. A realignment of value chains is likely to occur because of countries with raw materials exploiting this pandemic for their sustainable growth and new world order not shaped by the technological superiority of super-powers is likely to emerge.

During the lockdown, office and commercial spaces were massively underutilized and the need to increase ventilation rates, e.g. in hospitals is leading to more energy consumption. However, there are opportunities to (re)design buildings to have movable walls for adaptable use. The use of modular techniques for fast construction of buildings that can be disassembled and re-configured for new needs, as demonstrated in China, will increase. Renovation and refurbishment will witness a renewed vigour as existing buildings get a new lease of life with reduced carbon emissions and new jobs being created. Nonetheless, integrating circularity (product durability, energy efficiency, recyclability, etc.) via design thinking is essential from the onset. Digital technologies will play a crucial role in ensuring the low carbon and energy-efficient future of the built environment.

Governments are recognizing the need for national-level CE policies in many aspects, such as: (a) reducing over-reliance on other manufacturing countries for essential goods as massive shortages forced the unwitting adoption of CE principles such as re-use; (b) intensive research into bio-based materials for the development of biodegradable products and the promotion of bio-economy; (c) legal framework for local, regional and national authorities to promote green logistics and waste management regulations which incentivize local production and manufacturing; and (d) development of compact cities for effective mobility (with social distancing considerations) as well as enabling environment for shared mobility options (e.g. ride-shares) and active mobility options (e.g. bicycling, walking).

Going forward, resilience thinking should guide lessons learnt and innovations emanating from circular thinking should target the general well-being of the populace and not merely focus on boosting the competitiveness, profitability or growth of businesses and national economies. The post-COVID-19 investments needed to accelerate towards more resilient, low carbon and circular economies should also be integrated into the stimulus packages being promised by governments since the shortcomings in the dominant linear economic model are now recognized and the gaps to be closed are known.

References

Abbas Elmualim, S.M., Chileshe, N., Rameezdeen, R., 2018. Construction and the Circular Economy: Smart and Industrialised Prefabrication. Unmaking Waste in Production and Consumption: Towards The Circular Economy, 323.
ACI, 2020. Policy Brief – COVID-19: Relief measures to ensure the survival of the airport industry. Airport Council International.
Acquaye, A., Feng, K., Oppon, E., Salhi, S., Ibn-Mohammed, T., Genovese, A., Hubacek, K., 2017. Measuring the environmental sustainability performance of global supply chains: A multi-regional input-output analysis for carbon, sulphur oxide and water footprints. Journal of Environmental Management 187, 571-585.
Ahmed, F., Ahmed, N.e., Pissarides, C., Stiglitz, J., 2020. Why inequality could spread COVID-19. The Lancet Public Health 5, e240.
Air Transport Bureau, 2020. Effects of Novel Coronavirus (COVID‐19) on Civil Aviation: Economic Impact Analysis. International Civil Aviation Organization (ICAO), Montréal, Canada.
Akgün, E.Z., Monios, J., Rye, T., Fonzone, A., 2019. Influences on urban freight transport policy choice by local authorities. Transport Policy 75, 88-98.
Allan, J., Donovan, C., Ekins, P., Gambhir, A., Hepburn, C., Robins, N., Reay, D., Shuckburgh, E., Zenghelis, D., 2020. A net-zero emissions economic recovery from COVID-19. COP26 Universities Network Briefing, April.
Allison, A.L., Ambrose-Dempster, E., Domenech Aparsi, T., Bawn, M., Casas Arredondo, M., Chau, C., Chandler, K., Dobrijevic, D., Hailes, H.C., Lettieri, P., 2020. The environmental dangers of employing single-use face masks as part of a COVID-19 exit strategy. UCL Open: Environment Preprint.
American Geriatrics Society, 2020. American Geriatrics Society (AGS) policy brief: COVID‐19 and nursing homes. Journal of the American Geriatrics Society.
Anderson, R.M., Heesterbeek, H., Klinkenberg, D., Hollingsworth, T.D., 2020. How will country-based mitigation measures influence the course of the COVID-19 epidemic? The Lancet 395, 931-934.
Andrew, A., Armand, A., Augsburg, B., Taveras, I.K., 2020. Challenges of adopting coronavirus precautions in low-income countries. The IFS, Institute of Fiscal Studies.
Ang, B.W., 2005. The LMDI approach to decomposition analysis: a practical guide. Energy policy 33, 867-871.
Antikainen, M., Uusitalo, T., Kivikytö-Reponen, P., 2018. Digitalisation as an enabler of circular economy. Procedia CIRP 73, 45-49.
Arafat, S.Y., Kar, S.K., Marthoenis, M., Sharma, P., Apu, E.H., Kabir, R., 2020. Psychological underpinning of panic buying during pandemic (COVID-19). Psychiatry Research.
Ardente, F., Beccali, M., Cellura, M., Mistretta, M., 2011. Energy and environmental benefits in public buildings as a result of retrofit actions. Renewable and Sustainable Energy Reviews 15, 460-470.
Artola, I., Rademaekers, K., Williams, R., Yearwood, J., 2016. Boosting building renovation: What potential and value for Europe. Study for the iTRE Committee, Commissioned by DG for Internal Policies Policy Department A, 72.
ARUP, 2020. Transform and Reuse:Low-Carbon Futures for Existing Buildings. ARUP.
Atelge, M., Atabani, A., Banu, J.R., Krisa, D., Kaya, M., Eskicioglu, C., Kumar, G., Lee, C., Yildiz, Y., Unalan, S., 2020. A critical review of pretreatment technologies to enhance anaerobic digestion and energy recovery. Fuel 270, 117494.
Aubrecht, P., Essink, J., Kovac, M., Vandenberghe, A.-S., 2020. Centralized and Decentralized Responses to COVID-19 in Federal Systems: US and EU Comparisons. Available at SSRN 3584182.
Auffhammer, M., Burke, M., Burney, J., Hsiang, S., Lobell, D., Roberts, M., Schlenker, W., 2020. COVID-19 reduces economic activity, which reduces pollution, which saves lives. Global Food, Environment and Economic Dynamics (G-FEED), United States.
Ayambire, R.A., Amponsah, O., Peprah, C., Takyi, S.A., 2019. A review of practices for sustaining urban and peri-urban agriculture: Implications for land use planning in rapidly urbanising Ghanaian cities. Land Use Policy 84, 260-277.
Bachman, D., 2020. COVID-19 could affect the global economy in three main ways. Deloitte.
Baker, S.R., Bloom, N., Davis, S.J., Terry, S.J., 2020. Covid-induced economic uncertainty. National Bureau of Economic Research.
Baldwin, R., Evenett, S., 2020. Covid-19 and Trade Policy: Why turning inward won't work. London: CEPR Press.
Baseler, L., Chertow, D.S., Johnson, K.M., Feldmann, H., Morens, D.M., 2017. The Pathogenesis of Ebola Virus Disease. Annu Rev Pathol 12, 387-418.
Basilaia, G., Kvavadze, D., 2020. Transition to Online Education in Schools during a SARS-CoV-2 Coronavirus (COVID-19) Pandemic in Georgia. Pedagogical Research 5.

Bauwens, T., Hekkert, M., Kirchherr, J., 2020. Circular futures: What Will They Look Like? Ecological Economics 175, 106703.
Bayram, M., Springer, S., Garvey, C.K., Özdemir, V., 2020. COVID-19 digital health innovation policy: A portal to alternative futures in the making. OMICS: A Journal of Integrative Biology.
Becque, R., Roy, N., Hamza-Goodacre, D., 2016. The Political Economy of the Circular Economy-lessons to date and questions for research., San Francisco, pp. 1-16.
Beretta, C., Hellweg, S., 2019. Potential environmental benefits from food waste prevention in the food service sector. Resources, Conservation and Recycling 147, 169-178.
Bloom, D.E., Cadarette, D., 2019. Infectious Disease Threats in the 21st Century: Strengthening the Global Response. Frontiers in immunology 10, 549.
Bloom, D.E., Canning, D., 2004. Epidemics and economics. Interactions Between Global Change and Human Health (Scripta Varia 106, 304-331.
Bocken, N.M., De Pauw, I., Bakker, C., van der Grinten, B., 2016. Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering 33, 308-320.
Bown, C.P., 2020. COVID-19: Demand spikes, export restrictions, and quality concerns imperil poor country access to medical supplies. A CEPR Press VoxEU.org eBook, 31.
Bradsher, K., Alderman, L., 2020. The world needs masks. China makes them, but has been hoarding them. New York Times.
Bramanti, B., Dean, K.R., Walloe, L., Chr Stenseth, N., 2019. The Third Plague Pandemic in Europe. Proc Biol Sci 286, 20182429.
Braungart, M., McDonough, W., Bollinger, A., 2007. Cradle-to-cradle design: creating healthy emissions – a strategy for eco-effective product and system design. Journal of Cleaner Production 15, 1337-1348.
Bretscher, L., Hsu, A., Tamoni, A., 2020. The Supply Channel of Uncertainty Shocks and the Cross-Section of Returns: Evidence From the COVID-19 Crisis. Available at SSRN 3588418.
Browne, M., Sweet, M., Woodburn, A., Allen, J., 2005. Urban freight consolidation centres final report. Transport Studies Group, University of Westminster 10.
Buldeo Rai, H., Verlinde, S., Merck, J., Macharis, C., 2017a. Crowd Logistics: An Opportunity for More Sustainable Urban Freight Transport?"European Transport Research Review", Vol. 9 (39).
Buldeo Rai, H., Verlinde, S., Merckx, J., Macharis, C., 2017b. Crowd logistics: an opportunity for more sustainable urban freight transport? European Transport Research Review 9, 39.
Carra, G., Magdani, N., 2017. Circular business models for the built environment. Arup BAM, 1-44.
Carrillo-Hermosilla, J., Del Río, P., Könnölä, T., 2010. Diversity of eco-innovations: Reflections from selected case studies. Journal of cleaner production 18, 1073-1083.
Castañé, S., Antón, A., 2017. Assessment of the nutritional quality and environmental impact of two food diets: A Mediterranean and a vegan diet. Journal of Cleaner Production 167, 929-937.
Chandra, S., 2020. Speed, Space and Sustainability (3S) in Transportation Amid COVID-19 Crisis. SSRN 3598501.
Chang, H.-H., Meyerhoefer, C., 2020. COVID-19 and the Demand for Online Food Shopping Services: Empirical Evidence from Taiwan. National Bureau of Economic Research.
Chen, C., Zhao, B., 2020. Makeshift hospitals for COVID-19 patients: where health-care workers and patients need sufficient ventilation for more protection. Journal of Hospital Infection 105, 98-99.
Chi, M., George, J.F., Huang, R., Wang, P., 2020. Unraveling sustainable behaviors in the sharing economy: An empirical study of bicycle-sharing in China. Journal of Cleaner Production, 120962.
Cimprich, A., Santillán-Saldivar, J., Thiel, C.L., Sonnemann, G., Young, S.B., 2019. Potential for industrial ecology to support healthcare sustainability: Scoping review of a fragmented literature and conceptual framework for future research. Journal of Industrial Ecology 23, 1344-1352.
Clair, A., 2020. Homes, health, and COVID-19: how poor housing adds to the hardship of the coronavirus crisis. Social Market Foundation (SMF), Online.
Company, M., 2020. A global view of how consumer behavior is changing amid COVID-19. mckinsey.
Da Silva, C., Hoppe, A., Ravanello, M., Mello, N., 2005. Medical wastes management in the south of Brazil. Waste management 25, 600-605.
Danieli, A., Olmstead-Rumsey, J., 2020. Sector-specific shocks and the expenditure elasticity channel during the covid-19 crisis. Available at SSRN 3593514.
Dannenberg, P., Fuchs, M., Riedler, T., Wiedemann, C., 2020. Digital transition by COVID-19 pandemic? The German food online retail. Tijdschrift voor economische en sociale geografie.
Dargaville, T., Spann, K., Celina, M., 2020. Opinion to address a potential personal protective equipment shortage in the global community during the COVID-19 outbreak. Polymer Degradation and Stability, 109162.
Daszak, P., 2012. Anatomy of a pandemic. The Lancet 380, 1883-1884.

De Cock, K.M., Jaffe, H.W., Curran, J.W., 2012. The evolving epidemiology of HIV/AIDS. Aids 26, 1205-1213.
De Gioannis, G., Muntoni, A., Polettini, A., Pomi, R., Spiga, D., 2017. Energy recovery from one-and two-stage anaerobic digestion of food waste. Waste Management 68, 595-602.
De Jesus, A., Mendonça, S., 2018. Lost in transition? Drivers and barriers in the eco-innovation road to the circular economy. Ecological economics 145, 75-89.
De Soete, W., Jiménez-González, C., Dahlin, P., Dewulf, J., 2017. Challenges and recommendations for environmental sustainability assessments of pharmaceutical products in the healthcare sector. Green Chemistry 19, 3493-3509.
Deloitte, 2020. Understanding the sector impact of COVID-19: Engineering and Construction sector. Deloitte p. 2.
Devakumar, D., Shannon, G., Bhopal, S.S., Abubakar, I., 2020. Racism and discrimination in COVID-19 responses. The Lancet 395, 1194.
Diaz, L.F., Eggerth, L., Enkhtsetseg, S., Savage, G., 2008. Characteristics of healthcare wastes. Waste management 28, 1219-1226.
Dilkes-Hoffman, L.S., Lane, J.L., Grant, T., Pratt, S., Lant, P.A., Laycock, B., 2018. Environmental impact of biodegradable food packaging when considering food waste. Journal of Cleaner Production 180, 325-334.
Dingel, J.I., Neiman, B., 2020. How many jobs can be done at home? National Bureau of Economic Research.
Duflou, J.R., Sutherland, J.W., Dornfeld, D., Herrmann, C., Jeswiet, J., Kara, S., Hauschild, M., Kellens, K., 2012. Towards energy and resource efficient manufacturing: A processes and systems approach. CIRP annals 61, 587-609.
Duncan-Jones, R.P., 1996. The impact of the Antonine plague. Journal of Roman Archaeology 9, 108-136.
Eaton, J., Connor, Y., 2020. How to strengthen your supply chain in the face of COVID-19 disruption: 8 Lessons for strengthening your supply chain today. Grant Thornton, Online.
Eberhardt, L.C.M., Birgisdottir, H., Birkved, M., 2019. Potential of circular economy in sustainable buildings, IOP Conference Series: Materials Science and Engineering. IOP Publishing.
EEA, 2020. Environmental noise in Europe — 2020. European Environment Agency (EEA), Luxembourg: Publications Office of the European Union, 2020, pp. 1-104.
Ekins, P., Hughes, N., Brigenzu, S., Arden Clark, C., Fischer-Kowalski, M., Graedel, T., Hajer, M., Hashimoto, S., Hatfield-Dodds, S., Havlik, P., 2016. Resource efficiency: Potential and economic implications.
Eleyan, D., Al-Khatib, I.A., Garfield, J., 2013. System dynamics model for hospital waste characterization and generation in developing countries. Waste Management & Research 31, 986-995.
EMF, 2016. Circular economy in India: Rethinking growth for long-term prosperity. Ellen MacArthur Foundation, London, p. 86.
EMF, 2019. Planning effective transport of people, products and materials. Ellen MacArthur Foundation, p. 6.
EMF, 2020a. 10 circular investment opportunities to build back better: food sector. Ellen MacArthur Foundation, p. 13.
EMF, 2020b. 10 circular investment opportunities to build back better: The built environment. Ellen MacArthur Foundation, London, p. 10.
Enkvist, P., Klevnäs, P., Teiwik, A., Jönsson, C., Klingvall, S., Hellberg, U., 2018. The circular economy–a powerful force for climate mitigation: transformative innovation for prosperous and low-carbon industry. Material Economics Sverige AB: Stockholm, Sweden.
EPRS, 2014. Urban And Peri-Urban Agriculture. European Parliamentary Research Service (EPRS).
ESA, 2020. Air pollution remains low as Europeans stay at home. European Space Agency (ESA) Online.
European Commission, 2011. The Roadmap to a Resource Efficient Europe. European Commission, p. 26.
European Commission, 2020. EU Circular Economy Action Plan: A new Circular Economy Action Plan for a Cleaner and More Competitive Europe. European Commission.
Evenett, S.J., 2020. Flawed prescription: Export curbs on medical goods won't tackle shortages. COVID-19 and Trade Policy: Why Turning Inward Won't Work, 49.
Fast Company, 2019. Is it possible to raise a carbon-neutral cow? . Fast Company.
Feber, D., Lingqvist, O., Nordigården, D., 2020. Shaping the next normal of packaging beyond COVID-19. McKinsey & Company McKinsey & Company p. 6.
Feng, K., Davis, S.J., Sun, L., Hubacek, K., 2015. Drivers of the US CO2 emissions 1997-2013. Nature communications 6.
Fernandes, N., 2020. Economic effects of coronavirus outbreak (COVID-19) on the world economy. Available at SSRN 3557504.
Fischer, R., Morris, D.H., van Doremalen, N., Sarchette, S., Matson, J., Bushmaker, T., Yinda, C.K., Seifert, S., Gamble, A., Williamson, B., 2020. Assessment of N95 respirator decontamination and re-use for SARS-CoV-2. medRxiv.

Ford, T.E., Colwell, R.R., Rose, J.B., Morse, S.S., Rogers, D.J., Yates, T.L., 2009. Using satellite images of environmental changes to predict infectious disease outbreaks. Emerging infectious diseases 15, 1341.
Friant, M.C., Vermeulen, W.J., Salomone, R., 2020. A typology of circular economy discourses: Navigating the diverse visions of a contested paradigm. Resources, Conservation and Recycling 161, 104917.
Fujii, H., Managi, S., Kaneko, S., 2013. Decomposition analysis of air pollution abatement in China: empirical study for ten industrial sectors from 1998 to 2009. Journal of Cleaner Production 59, 22-31.
Galvão, G.D.A., Homrich, A.S., Geissdoerfer, M., Evans, S., Ferrer, P.S.s., Carvalho, M.M., 2020. Towards a value stream perspective of circular business models. Resources, Conservation and Recycling 162, 105060.
Gates, B., 2020a. COVID-19 is awful. Climate change could be worse., CLIMATE AND THE CORONAVIRUS. GatesNotes.
Gates, B., 2020b. Responding to Covid-19—a once-in-a-century pandemic? New England Journal of Medicine 382, 1677-1679.
Gatta, V., Marcucci, E., Delle Site, P., Le Pira, M., Carrocci, C.S., 2019. Planning with stakeholders: Analysing alternative off-hour delivery solutions via an interactive multi-criteria approach. Research in Transportation Economics 73, 53-62.
Geissdoerfer, M., Savaget, P., Bocken, N.M., Hultink, E.J., 2017. The Circular Economy–A new sustainability paradigm? Journal of Cleaner Production 143, 757-768.
Gibbs, M.J., Armstrong, J.S., Gibbs, A.J., 2001. Recombination in the hemagglutinin gene of the 1918" Spanish flu". Science 293, 1842-1845.
Girling, R., 2011. Rubbish!: Dirt on Our Hands and Crisis Ahead. Random House.
Gondi, S., Beckman, A.L., Deveau, N., Raja, A.S., Ranney, M.L., Popkin, R., He, S., 2020. Personal protective equipment needs in the USA during the COVID-19 pandemic. The Lancet.
Gopinath, G., 2020. Limiting the Economic Fallout of the Coronavirus with Large Targeted Policies. IMF.
Govindan, K., Hasanagic, M., 2018. A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. International Journal of Production Research 56, 278-311.
Grant, M.J., Booth, A., 2009. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Information & Libraries Journal 26, 91-108.
Greenhalgh, T., Thorne, S., Malterud, K., 2018. Time to challenge the spurious hierarchy of systematic over narrative reviews? European journal of clinical investigation 48.
Guan, D., Hallegatte, S., 2020. The containment divide: COVID-19 lockdowns and basic needs in developing countries.
Guan, D., Wang, D., Hallegatte, S., Huo, J., Li, S., Bai, Y., Lei, T., Xue, Q., Davis, S.J., Coffman, D.M., 2020. Global economic footprint of the COVID-19 pandemic.
Guerrieri, V., Lorenzoni, G., Straub, L., Werning, I., 2020. Macroeconomic Implications of COVID-19: Can Negative Supply Shocks Cause Demand Shortages? National Bureau of Economic Research.
Gungor, A., Gupta, S.M., 1999. Issues in environmentally conscious manufacturing and product recovery: a survey. Computers & Industrial Engineering 36, 811-853.
Haigh, L., Bäunker, L., 2020. Covid-19 and the circular economy: opportunities and reflections.
Hasanat, M.W., Hoque, A., Shikha, F.A., Anwar, M., Hamid, A.B.A., Tat, H.H., 2020. The Impact of Coronavirus (Covid-19) on E-Business in Malaysia. Asian Journal of Multidisciplinary Studies 3, 85-90.
Herrmann, C., Schmidt, C., Kurle, D., Blume, S., Thiede, S., 2014. Sustainability in manufacturing and factories of the future. International Journal of precision engineering and manufacturing-green technology 1, 283-292.
Hobbs, J.E., 2020. Food supply chains during the COVID‐19 pandemic. Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie.
Hockley, L., 2020. Coronavirus roundtable: How is the aviation industry responding to the COVID-19 pandemic? International Airport Review, Online.
Hoornweg, D., Bhada-Tata, P., 2012. What a waste: a global review of solid waste management.
Horrox, R., 2013. The Black Death. Manchester University Press.
Hotez, P.J., Alvarado, M., Basáñez, M.-G., Bolliger, I., Bourne, R., Boussinesq, M., Brooker, S.J., Brown, A.S., Buckle, G., Budke, C.M., 2014. The global burden of disease study 2010: interpretation and implications for the neglected tropical diseases. PLoS neglected tropical diseases 8.
Hu, M.R., Lee, A.D., 2020. Airbnb, COVID-19 Risk and Lockdowns: Global Evidence. COVID-19 Risk and Lockdowns: Global Evidence (April 30, 2020).
Huang, W., Zhao, Z., Yuan, T., Huang, W., Lei, Z., Zhang, Z., 2017. Low-temperature hydrothermal pretreatment followed by dry anaerobic digestion: A sustainable strategy for manure waste management regarding energy recovery and nutrients availability. Waste Management 70, 255-262.
Hussey, L.K., Arku, G., 2020. Are we ready for it? Health systems preparedness and capacity towards climate change-induced health risks: perspectives of health professionals in Ghana. Climate and Development 12, 170-182.

IATA, 2020. Air Transport & COVID-19 Coronavirus. International Air Transport Association www.airlines.iata.org.
Ibn-Mohammed, T., 2017. Application of mixed-mode research paradigms to the building sector: a review and case study towards decarbonising the built and natural environment. Sustainable Cities and Society 35, 692-714.
Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L., Acquaye, A., 2013. Operational vs. embodied emissions in buildings—A review of current trends. Energy and Buildings 66, 232-245.
Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L., Acquaye, A., 2014. Integrating economic considerations with operational and embodied emissions into a decision support system for the optimal ranking of building retrofit options. Building and Environment 72, 82-101.
Ibn-Mohammed, T., Reaney, I., Koh, S., Acquaye, A., Sinclair, D., Randall, C., Abubakar, F., Smith, L., Schileo, G., Ozawa-Meida, L., 2018. Life cycle assessment and environmental profile evaluation of lead-free piezoelectrics in comparison with lead zirconate titanate. Journal of the European Ceramic Society.
ICAO, 2020. Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis. Uniting Aviation.
IEA, 2020. Global Energy Review 2020:The impacts of the COVID-19 crisis on global energy demand and CO2 emissions. International Energy Agency, IEA Publications, pp. 1-56.
Ijomah, W.L., 2010. The application of remanufacturing in sustainable manufacture, Proceedings of the Institution of Civil Engineers-Waste and Resource Management. Thomas Telford Ltd, pp. 157-163.
IMF, 2020. World Economic Outlook : The Great Lockdown. The International Monetary Fund (IMF), Washington, DC, pp. 37-37.
Insa, E., Zamorano, M., López, R., 2010. Critical review of medical waste legislation in Spain. Resources, Conservation and Recycling 54, 1048-1059.
Iyengar, K., Bahl, S., Vaishya, R., Vaish, A., 2020. Challenges and solutions in meeting up the urgent requirement of ventilators for COVID-19 patients. Diabetes & Metabolic Syndrome: Clinical Research & Reviews.
Jaeger, B., Upadhyay, A., 2020. Understanding barriers to circular economy: cases from the manufacturing industry. Journal of Enterprise Information Management.
Janné, M., Fredriksson, A., 2019. Construction logistics governing guidelines in urban development projects. Construction Innovation.
Javorcik, B., 2020. Global supply chains will not be the same in the post-COVID-19 world. COVID-19 and Trade Policy: Why Turning Inward Won't Work, 111.
JHU, 2020. MAPS & TRENDS: New Cases of COVID-19 In World Countries. Coronavirus Resource Center, Johns Hopkins University (JHU).
Johansson, H., Björklund, M., 2017. Urban consolidation centres: retail stores' demands for UCC services. International Journal of Physical Distribution & Logistics Management.
Kaiser, B., Eagan, P.D., Shaner, H., 2001. Solutions to health care waste: life-cycle thinking and" green" purchasing. Environmental Health Perspectives 109, 205-207.
Kanda, W., Kivimaa, P., 2020. What opportunities could the COVID-19 outbreak offer for sustainability transitions research on electricity and mobility? Energy Research & Social Science 68.
Kane, G.M., Bakker, C.A., Balkenende, A.R., 2018. Towards design strategies for circular medical products. Resources, Conservation and Recycling 135, 38-47.
Kiba-Janiak, M., 2019. EU cities' potentials for formulation and implementation of sustainable urban freight transport strategic plans. Transportation Research Procedia 39, 150-159.
Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., Hekkert, M., 2018. Barriers to the circular economy: evidence from the European Union (EU). Ecological Economics 150, 264-272.
Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: An analysis of 114 definitions. Resources, conservation and recycling 127, 221-232.
Klemeš, J.J., Fan, Y.V., Tan, R.R., Jiang, P., 2020. Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. Renewable and Sustainable Energy Reviews 127, 109883-109883.
Koh, S., Ibn-Mohammed, T., Acquaye, A., Feng, K., Reaney, I., Hubacek, K., Fujii, H., Khatab, K., 2016. Drivers of US toxicological footprints trajectory 1998–2013. Scientific Reports 6, 39514.
Korhonen, J., Honkasalo, A., Seppälä, J., 2018. Circular economy: the concept and its limitations. Ecological economics 143, 37-46.
Kraemer, M.U., Yang, C.-H., Gutierrez, B., Wu, C.-H., Klein, B., Pigott, D.M., du Plessis, L., Faria, N.R., Li, R., Hanage, W.P., 2020. The effect of human mobility and control measures on the COVID-19 epidemic in China. Science 368, 493-497.
Laing, T., 2020. The economic impact of the Coronavirus 2019 (Covid-2019): Implications for the mining industry. The Extractive Industries and Society.

Le Quéré, C., Jackson, R.B., Jones, M.W., Smith, A.J., Abernethy, S., Andrew, R.M., De-Gol, A.J., Willis, D.R., Shan, Y., Canadell, J.G., 2020. Temporary reduction in daily global CO 2 emissions during the COVID-19 forced confinement. Nature Climate Change, 1-7.
Lee, C., Huffman, G., Nalesnik, R., 1991. Medical waste management. Environmental science & technology 25, 360-363.
Lee, G.-G., Lee, H.-W., Lee, J.-H., 2015. Greenhouse gas emission reduction effect in the transportation sector by urban agriculture in Seoul, Korea. Landscape and Urban Planning 140, 1-7.
Lee, J.-W., McKibbin, W.J., 2004. Estimating the global economic costs of SARS, Learning from SARS: preparing for the next disease outbreak: workshop summary. National Academies Press Washington, DC, p. 92.
Liao, L., Xiao, W., Zhao, M., Yu, X., Wang, H., Wang, Q., Chu, S., Cui, Y., 2020. Can N95 Respirators Be Reused after Disinfection? How Many Times? ACS nano.
Lieder, M., Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. Journal of cleaner production 115, 36-51.
Littman, R.J., Littman, M.L., 1973. Galen and the Antonine plague. The American Journal of Philology 94, 243-255.
Liu, X., Zhang, S., 2020. COVID‐19: Face masks and human‐to‐human transmission. Influenza and Other Respiratory Viruses.
Livingston, E., Desai, A., Berkwits, M., 2020. Sourcing personal protective equipment during the COVID-19 pandemic. Jama.
Lucrezi, S., Saayman, M., Van der Merwe, P., 2016. An assessment tool for sandy beaches: A case study for integrating beach description, human dimension, and economic factors to identify priority management issues. Ocean & coastal management 121, 1-22.
Lwasa, S., Mugagga, F., Wahab, B., Simon, D., Connors, J., Griffith, C., 2014. Urban and peri-urban agriculture and forestry: Transcending poverty alleviation to climate change mitigation and adaptation. Urban Climate 7, 92-106.
Lyche, H., 2020. Might a disaster trigger a new circular-economy?
Mabahwi, N.A.B., Leh, O.L.H., Omar, D., 2014. Human health and wellbeing: Human health effect of air pollution. Procedia-Social and Behavioral Sciences 153, 221-229.
MacArthur, E., 2013. Towards the circular economy, economic and business rationale for an accelerated transition. Ellen MacArthur Foundation: Cowes, UK.
Mahler, D.G., Lakner, C., Aguilar, R.A.C., Wu, H., 2020. The impact of COVID-19 (Coronavirus) on global poverty: Why Sub-Saharan Africa might be the region hardest hit. World Bank, Washington, D.C., United States.
Manninen, K., Koskela, S., Antikainen, R., Bocken, N., Dahlbo, H., Aminoff, A., 2018. Do circular economy business models capture intended environmental value propositions? Journal of Cleaner Production 171, 413-422.
Marcucci, E., Le Pira, M., Carrocci, C.S., Gatta, V., Pieralice, E., 2017. Connected shared mobility for passengers and freight: Investigating the potential of crowdshipping in urban areas, 2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS). IEEE, pp. 839-843.
Marques, G., Roque Ferreira, C., Pitarma, R., 2018. A system based on the internet of things for real-time particle monitoring in buildings. International journal of environmental research and public health 15.
Masiero, G., Ogasavara, M.H., Jussani, A.C., Risso, M.L., 2017. The global value chain of electric vehicles: A review of the Japanese, South Korean and Brazilian cases. Renewable and Sustainable Energy Reviews 80, 290-296.
McDonough, W., Braungart, M., 2010. Cradle to cradle: Remaking the way we make things. North point press.
McKee, M., Stuckler, D., 2020. If the world fails to protect the economy, COVID-19 will damage health not just now but also in the future. Nature Medicine 26, 640-642.
McKenzie, B., 2020. Beyond COVID-19: supply chain resilience holds key to recovery. Oxford Economics 24, 20.
McKibbin, W.J., Fernando, R., 2020. The global macroeconomic impacts of COVID-19: Seven scenarios.
Minunno, R., O'Grady, T., Morrison, G.M., Gruner, R.L., Colling, M., 2018. Strategies for applying the circular economy to prefabricated buildings. Buildings 8, 125.
Moazzami, B., Razavi-Khorasani, N., Moghadam, A.D., Farokhi, E., Rezaei, N., 2020. COVID-19 and telemedicine: Immediate action required for maintaining healthcare providers well-being. Journal of Clinical Virology, 104345.
Monlau, F., Sambusiti, C., Antoniou, N., Barakat, A., Zabaniotou, A., 2015. A new concept for enhancing energy recovery from agricultural residues by coupling anaerobic digestion and pyrolysis process. Applied Energy 148, 32-38.
Morlet, A., Blériot, J., Opsomer, R., Linder, M., Henggeler, A., Bluhm, A., Carrera, A., 2016. Intelligent assets: Unlocking the circular economy potential. Ellen MacArthur Foundation, 1-25.

Morrison, A., Polisena, J., Husereau, D., Moulton, K., Clark, M., Fiander, M., Mierzwinski-Urban, M., Clifford, T., Hutton, B., Rabb, D., 2012. The effect of English-language restriction on systematic review-based meta-analyses: a systematic review of empirical studies. International journal of technology assessment in health care 28, 138.
Muhammad, S., Long, X., Salman, M., 2020. COVID-19 pandemic and environmental pollution: A blessing in disguise? Science of The Total Environment, 138820.
Murray, N.E.A., Quam, M.B., Wilder-Smith, A., 2013. Epidemiology of dengue: past, present and future prospects. Clinical epidemiology 5, 299.
Naidoo, R., Fisher, B., 2020. Reset Sustainable Development Goals for a pandemic world. Nature Publishing Group.
NASA, 2020a. Airborne Nitrogen Dioxide Plummets Over China. National Aeronautics and Space Administration (NASA) Online.
NASA, 2020b. Airborne Particle Levels Plummet in Northern India. NASA.
OECD, 2018. Financing Climate Futures - Rethinking Infrastructure. OECD, Paris.
Omary, M.B., Eswaraka, J., Kimball, S.D., Moghe, P.V., Panettieri, R.A., Scotto, K.W., 2020. The COVID-19 pandemic and research shutdown: staying safe and productive. The Journal of clinical investigation 130.
Opitz, I., Berges, R., Piorr, A., Krikser, T., 2016. Contributing to food security in urban areas: differences between urban agriculture and peri-urban agriculture in the Global North. Agriculture and Human Values 33, 341-358.
Oweis, R., Al-Widyan, M., Al-Limoon, O., 2005. Medical waste management in Jordan: A study at the King Hussein Medical Center. Waste management 25, 622-625.
Özkan, A., 2013. Evaluation of healthcare waste treatment/disposal alternatives by using multi-criteria decision-making techniques. Waste Management & Research 31, 141-149.
Paez, A., 2017. Gray literature: An important resource in systematic reviews. Journal of Evidence‐Based Medicine 10, 233-240.
Pagoropoulos, A., Pigosso, D.C., McAloone, T.C., 2017. The emergent role of digital technologies in the Circular Economy: A review. Procedia CIRP 64, 19-24.
Partelow, S., von Wehrden, H., Horn, O., 2015. Pollution exposure on marine protected areas: a global assessment. Marine pollution bulletin 100, 352-358.
Paxton, N.C., Forrestal, D.P., Desselle, M., Kirrane, M., Sullivan, C., Powell, S.K., Woodruff, M.A., 2020. N95 Respiratory Masks for COVID-19: A Review of the Literature to Inform Local Responses to Global Shortages.
Pearce, J.M., 2020. A review of open source ventilators for COVID-19 and future pandemics. F1000Research 9.
Peng, J., Wu, X., Wang, R., Li, C., Zhang, Q., Wei, D., 2020. Medical waste management practice during the 2019-2020 novel coronavirus pandemic: Experience in a general hospital. Am J Infect Control, S0196-6553(0120)30351-30355.
Penn, E., Yasso, S.F., Wei, J.L., 2012. Reducing disposable equipment waste for tonsillectomy and adenotonsillectomy cases. Otolaryngology--Head and Neck Surgery 147, 615-618.
PHE, 2020. Review of interventions to improve outdoor air quality and public health. Public Health England (PHE), London, pp. 1-262.
Piguillem, F., Shi, L., 2020. The optimal COVID-19 quarantine and testing policies., EIEF Working Papers Series 2004, revised Apr 2020. Einaudi Institute for Economics and Finance (EIEF), p. 40.
Pinheiro, M.D., Luís, N.C., 2020. COVID-19 Could Leverage a Sustainable Built Environment. Sustainability 12.
Pinner, D., Rogers, M., Samandari, H., 2020. McKinsey Quarterly: Addressing climate change in a post-pandemic world. McKinsey & Company, pp. 1-6.
Pitarma, R., Marques, G., Ferreira, B.R., 2017. Monitoring indoor air quality for enhanced occupational health. Journal of medical systems 41.
Pomponi, F., Moncaster, A., 2017. Circular economy for the built environment: A research framework. Journal of cleaner production 143, 710-718.
Prata, J.C., Silva, A.L.P., Walker, T.R., Duarte, A.C., Rocha-Santos, T., 2020. COVID-19 Pandemic Repercussions on the Use and Management of Plastics. Environmental Science & Technology 54, 7760-7765.
Preston, F., Lehne, J., Wellesley, L., 2019. An Inclusive Circular Economy; Priorities for Developing Countries, Priorities for Developing Countries. CHATAM HOUSE, The Royal Institute of International Affairs, London, pp. 1-82.
Prüss-Üstün, A., Prüss, A., Giroult, E., Townend, W.K., Rushbrook, P., Organization, W.H., 1999. Safe Management of Wastes from Health-care Activities. World Health Organization.
Rai, H.B., Verlinde, S., Macharis, C., 2018. Shipping outside the box. Environmental impact and stakeholder analysis of a crowd logistics platform in Belgium. Journal of Cleaner Production 202, 806-816.

Raj, M., Sundararajan, A., You, C., 2020. COVID-19 and Digital Resilience: Evidence from Uber Eats. arXiv preprint arXiv:2006.07204.
Ranganatha, J., Waite, R., Searchinger, T., Zionts, J., 2020. Regenerative Agriculture: Good for Soil Health, but Limited Potential to Mitigate Climate Change. World Resources Institute,.
Ranney, M.L., Griffeth, V., Jha, A.K., 2020. Critical supply shortages—the need for ventilators and personal protective equipment during the Covid-19 pandemic. New England Journal of Medicine.
Rashid, A., Asif, F.M., Krajnik, P., Nicolescu, C.M., 2013. Resource Conservative Manufacturing: an essential change in business and technology paradigm for sustainable manufacturing. Journal of Cleaner production 57, 166-177.
Rees, W.E., 2002. Footprint: our impact on Earth is getting heavier. Nature 420, 267-268.
Rhodes, C.J., 2017. The imperative for regenerative agriculture. Science Progress 100, 80-129.
Rios, F.C., Chong, W.K., Grau, D., 2015. Design for disassembly and deconstruction-challenges and opportunities. Procedia engineering 118, 1296-1304.
Rubio-Romero, J.C., del Carmen Pardo-Ferreira, M., García, J.A.T., Calero-Castro, S., 2020. Disposable masks: Disinfection and sterilization for reuse, and non-certified manufacturing, in the face of shortages during the COVID-19 pandemic. Safety Science, 104830.
San Juan, D.M., 2020. Responding to COVID-19 Through Socialist (ic) Measures: A Preliminary Review. Available at SSRN 3559398.
Sarkis, J., Cohen, M.J., Dewick, P., Schröder, P., 2020. A Brave New World: Lessons from the COVID-19 Pandemic for Transitioning to Sustainable Supply and Production. Resources, Conservation, and Recycling.
Sauerwein, M., Doubrovski, E., Balkenende, R., Bakker, C., 2019. Exploring the potential of additive manufacturing for product design in a circular economy. Journal of Cleaner Production 226, 1138-1149.
Saunders-Hastings, P.R., Krewski, D., 2016. Reviewing the history of pandemic influenza: understanding patterns of emergence and transmission. Pathogens 5, 66.
Schluep, M., 2009. Recycling-from e-waste to resources: Sustainable innovation technology transfer industrial sector studies. UNEP.
Shaheen, S., Cohen, A., 2020. Mobility on demand (MOD) and mobility as a service (MaaS): early understanding of shared mobility impacts and public transit partnerships, Demand for Emerging Transportation Systems. Elsevier, pp. 37-59.
Sherwood, S., Uphoff, N., 2000. Soil health: research, practice and policy for a more regenerative agriculture. Applied Soil Ecology 15, 85-97.
Sim, K., Chua, H.C., Vieta, E., Fernandez, G., 2020. The anatomy of panic buying related to the current COVID-19 pandemic. Psychiatry Research.
Siow, W.T., Liew, M.F., Shrestha, B.R., Muchtar, F., See, K.C., 2020. Managing COVID-19 in resource-limited settings: critical care considerations. Springer.
Snider-Mcgrath, B., 2020. Exercise rates on the rise during COVID-19.
Snyder, H., 2019. Literature review as a research methodology: An overview and guidelines. Journal of Business Research 104, 333-339.
Sohrabi, C., Alsafi, Z., O'Neill, N., Khan, M., Kerwan, A., Al-Jabir, A., Iosifidis, C., Agha, R., 2020. World Health Organization declares global emergency: A review of the 2019 novel coronavirus (COVID-19). International Journal of Surgery.
Solomon, M.Z., Wynia, M., Gostin, L.O., 2020. Scarcity in the Covid‐19 Pandemic. Hastings Center Report 50, 3-3.
Spash, C.L., 2020. 'The economy'as if people mattered: revisiting critiques of economic growth in a time of crisis. Globalizations, 1-18.
Stahel, W.R., 2016. The circular economy. Nature 531, 435-438.
Stahel, W.R., 2019. The circular economy: A user's guide. Routledge.
Stellinger, A., Berglund, I., Isakson, H., 2020. How trade can fight the pandemic and contribute to global health. COVID-19 and Trade Policy: Why Turning Inward Won't Work, 21.
Stockholm Resilience Centre, 2016. Through resilience thinking towards sustainability and innovation: recommendations for policy makers in the EU. Stockholm Resilience Centre, Stockholm University, Stockholm, pp. 1-20.
SYSTEMIQ, 2017. ACHIEVING 'GROWTH WITHIN': A €320-billion circular economy investment opportunity available to Europe up to 2025. SUN Institute Environment & Sustainability in collaboration with The Ellen MacArthur Foundation, p. 149.
Tan, J., Liu, Y., Shen, E., Zhu, W., Wang, W., Li, R., Yang, L., 2002. Towards<< the atlas of plague and its environment in the People's Republic of China>>: idea, principle and methodology of design and research results. Huan jing ke xue= Huanjing kexue 23, 1-8.

Temmerman, S., Meire, P., Bouma, T.J., Herman, P.M., Ysebaert, T., De Vriend, H.J., 2013. Ecosystem-based coastal defence in the face of global change. Nature 504, 79-83.
Thebo, A., Drechsel, P., Lambin, E., 2014. Global assessment of urban and peri-urban agriculture: irrigated and rainfed croplands. Environmental Research Letters 9, 114002.
Thunstrom, L., Newbold, S., Finnoff, D., Ashworth, M., Shogren, J.F., 2020. The benefits and costs of flattening the curve for COVID-19. Available at SSRN 3561934.
Timmer, M., Erumban, A., Gouma, R., Los, B., Temurshoev, U., de Vries, G., Arto, I., 2012. The world input-output database (WIOD): contents, sources and methods. WIOD Background document available at www. wiod. org 40.
Toquero, C., 2020. Challenges and Opportunities for Higher Education amid the COVID-19 Pandemic: The Philippine Context. Pedagogical Research 5.
Trilla, A., Trilla, G., Daer, C., 2008. The 1918 "Spanish Flu" in Spain. Clinical Infectious Diseases 47, 668-673.
Tudor, T., Noonan, C., Jenkin, L., 2005. Healthcare waste management: a case study from the National Health Service in Cornwall, United Kingdom. Waste management 25, 606-615.
UN DESA, 2020. Everyone Included: Social Impact of COVID-19. UN Department of Economic and Social Affairs (UN DESA).
UN Habitat, 2013. Planning and design for sustainable urban mobility: Global report on human settlements 2013. Taylor & Francis.
UNWTO, 2020. Impact assessment of the covid-19 outbreak on international tourism United Nation World Tourism Organization
Van Bavel, J.J., Baicker, K., Boggio, P.S., Capraro, V., Cichocka, A., Cikara, M., Crockett, M.J., Crum, A.J., Douglas, K.M., Druckman, J.N., 2020. Using social and behavioural science to support COVID-19 pandemic response. Nature Human Behaviour, 1-12.
Van Buren, N., Demmers, M., Van der Heijden, R., Witlox, F., 2016. Towards a circular economy: The role of Dutch logistics industries and governments. Sustainability 8, 647.
Voudrias, E.A., 2018. Healthcare waste management from the point of view of circular economy.
Vousdoukas, M.I., Ranasinghe, R., Mentaschi, L., Plomaritis, T.A., Athanasiou, P., Luijendijk, A., Feyen, L., 2020. Sandy coastlines under threat of erosion. Nature climate change 10, 260-263.
Wagner, D.M., Klunk, J., Harbeck, M., Devault, A., Waglechner, N., Sahl, J.W., Enk, J., Birdsell, D.N., Kuch, M., Lumibao, C., 2014. Yersinia pestis and the Plague of Justinian 541–543 AD: a genomic analysis. The Lancet infectious diseases 14, 319-326.
Wang, P., Chen, K., Zhu, S., Wang, P., Zhang, H., 2020. Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak. Resources, Conservation and Recycling 158, 104814.
Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Berry, H., Bouley, T., Boykoff, M., Byass, P., Cai, W., 2018a. The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. The Lancet 392, 2479-2514.
Watts, N., Amann, M., Ayeb-Karlsson, S., Belesova, K., Bouley, T., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Chambers, J., 2018b. The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. The Lancet 391, 581-630.
Webster, R.G., 1997. Predictions for future human influenza pandemics. Journal of infectious diseases 176, S14-S19.
White, D.B., Lo, B., 2020. A framework for rationing ventilators and critical care beds during the COVID-19 pandemic. Jama.
WHO, 1998. Safe Management of Wastes from Health-Care Activities. 2014.
WHO, 2020a. Coronavirus Disease (COVID-19) Pandemic. World Health Organization.
WHO, 2020b. Coronavirus disease (COVID-19): Situation Report – 107, pp. 1-17.
Williamson, J., 2020. Every UK manufacturer helping to produce PPE and equipment for NHS workers. The Manufacturer.
Windapo, A.O., Moghayedi, A., 2020. Adoption of smart technologies and circular economy performance of buildings. Built Environment Project and Asset Management.
Windfeld, E.S., Brooks, M.S.-L., 2015. Medical waste management – A review. Journal of Environmental Management 163, 98-108.
Wong, H.J.Y., Deng, Z., Yu, H., Huang, J., Leung, C., Miao, C., 2020. A Testbed for Studying COVID-19 Spreading in Ride-Sharing Systems, Proceedings of the Twenty-Ninth International Joint Conference on Artificial Intelligence (IJCAI-20) Demonstrations Track, pp. 5294-5296.
Wong, K.-F.V., Narasimhan, R., Kashyap, R., Fu, J., 1994. Medical waste characterization. Journal of environmental health, 19-25.

World Economic Forum, 2019. A Vision for a Sustainable Battery Value Chain in 2030: Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation. World Economic Forum, Geneva, pp. 1-52.
World Economic Forum, 2020. New Nature Economy Report II: The Future of Nature and Business. World Economic Forum.
Wormer, B.A., Augenstein, V.A., Carpenter, C.L., Burton, P.V., Yokeley, W.T., Prabhu, A.S., Harris, B., Norton, S., Klima, D.A., Lincourt, A.E., 2013. The green operating room: simple changes to reduce cost and our carbon footprint. The American Surgeon 79, 666-671.
Wosik, J., Fudim, M., Cameron, B., Gellad, Z.F., Cho, A., Phinney, D., Curtis, S., Roman, M., Poon, E.G., Ferranti, J., 2020. Telehealth Transformation: COVID-19 and the rise of Virtual Care. Journal of the American Medical Informatics Association 27, 957-962.
Xiao, Y., Torok, M.E., 2020. Taking the right measures to control COVID-19. The Lancet Infectious Diseases 20, 523-524.
Yang, C., Peijun, L., Lupi, C., Yangzhao, S., Diandou, X., Qian, F., Shasha, F., 2009. Sustainable management measures for healthcare waste in China. Waste Manag 29, 1996-2004.
Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. Science of the Total Environment, 138813.
Zambrano-Monserrate, M.A., Silva-Zambrano, C.A., Ruano, M.A., 2018. The economic value of natural protected areas in Ecuador: A case of Villamil Beach National Recreation Area. Ocean & Coastal Management 157, 193-202.
Zhou, M., Chen, Y., Su, X., An, L., 2020. Rapid construction and advanced technology for a Covid-19 field hospital in Wuhan, China, Proceedings of the Institution of Civil Engineers-Civil Engineering. Thomas Telford Ltd, pp. 1-29.