Land use stewardship interventions to prevent the emergence of pandemics

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Abstract

Drawing on previous modelling of human-induced land use change, climate change and pandemics, this report focuses on the relationship between human activities and rises in novel disease cases at the community level. The 'DPSIR' model (Driving Forces, Pressures, State, Impacts and Responses) is used to understand society-environment interactions, and how alternative behaviours or decision-making by citizens, industry and governments across the globe might reduce disease emergence risk. We produce a conceptual model, and highlight how *local* consumer and producer decisions in one locale of the globe influence land use changes elsewhere. We offer five **land stewardship interventions** as call to action points to minimise the risk of emerging infectious diseases in a globally connected world.

Contents

1. Introduction

COVID-19 is a Black Swan event with the potential to have lasting and restructuring effects on our social and economic lives. It has been predicted that a changing world order may emerge from several themes: supply chain restructuring with the move from global to local, intensifying of tech-wars and issues around data, rise in the role of government, public health as a key national metric, and the switch to greater online engagement in the context of social distancing (Israel et al., 2020). The impact of a pandemic has been the subject of predictions for years (Madhav et al., 2017), though the extent of global response by governments worldwide was beyond what many experts anticipated (Johns Hopkins Center for Health Security et al., 2020). Responses included mass border closures, mandatory isolations and economic shutdowns that will have lasting impacts on the global economy and national recoveries (Hutchens, 2020). The world saw a significant drop in air pollution and greenhouse gas emissions during COVID-19 responses (Fedunik-Hofman, 2020; McGrath, 2020).

Research has long linked the emergence of pandemics to human activity and encroachment into natural areas, as well as the impacts of climate change (cf. in recent literature reviews by Dobson et al., 2020; Gibb et al., 2020; Martinus et al., 2020). COVID-19 has made us acutely aware of our vulnerability to novel viruses, and that there will be other pandemics, likely in the near future (cf. Hook, 2020). It is crucial then to consider how human activities lead to the emergence of pandemics, and how alternative behaviours or decision-making could reduce this risk (IPBES, 2020). This report does so by reviewing models of the land use and climate change drivers of emerging infectious diseases (EIDs[1]). It highlights current knowledge gaps in how 'localised' consumers' and producers' decisions impact land use changes elsewhere given that global value chains connect people in diverse locations, cultural contexts, and economic situations.

Drawing on conceptual understandings from human geography, public health, and environmental science, we put forward a model to conceptualise how human activities (through consumption and production) lead to land use changes and land degradation that increase the risk of EIDs as well as the spread of disease after a spillover event. Using this model, we outline key **land stewardship interventions (LSIs)** to target a reduction in the risk of human activities exacerbating climate change, land degradation, and land use change – the three factors linked to EIDs. The LSIs act as a set of **call to action points** which relate at global, national, city, *and* individual levels.

[1] EIDs are defined as diseases where the incidence in humans has increased within the past two decades or threatens to increase in the near future (van Doorn, 2014). An EID may appear in a population for the first time, or may have been present previously but was undetected, or has existed previously but is rapidly increasing, either in terms of the number of new cases within a population or in its spread to new geographical areas (WHO, 2014).

2. A framework linking global processes with local disease outbreaks

The impacts of climate change, land use change and environmental degradation are linked with a rise in emerging infectious diseases (EIDs) (Lambin et al., 2010; Martinus et al., 2020; Morse et al., 2012; Patz et al., 2008; Rohr et al., 2019; White and Razgour, 2020). EIDs caused by bacteria, viruses and parasites that have spread between animals (usually vertebrates) and humans are known as zoonotic diseases or zoonoses. Whilst there are known global 'hotspots' of zoonotic disease, most localised outbreaks rarely advance to become worldwide pandemics (Martinus et al., 2020; Morse et al., 2012; White and Razgour, 2020). COVID-19 is a (most likely zoonotic) disease (Mackenzie, 2020) that has viscerally demonstrated the interlinked health, economic, and social threats that a pandemic can cause in a highly connected and mobile world. Therefore, *it is imperative to more fully understand how human activity and global interconnectedness amplify the environmental changes that create the conditions for zoonotic disease emergence from wild hosts and transmission among people*.

To this end, and drawing on understandings of existing models, we developed a conceptual framework to describe pandemic emergence by integrating global, regional, and local-scale social, economic and political processes. There are several existing conceptual models that demonstrate the links between landscape change, agricultural activities, and EIDs (e.g. Lambin et al., 2010; Patz et al., 2004; Rohr et al., 2019). These tend to focus on local-scale activities and interactions at the site of disease emergence, with a concomitant focus on local or regional-level policy, planning, and management activities to reduce the likelihood of disease emergence and spread. We contend that global interconnectedness requires augmenting these models by highlighting how actions by people living in a geographically-distant, yet economically-linked, locations lead to different outcomes for EIDs. In the paragraphs that follow, we highlight the key features and critical gaps of the main models that have informed our novel framework.

A key model linking land use change and cases of disease emerged from a working group of international experts in infectious diseases, ecology, and environmental health (Patz et al., 2004). Patz et al.'s (2004) model includes two main exogenous variables that are ultimately related to disease emergence: 1) land-use change; and 2) the land-water interface. The model highlights that disease emergence can occur anywhere, but particularly where significant changes in biome (as extensive areas characterised by similar climate, plants, animals and soils - such as savannah, tropical forest, or desert) are observed. Economic circumstances (captured as 'wealth-poverty status of communities') feature as a key determinant of health *outcomes* once a disease is present within a community. Patz et al. (2004) recommend that in "*issues of land use and infectious disease emergence, the public needs to be attentive to entire ecosystems* *rather than simply their local environs*" (p.1097), and acknowledge the role of 'upstream' determinants (i.e. the social, physical, economic and environmental factors that determine land use) of land use change.

Building on the concept of 'unhealthy landscapes' espoused in Patz et al. (2004), Lambin et al. (2010) propose ten characteristics of 'pathogenic landscapes'. These ten characteristics cover elements of landscape attributes, spatial patterns and habitat connectivity, pathogen transmission pathways, interactions at multiple scales, land use, land ownership, and human behaviour (Lambin et al., 2010). Eight landscape-scale case studies of disease emergence (seven from Europe, one from Senegal) confirm that the propositions are indeed important determinants of disease transmission. The characteristics of 'pathogenic landscapes' are integrated with a multi-scale conceptual model that at the broadest spatial scale includes: climate and political, social, and economic context, both of which influence the regional environmental context. Lambin et al.'s (2010) model provides considerable detail on how landscape-linked drivers interact at the nested spatial scales of landscapes, natural habitats, and human settlements to suppress or exacerbate the spread of disease. However, the model provides only peripheral consideration of higher-level, global social and economic processes that also drive local-level land use decisions and changes.

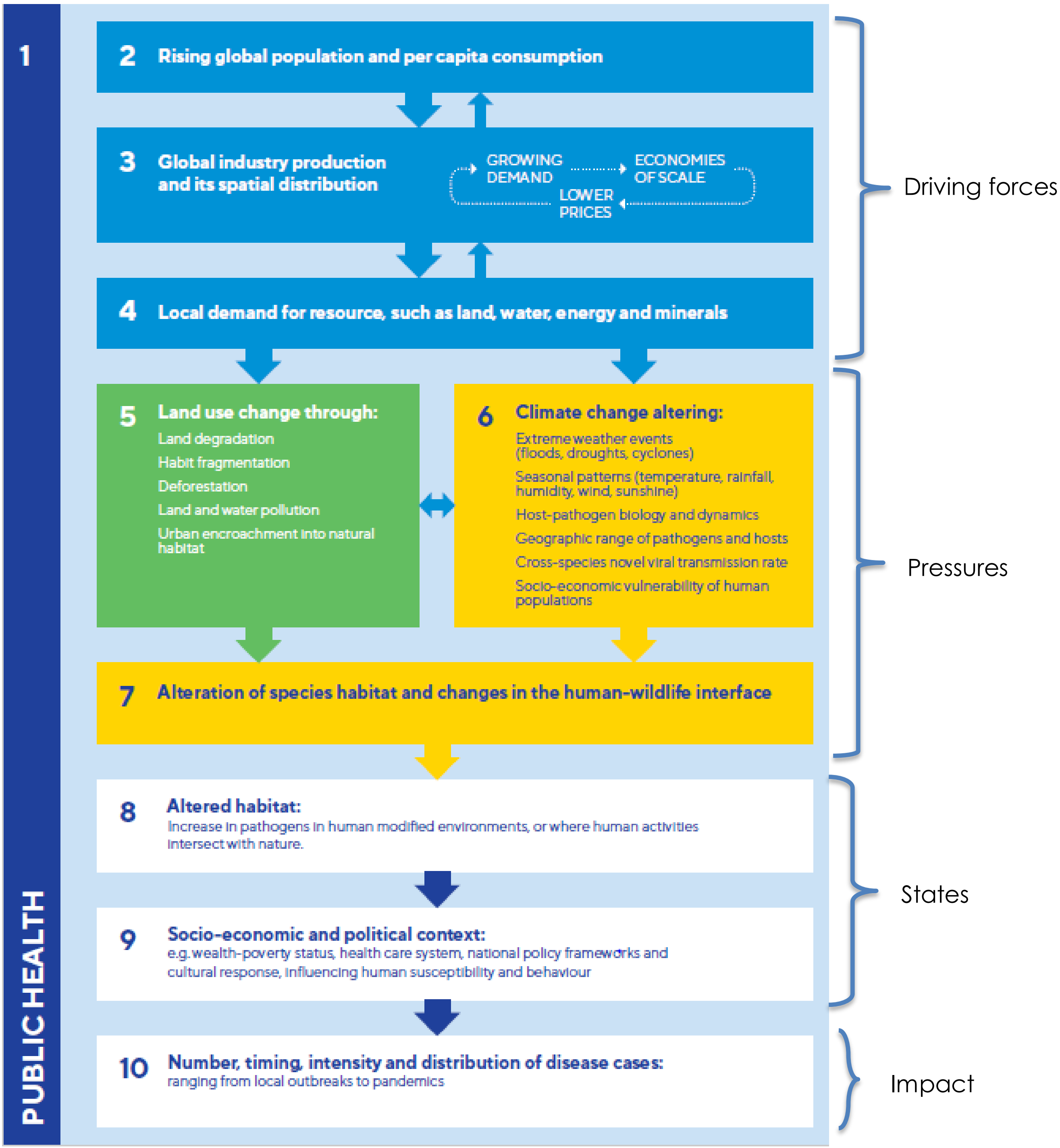
Models such as Patz et al. (2004) and Lambin et al. (2010), with an explicit focus on public health and landscape change, have significantly progressed how we conceptualise the socio-economic and environmental vulnerabilities to EIDs of some communities over others, and how we might minimise disease emergence and transmission. We agree with Patz et al. (2004) and Wood et al. (2012) that greater attention is needed on the global and regional level economic drivers of change, with local production a small part of understanding global production systems (Coe et al., 2004; Coe and Yeung, 2015; Murphy, 2012; Saxenian, 2002). As such, we argue for a model which explicitly integrates the structure of this global production system into local land use decision making and the emergence of infectious diseases. Indeed, there are many models linking land use change, climate change, and EIDs, with the emphasis being on the nationally influencing drivers such as government policy or incentives, social factors, level of violence, lack of options, migration, poverty, or markets (Hassell et al., 2017; Mastel et al., 2015; Rohr et al., 2019). Whilst most work acknowledges that global population pressures, politics, and globally connected markets play a role, how these drivers influence land use change is not necessarily addressed.

As such, there is a need to take an even broader multi-disciplinary approach to previous studies and draw in political economy and development studies. This requires incorporating explicit consideration of the global- and regional-scale social and economic factors that drive local land use decisions, due to the increased integration of global economies. This global integration means that the emergence of novel zoonotic diseases can be linked to decisions made by the everyday urban consumer, who may live in any city in any part of the world, through the cumulative impacts of these decisions on land use change. The importance of connecting land use decisions in local economies to global production networks is highlighted by Rohr et al.'s (2019) review of the links between EIDs and global food production.

Rohr et al. (2019) examined how increased agricultural production required to feed 11 billion people by 2100 could affect infectious diseases, recognising the importance of land use and economic decisions at local, regional, and global levels. A growing global population is conceptualised as placing pressure on global agricultural production, wild food harvest, forests, and freshwater ecosystems, as well as driving increased human-animal contact and increased resistance to drugs and pesticides among pathogens and vectors (Rohr et al., 2019). Rohr et al.'s (2019) research highlights the need for more comprehensive understanding of how global populations drive consumption choices across all industry sectors (not just food production), which in turn influence drivers of EIDs: climate change; the spatial distribution of global production systems; and local land use change. There is other work that connects land use change and the emergence of EIDs to global population pressures (e.g. Hassell et al., 2017) or to the global economy and society (e.g. Cumming et al., 2015), however the exact drivers of land use change remain unclear.

Building upon this prior research, we present an alternative model exploring how global processes, climate change, and land use change interact to influence the emergence, transmission, and distribution of EIDs, with public health as an integrating theme (Figure 1). In the following sections, we discuss the main components of our conceptual model, after which we offer a series of *land stewardship interventions* that could help to shift the system towards a state of reduced EID incidence.

Figure 1: Conceptual model of how global processes, climate change, and land use change interact to increase emergence and cases of infectious disease



Land Stewardship Interventions = Responses act on the Driving forces, Pressures and the State to reduce Impacts, as well as on the impacts to minimise or contain the spread of disease.

2.1 The foundations of our conceptual model

Our conceptual model (Figure 1) draws on the 'DPSIR' model (Driving Forces, Pressures, State, Impacts and Responses) for conceptualising society-environment interactions. The DPSIR framework was developed by the European Environment Agency (EEA) in 1999, and has since been widely adopted as a framework for analysing environmental issues. The framework categorises a particular society-environment issue or challenge through the use of cause-effect chains, highlighting feedback mechanisms and policy interventions that can lead to change within particular cause-effect chains (Patrício et al., 2016). The DPSIR model built on the 'Pressure-State-Response' (PSR) framework that was developed by Rapport and Friend (1979) and later adopted by the OECD for standardising environmental statistics, indicators and reporting. The DPSIR model is now widely used, including by the EEA, the United Nations Environment Program, and the US Environmental Protection Agency. Recently, DPSIR has been applied to the management of zoonotic diseases in the context of COVID-19 (Everard et al., 2020).

Driving forces (D) are large-scale processes and human needs that have widespread effects on a system (such as population growth, economic production, and consumption). Pressures (P) are specific human activities that affect the environment and are linked with the driving forces, such as land use change, greenhouse gas emissions resulting in anthropogenic climate change, agricultural activities, and urbanisation. As a result of these pressures, there are changes in the State (S) of the environment, such as air, soil and water quality, and biodiversity. The changes in state may lead to environment, social or economic Impacts (I), including ecosystem functioning, human health and welfare, and the economic and social performance of a society. Undesirable impacts may lead to Responses (R) by society or decision makers, which capture any measure(s) put in place to address adverse impacts, and which can take effect at any level along the cause-effect chain from D, P, S, or I (summary drawn from Kristensen, 2004). The components of DPSIR have been interpreted in various ways by different authors, with some notable differences in interpretation among natural and social scientists (Patrício et al., 2016). Here, we take a broad perspective incorporating global drivers, which we believe is appropriate to the spatial scale of responding to pandemic disease. Our model is complementary to the work of Everard et al. (2020), but takes a greater emphasis on the 'Responses' element of the model, recognising the need to take action to alter the nature of multiple cause-effect chains throughout the global system.

2.2 Driving forces: Rising global population and per capita consumption

Previous models linking EIDs with land use change largely focused on mitigating land degradation in low income nations, given that zoonotic spillover events are more frequently recorded in poorer communities in lower income nations and are often associated with biodiverse habitats undergoing rapid land-use change (for example, Allen et al., 2017; Carlson et al., 2020; Brierley et al., 2016; Martinus et al., 2020; Morse et al., 2012; White and Razgour, 2020). However, there is a critical need to unpack the wider global processes that are putting these communities at higher risk, in order to highlight that global action is required to address zoonotic spillover events, rather than putting the onus on local communities to tackle the issue. Our model seeks to redress this issue by placing ***rising global population and per capita consumption*** as the primary driving force behind outbreaks of EIDs.

Our model follows an understanding of global economic restructuring experienced through the industrial (approximately the 1760s to 1950s) to post-industrial (from around the 1950s onwards) periods, which saw large changes in how society consumed and produced goods. The industrial era was defined by mechanisation of production processes and growing international trade of goods, whereas the post-industrial society saw the rise in demand for services, together with growing use of personal computers and internet technologies. These changes were accompanied by shifts in consumer preferences towards quantity over quality, whereby goods and services bought cheaply would be replaced as new technologies or designs made them obsolete (Whiteley, 1987). Indeed, as Miles (1998) argued, the shifts in consumer preferences were linked to growing consumerism where "*products and services potentially play[ed] an important role in who we are and how we construct our social lives … [that is] we relate to other people through such goods and services*" (p.3). This was in part driven by governments who saw consumption as critical to achieving economic recovery and national security after two World Wars and a worldwide economic depression. By the 1960s, growing spatial inequality had emerged as a global phenomenon, dividing the world into high, middle, and lower income nations (World Bank, n.d.). And by the 1980s and 1990s, consumerism lifestyles were seen as a serious global issue, given the disconnectedness of consumers with understandings of the where and how of goods and services production (Miles, 1998).

The intensifying globalisation and the spatial reorganisation of production and consumption over the last 100 years have led to major theorisations associated with global economic restructuring, including seminal works of the new international division of labour[2] (Fröbel et al., 1978); world systems theory[3] (Wallenstein, 1974); the role of global cities[4] (Sassens, 2001); and spaces of flows[5] (Castells, 1996). These bodies of work led to ground-breaking theorisations from the 1990s on the governance of global production networks, global commodity chains or value chains through inter and intra-firm multinational operations and production activities (Coe et al., 2004; Gereffi, 1994; Gereffi et al., 2005; Henderson et al., 2002). The interconnectedness of economic production and consumption processes across the globe has emerged strongly through these developments in academic thought across the fields of sociology, development economics, development studies, international business, and political and economic geography. It is therefore impossible to discuss the pressures on a small village in a low or lower-middle income nation to produce low-cost agricultural or manufactured goods, without also discussing global consumption demand and preferences.

Global consumer demand for goods and services, economies of scale and size, and pressure to lower prices influences the spatial distribution and governance of global industry production networks. In our model lowering prices works to increase demand and place further pressure on local resources (such as human capital, land, water, energy, and materials) and the way these resources are used. Following this conceptualisation, rising global population and per capita consumption are ultimately the primary drivers of land use changes in a local area, and contribute to climate change at a more aggregate level.

2.3 Pressures: Land use change and climate change

The driving forces of population growth coupled with increased consumption and production lead to human activities that put pressure on the environment, and create conditions that can lead to zoonotic disease outbreaks. Our model conceptualises pressures in the system into two broad categories: those arising from land use practices (and most importantly, land use change), and those arising from anthropogenic climate change. UNEP (2020) counts climate change as one of the five key pressures acting to increase the emergence of zoonotic disease, alongside land use change and deforestation; agricultural intensification; increased antimicrobial resistance; and illegal or unregulated trade in wildlife (Everard et al., 2020; UNEP, 2020). Land use change and

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[2] The *new international division of labour* refers to the de-industrialisation of high-income nations and the growth of transnational corporations, which resulted in low skilled low wage workers in lower income nations and high skilled high wage workers in wealthier nations (see Oxford Reference for New International Division of Labour)

[3] Emerging from sociology, *world systems theory* suggested there was a global system of nations which benefited some nations and exploited others.

[4] The notion of *global cities* highlighted how cities facilitated the flow of information, wealth and resources. Further, particular cities sat at the apex of a global urban system capturing these flows, which were no longer bound by the nation-state, given the way corporations moved resources.

[5] *Spaces of flows* reflects that increasing innovation and technology have intensified globalisation, and have the potential to exclude or marginalise whole nations or particular groups of people.

climate change also interact to create an additional suite of pressures, as shown by the double-headed arrow in our conceptual model. The conceptualisations in our model regarding these two categories of pressure are summarised in the remaining part of this section.

First, in terms of pressures from land use practices, studies exist on how land use changes may increase the risk of zoonotic spillover and disease spread (Daszak et al., 2013; Lambin et al., 2010; Lloyd-Smith et al., 2009; Morse et al., 2012; Wood et al., 2012). Some have explicitly tried to model the relationships. Whilst some previous studies do not detail what 'land use change' entails (e.g. Cummings et al., 2015; Hassell et al., 2017; Lambin et al., 2010; Mastel et al., 2018), most cite key aspects as including intensification and expansion of agricultural production; urbanisation; land degradation, deforestation, and habitat fragmentation; and pollution of land and waterways (Patz et al., 2004; Morse et al., 2012; McFarlane et al., 2011; Karesh et al., 2012; Murray and Daszak, 2013). For our model, we classified land use changes as those generally relating to: 1) industry itself (e.g. agriculture or resource extraction, such as is found in Patz et al., 2004; Rohr et al., 2019); 2) human activities that directly generate a land use change (e.g. human settlement, habitat fragmentation, deforestation, as in Cummings et al., 2015; Lambin et al., 2010; Patz et al., 2004); and 3) human activities where the land use change is unclear, but humans play a role in disease spread (e.g. land/water interface, movement of population and trade, as in Lloyd-Smith et al., 2009; Mastel et al., 2018; Morse et al., 2012; Patz et al., 2004).

We argue there is a need to more deeply engage with land use changes themselves, since such human activities directly lead to spillover events and are *not* necessarily attached to a particular industry. Indeed, identifying specific industries (as per most of the models above) may lead to misconceptions regarding the drivers of land use change. To this end, we highlight five key land use changes where perpetuations to the environment may result in spillover events. These are:

1) Land use degradation,
2) Habitat fragmentation,
3) Deforestation,
4) Land and water pollution, and,
5) Urban encroachment into natural habitats.

Examples in the literature linking such land use changes to EID are the Zika virus in Brazil, where natural habitat encroachment and deforestation generated habitats favourable to the mosquito which acted as a vector of the disease (Ali et al., 2017). The spillover of Hendra virus from fruitbats into horses and humans was associated with degradation of fruitbat habitat on the spatial periphery of a large Australian city (Plowright et al., 2008; Field et al., 2001). Further, the movement of people and trade, as highlighted by Patz et al. (2004), Lloyd-Smith et al. (2009) and Morse et al. (2012), are related to later stages in how a pandemic spreads rather than land use changes itself (as is assigned in Lambin et al., 2010), and is therefore captured in the factors influencing **human behaviour and susceptibility** of our model.

Second, in terms of pressures from anthropogenic climate change, there is unequivocal evidence that human-induced climate change and changes in weather conditions impact infectious diseases through affecting pathogens (or agents), their vectors (or hosts), and the transmission environment (Wu et al., 2014; Epstein, 2001; Wu et al., 2016). Long-term warming fosters a shift in the geographic range of pathogens and hosts, while extreme weather events can affect the timing and intensity of outbreaks (Epstein, 1999, 2000, 2001). For example, West Nile Virus epidemics have increased globally as a result of droughts and extreme weather events (Harrigan et al., 2014; Paz, 2015; Wang et al., 2010). And, an increase in sudden and extreme weather events played a role in Ebola outbreaks (Pinzon et al., 2004). While vector-borne diseases (including malaria, Hanta virus, Lyme disease, tick-borne encephalitis, yellow fever, and dengue fever) have all expanded ranges following increased temperatures, including to temperate regions such as the USA, Canada and Europe (Engelthaler et al., 1994; Epstein, 2001; Bouchard et al., 2019; Ludwig et al., 2019; Harrigan et al., 2014; Semenza and Menne, 2009).

Many studies demonstrate the potential impact of climate change on infectious diseases (e.g. Altizer et al., 2013; Carlson et al., 2020; Escobar et al, 2016; Epstein, 2001; Lafferty, 2009; NRC, 2001; Sari Kovats et al., 2000). Numerous (mathematical and ecological) models predict how changes in meteorological parameters affect vector redistribution (e.g. Molnár et al., 2013; Parham et al., 2015; Rogers and Randolph, 2000; Ryan et al., 2019). Few of these frameworks identify the *socio-economic mechanisms* through which human activities drive climate change and consequently lead to more (or less) EID events. Wu et al. (2016) succinctly summarise how climate change affects the trifecta of pathogen, host, and disease transmission, but do not address how human activities influence climate change (the authors do discuss how social and economic factors play a role in population vulnerability to disease).

Heffernan (2018) presents a framework where climate change is the primary driver of host/pathogen interactions, as well as cascading effects on primary production, secondary impacts on food and livelihood security, and tertiary impacts on human behaviour which, in turn, can affect infectious disease risk. Their work discusses mitigating factors within this cascade, but does not consider the drivers of climate change itself. Frameworks that integrate both climate change and land use change impacts on EIDs are relatively uncommon. The framework of Myers and Patz (2009) captures how interactions between climate change and changes in land use and cover lead to ecosystem services degradation, which in turn affects human health. However, the framework does not adequately expand on the drivers of land use change and climate change—which are needed to identify critical intervention points, especially in relation to public health.

Furthermore, a key focus of existing work is on early detection, prevention, and adaptation measures, particularly for vulnerable communities. Whilst these are strategies to address the increased risks of EIDs once they are apparent, they do not target the overarching drivers of the system, which are global consumption patterns and demand. While such improved surveillance strategies and prediction are clearly important, addressing the drivers of land use change and climate change will be fundamental to reducing the increasing risk of EIDs across the globe.

2.4 State: Altered habitat and environmental conditions

The pressures described in the previous section lead to altered habitat states: reduced biodiversity, reduced forest cover, increased contact between species that may have otherwise never met, and altered weather patterns. Altered habitat states place human beings at risk of coming in contact with novel diseases, with the degree of risk (number of cases and distribution of disease) associated with specific contextual states related to the socio-economic and political conditions of an individual or community.

The current state of the biosphere has been well documented in recent major reports: human activities directly affect more than 70% of ice-free land across the globe (IPCC, 2019). Since at least the 1960s, global population growth and increasing per capita consumption of food, livestock feed, fibre, timber, and energy have led to sharp increases in the use of land and freshwater, with over 70% of freshwater now used for agricultural purposes (IPCC, 2019). Land degradation negatively affects the livelihoods and wellbeing of at least 3.2 billion people (IPBES, 2018). Each year, the world effectively loses 10% of annual global gross product through the economic impact of land degradation, due to the associated loss of biodiversity and ecosystem services (IPBES, 2018). Human activities have increased global greenhouse gas emissions to the extent that global average temperature is now 1.1°C warmer than in the pre-industrial period (IPCC, 2019). Greenhouse gas emissions continue to climb each year.

Added to these human induced changes in the biosphere, rising consumption and population growth are intricately linked with declines in biodiversity and environmental quality (IPBES, 2018; IPCC, 2019). The 2020 Global Biodiversity Outlook 5 report (a flagship publication of the Convention on Biological Diversity) demonstrated that biodiversity was declining at an unprecedented rate around the world (Secretariat of the CBD, 2020). Further, the 2020 Global Living Planet Index recorded an average 68% decline in monitored populations of fish, birds, mammals, reptiles and amphibians in the years between 1970 and 2016 (WWF, 2020). Some regions have been particularly severely impacted, including the tropical Americas with a decline of 94% in monitored populations of vertebrates, and freshwater ecosystems globally recording an average decline of 84% (WWF, 2020). The intertwined effects of habitat loss coupled with climate-change driven shifts in species distribution mean a higher likelihood of interactions between species that may have previously never occupied the same location, leading to a higher likelihood of novel zoonotic diseases from spillover events (Carlson et al., 2020).

Whilst this altered habitat state places human beings at increased risk of EIDs, the capacity of regions and individuals to minimise the spread and number of disease cases is influenced by the specific socio-economic and political environment. Poverty, a key social determinant of health increases the risk of infectious disease through reduced access to safe water and sanitation, education, nutrition, health care and housing, and employment in more hazardous work (Schneider et al., 2015; Quinn and Kumar, 2014; Landrigan et al., 2018). Furthermore, poverty impedes participation in civil society and political processes, engendering limited influence to improve their communities (Landrigan et al., 2018). For example, because of a limited ability to physically distance and limited access to testing facilities and health care services, the poor and the homeless are a greater risk of COVID-19 (Abrams and Szefler, 2020). Similarly in the US during the H1N1 pandemic influenza-like illness was more likely to be reported among groups who were less able to physically distance and had less access to health care (Quinn et al., 2011.)

Ethnic minority groups have a greater risk of infectious disease and mortality as a result of greater employment in health and social care roles, higher levels of underlying health conditions and economic vulnerability (Platt and Warwick, 2020). Even though effective treatments for tuberculosis were developed in the latter half of the 20th century, tuberculosis is still prevalent because of social and political factors as well as the emergence of multi drug resistant strains of the bacteria (Bulter-Jones and Wong, 2016). A lower incidence of tuberculosis across 229 countries was associated with greater political stability [6] and better health systems [7] (Rutherford and Unruh, 2017). While economic stability did not impact on incidence, it co-varied positively with political stability (Rutherford and Unruh, 2019). The influence of socio-economic and political environments on infectious diseases, which in turn affects access to health and public health infrastructure, highlights the need to focus upon the upstream drivers of land use and climate change in order that downstream consequences of diseases can be prevented.

[6] Defined by measures of voice and accountability, absence from violence and terrorism, control of corruption, and regulatory quality and rule of law.

[7] Defined by measures of case detection rate, immunization uptake, health expenditure and improved water and sanitation).

2.5 Impact: Emerging infectious diseases and human health

Our conceptual model focusses on the specific impact of EIDs on human health, and on the emergence and distribution of disease cases. We acknowledge that the driving forces and pressures highlighted in our model will have far more wide-ranging effects on society and environment as well as disease in human populations. Nevertheless, the focus of our discussion is on reducing human pressure to mitigate the impacts of EIDs.

Many EIDs have a zoonotic origin, including diseases such as swine flu (H1N1), Ebola virus disease (EVD), Zika, and recently COVID-19. A virus crossing from an animal host in a human population (such as likely has occurred with COVID-19) is not a unique event, however, the impacts of particular EIDs will vary greatly depending on the characteristics of the virus as well as the level of contagion and potential for transmission. With greater frequency of events that could result in zoonotic spillover, there is a greater likelihood of an EID that will have severe local, regional and global consequences.

The impact of COVID-19 has been profound, providing a visceral demonstration of the multi-faceted impacts of EIDs across space and time. The first cases of COVID-19 were reported in China in December 2019. By the end of October 2020, over 45 million cases have been confirmed worldwide, with at least 1.1 million people dying from the disease (Johns Hopkins University of Medicine, 2020a). The social and economic impacts have been severe, with projections of a global contraction in GDP lasting until at least the end of 2021, with some countries experiencing greater contraction in GDP than others (for example, the US, UK, Sweden and a number of emerging economies are likely to experience some of the largest contractions in GDP). Workers in low-paid and insecure jobs have been amongst the hardest hit (Kantamneni, 2020; Lemieux et al., 2020; Platt and Warwick, 2020). The contraction in the global economy has feedback effects on planetary systems. For example, the International Energy Agency projects a global drop in greenhouse gas emissions by 8% in 2020 compared with 2019 levels (IEA, 2020).

2.6 Model: Embedding public health

Our framework conceptualises public health as not only a means of controlling and mitigating the spread of disease once an outbreak has occurred, but also – and very importantly – as a means of designing local- to global-scale landscapes and processes to encourage positive health outcomes and prevent disease outbreaks from occurring in the first place. Public health responses need to be tailored to where they can be most effective. Therefore, our conceptual model embeds public health throughout the entire chain of events leading to the emergence of an infectious disease. By doing so, we highlight that the potential for prevention exists from the most distal causes to the point where disease has emerged. The policies and actions that are put in place to reduce rising global production and per capita consumption will in turn reduce conditions that can lead to zoonotic disease outbreaks. What this means will become clearer in proceeding sections detailing *land use stewardship interventions* (LSIs), but we touch briefly on this here.

As identified by other scholars (Heymann and Dar, 2014; Patz et al., 2004; Lambin et al., 2010; McMichael et al., 2017), our framework also reflects the need to broaden thinking about discrete risk factors for disease (how specific exposures impact on health) to upstream determinants of detrimental land use practices, which in turn increase infectious disease risk. There is a need to develop this better conceptually as solutions in current models tend to focus on when disease has emerged. For example, Lambin et al. (2010) predominantly focus upon the change in human behaviours needed to decrease disease transmission and the need for an expanded public health surveillance system. Both of these occur at the state level in the DPSIR model. Patz et al. (2004) identify the need to bring land use into public health policy, through the evaluation of approaches to achieve optimal human development and sustainable goals while balancing the trade-offs of environmental and development decisions.

Morse et al. (2012) highlight that the geographic conditions and interactions between people, animals and the environment, can be used to predict patterns in the origins and spread of new pathogens. This is particularly the case when combined with a better understanding of the dynamics of pathogen ecology and transmission. The PREDICT project (https://ohi.vetmed.ucdavis.edu/programs-projects/predict-project) brings together expertise from several disciplines (wildlife ecology, epidemiology, genetics, virology, veterinary medicine etc.) to forecast where new public health threats are most likely to occur and to increase local capacity to mitigate such threats (Morse et al., 2012). While PREDICT has provided invaluable data on potential zoonotic transmission and supported the development of surveillance and diagnostic programs, to prevent pandemics we need to address the underlying drivers (IPBES, 2020). For example, the urbanisation and economic development drivers of land use change.

Patz et al. (2004) identify the need to bring land use into public health policy, through the evaluation of approaches to achieve optimal human development and sustainable goals while balancing the trade-offs of environmental and development decisions. A potential approach is to use Health Impact Assessments (similar to environmental impact assessment) to evaluate positive and negative health consequences, and identify the healthiest planning scenarios (Myers and Patz, 2009, Patz et al., 2004, Morse et al., 2012). The call for health input into such decisions is not new and until it is embedded in a regulatory framework, the uptake may be limited.

A further challenge is developing a health impact assessment framework that incorporates the complexity of changing hazards and interactions with local environmental conditions, multiple exposure pathways, the characteristics of the exposed populations and the social, cultural, political and economic factors that might mediate health risks (Myers and Patz, 2009). Ideally these assessments would address local, regional and global health impacts but in reality these are more likely to be location specific (Patz et al., 2004). Recently, and even more so in this COVID-19 era, we are seeing greater consideration of health impact into decisions regarding urban planning. For example Stevenson et al., (2016) argues for a more compact city design, that is a city of short distances that promotes higher residential density, mixed land use, proximate and enhanced public transport, and an urban form that encourages cycling and walking, using a health impact assessment framework. They found health gains (diabetes, cardiovascular disease, and respiratory disease) of 420–826 disability-adjusted life-years (DALYs) per 100,000 population for all cities of the study. However, a small increase in road trauma for cyclists and pedestrians (health loss of between 34 and 41 DALYs per 100,000 population was observed, indicating that policies for compact cities must also provide safe walking and cycling infrastructure (Stevenson et al., 2016).

The responses that occur at the level of the *driving forces* (global consumption) may not be direct public health responses. Indeed decisions about development trends related to increasing demand for energy, transport and technology rarely have health as central to this decision-making (WHO, 2020). However, we would argue, as Wood et al. (2012) do, that policies should not reflect sectorial divisions. For example, WHO acknowledges the Paris Climate Agreement is a fundamental public health agreement because of the direct and indirect health risks associated with climate change (WHO 2018). The World Health Organization recently published a manifesto[8] for a healthy recovery from the COVID-19 pandemic, which included protection and preservation of nature as a source of human health and building healthy and liveable cities.

The *pressures* of land use and climate change on health are described above (Section 2.3). The role of public health is to promote environments that are conducive to health and well-being. While suboptimal urban planning and transport planning are responsible for an estimated 2,904 (nearly 20%) of premature deaths per year in Barcelona (Mueller et al., 2017), COVID-19 has highlighted the opportunity to make our cities better through promotion of environments that are conducive to health. Barcelona is now revisiting the ideas of its 19th century planner, Ildelfons Cerdà, who considered the human needs for natural lighting, ventilation, open space and greenery, and a transport network accommodating pedestrians, horse-drawn carriages and public tram lines by implementing "*an innovative land use intervention that aims to reclaim space for people, reduce motorised transport, promote sustainable mobility and active lifestyles, provide urban greening and mitigate the effects of climate change.*" (Mueller et al., 2020). This planning approach is estimated to be capable of preventing 667 premature deaths each year. This would result in an average increase in life expectancy for the Barcelona adult population of almost 200 days, and result in an annual economic impact of 1.7 billion EUR. Public health responses must be incorporated into urban planning to ensure

[8] See https://www.who.int/news-room/feature-stories/detail/who-manifesto-for-a-healthy-recovery-from-covid-19

cities facilitate active lifestyles and green spaces over cars and roads (Mueller et al., 2020).

As we move to the *state*, the focus is on public health surveillance. The aim is to assess the burden and distribution of adverse health events that may have a significant impact upon population health (Groseclose and Buckeridge, 2017), to prioritise public health actions and monitor the impact of control measures. However, within our framework we advocate for a broader surveillance for the detection of conditions that might lead to disease. This includes not only data on disease cases but also measures of changing ecological niches and environmental precursors of diseases, such as changes in land uses and seasonal patterns (Lindgren at al., 2012; Lambin et al., 2010).

At *impact*, where increased exposure to pathogens has occurred and disease cases have emerged, our framework is consistent with other models highlighting the need for diagnosis and treatment as well as public health responses to manage and control the disease outbreak. Public health at this stage is focused upon case-detection and limiting the further disease spread by identifying the local source, interrupting transmission and protecting persons at risk through behaviour change and public policy such as on lockdowns and border control strategies.

It is important to acknowledge the local political, social and economic context will influence public health responses (Lee et al., 2020; Al Mossawi et al., 2020; Martinus et al., 2020). In particular this context will influence the strength, or lack thereof, of the health system and public health infrastructure to respond (Lee et al., 2020; Al Mossawi et al., 2020). COVID-19 as well as previous outbreaks clearly illustrate the varying preparedness of countries to address emerging epidemics (Lee et al., 2020). Italy is a case in point, where the health system in several regions was quickly overwhelmed, a situation exacerbated by an ageing population with a higher degree of underlying smoking-related illnesses (Boccia et al., 2020).

2.7 Responses: Introducing Land Stewardship Interventions

The causal links between the driving forces, pressures, state of the environment, and impacts on human health have been documented in depth for the case of EIDs (Hambling et al., 2011; Boelee et al., 2019; Everard et al., 2020; IPBES, 2020). Because of the global nature of driving forces and pressures, a broad suite of policy responses are required to influence causal links and feedbacks within the human-environment system, and ultimately reduce our vulnerability to EIDs.

In the next section, we detail five critical 'Land Stewardship Interventions' that reach across society, economy, health, and environment, and which could alter the impact pathway and reduce the likelihood and severity of future pandemic diseases. The five proposed Land Stewardship Interventions are summarised in Table 1.

Table 1: Land Stewardship Intervention summary and interventions points to alter state of the model

Land Stewardship Intervention	Impact on the model (numbers indicate which point)
1. Change in global consumption and industry practices to be more environmentally and socially sensitive	[1] Configures a healthier landscape through preventative health measures, education and information, and reduced land degradation [2] Provides more transparent consumer choices, which include the costs of sustainable production [3] Provides impetus for changing production practices [5] Promotes land use practices that reduce the pressures from human activities [7] Promotes practices that actively restore and improve species habitat
2. Localising supply chains in certain products and services to improve national food and energy security, and minimise negative health and environmental impacts	[5] More efficient, sustainable, environmentally-sensitive land use decisions [6] Decrease human-induced climate change [9] Encourages better decisions regarding socio-economic live/work conditions [10] Minimises impact if there is an outbreak
3. Using technology to reconfigure the traditional land intensive business models and enhance resource efficiency	[3] Technological advances restructuring geographies of production [5] Better and more efficient land use decisions [6] Decrease human-induced climate change [10] Minimises impact if there is an outbreak
4. Increase public education, engagement and appreciation of the natural world, and willingness to advocate on its behalf	[4] Changes local demand for resources [9] Increases societal awareness of benefit of nature in reduction of disease risk [10] Minimises impact if there is an outbreak
5. Integrated effort to address climate change, pollution and land degradation	[5] More sustainable and environmentally-sensitive land use decisions [6] Decrease human-induced climate change [9] Encourages better decisions regarding socio-economic live/work conditions [10] Minimises impact if there is an outbreak

3. LSI1: Change in global consumption and industry practices to be more environmentally and socially sensitive

Recognising that we live in a globally connected world of goods and service trade as well as high human mobility, consumption and production decisions made in one location will have effects elsewhere. The chain of events that occur between the extraction, harvest or manufacture of a product and the purchase of that product are often opaque, and not easily interrogated by consumers who may be living in an entirely different geographic and cultural context.

In this Land Stewardship Intervention (LSI), we advocate for greater emphasis on providing transparency and knowledge around environmentally and socially sensitive producer and consumer choices, in order to reduce the extent of unsustainable production and consumption practices that may exacerbate the conditions leading to an increased risk of emerging infectious diseases (EIDs). We propose a complementary LSI that focusses on localising supply chains for certain goods and services (LSI2). Changes in consumer demand preferences towards more environmentally-sensitive economic production means a greater awareness in both buying local and understanding the conditions under which production occurs in other nations.

Consumer mindset was already shifting towards more sustainable and environmentally sensitive goods and services prior to COVID-19 (Accenture, 2020). The consumption 'pause' during lock-down could accelerate some of these consumer shifts, such as growing antipathy toward waste-producing business models and expectations for greater business involvement in improving social and environmental outcomes (Amed et al., 2020). A survey of 6,000 consumers in North America, Europe, and Asia found that over 80% of consumers reported that they are likely to continue to make more environmentally friendly, sustainable, or ethical purchases (Accenture, 2020).

Changing consumption and industry practices relates to several elements of our conceptual framework, primarily intervening at the scale of drivers and pressures, and secondarily at the level of state. This LSI also includes an explicit focus on disease prevention through advocating for healthier human and natural environments.

Emphasising socially- and environmentally- responsible production practices reduces the pathogenic potential of landscapes as part of disease prevention. For instance, certification schemes and lending frameworks can explicitly require land use practices that are less likely to result in spillover of zoonotic diseases. These practices can promote healthier environments when integrated with social standards for access to clean water, sanitation and health facilities, and provision of locally appropriate education and training around EIDs.

Providing more transparent choices can influence consumption patterns, and ties in with rising per capita consumption. Consumers who are more affluent, and/or concerned with ethical production practices, may choose to pay more for certified produce, and purchase lower volumes of non-certified goods. Consumer choices are intertwined with production, with greater demand providing an incentive to switch to more environmentally and socially sustainable land use practices that in turn reduce pressures from human activities. Finally, there is scope for certification schemes and operating standards to incorporate ecological restoration as part of their management, in order to improve the state of species habitat and further reduce the risk of EIDs.

3.1 Policy levers that may be applied to achieve change

There is a need to solidify changes in purchasing habits and push for changes to consumer demand that can have direct impacts on land use change and degradation across the globe. Eventuating such a change will involve a range of actors. Consumers may be persuaded to consider the global impacts of their consumption decisions through information provision that clearly links unsustainable consumption to increased emergence and spread of EIDs. This would require targeted campaigns. Researchers, media, and governments have a responsibility to deliver information in a manner that connects to the target audience. Using their collective purchasing power, consumers can in turn put pressure on industry to demand more sustainable production practices.

Consumer awareness of certification and provenance of goods and services is not automatic, and requires promotion. The trade of live and recently killed wildlife through 'wet markets' (which have been associated with increased risk of transfer of viruses across species) may be 'invisible' to the average consumer; the targeted provision of information and education can increase awareness of the importance of protecting wild species and not supporting illegal, unsanctioned or poorly sanctioned trade in wildlife (Volpato et al., 2020). For instance, information campaigns on shark fin soup have reduced consumption in China by 50-70% since 2011 (Volpato et al., 2020).

Certification schemes can provide information about the social and environmental conditions under which commodities are sourced and sold, providing guidance to consumers and producers. Such schemes are widespread and growing for a range of commodities and services (Prag et al., 2016), with the goal of transparently auditing and verifying that a product or service meets particular ethical, social and environmental standards (DeFries et al., 2017; Oya et al., 2018). Studies have already shown that 'eco-friendly' labelling can encourage consumers toward sustainable fashion, food consumption, and environmentally-friendly groceries (Lee et al., 2020; Kristensson et al., 2017; Vlaeminck et al., 2014). Growth in these certification schemes is likely to continue, opening up an opportunity for certifying land-use practices that reduce the risk of zoonotic disease. For example, certification schemes set by the Roundtable on

Sustainable Palm Oil, promote palm oil cultivation that is environmentally responsible and aim to conserve natural resources and biodiversity (RSPO, 2020).

Future certification schemes could verify whether production modes exploited or caused land degradation that could lead to an increased risk of EIDs. This would need a strengthening of existing schemes with regulatory support and reshaping them to face current challenges. It must be acknowledged that there is a limited evidence base so far gathered on the social and environmental impacts of certification programmes (Ola et al., 2018; DeFries et al., 2017), and that some certification programmes (such as for forestry) have far greater uptake in temperate regions than in tropical forests (Ebeling and Yasue, 2009). Strengthening of incentives for certification, improving land tenure security and enforcing regulations can aid in the uptake and success of commodity certification (Ebeling and Yasue, 2009). If certification schemes help shape consumers' decision and industry practice, they will have a positive impact on climate change and reduce the risks of EIDs.

A major challenge for certified products is obtaining enough market share that sustainable production practices become the 'norm' rather than the exception. To increase demand for certified products, governments and multinational businesses can opt to change their procurement policies for goods and services. For example, around 20 EU member states have government procurement policies on legally sourced timber (White, 2019), as do many entities in the private sector. These trends are expected to continue, aided by technological advances that have allowed for greater transparency in tracing and visualising of supply chains, generating distinct benefits for producers to align themselves with certification schemes.

There is a financial incentive for businesses to engage in more sustainable production practices. Not only is there an incentive to retain a 'social license to operate' – there are also significant risks for business and industries engaging in practices that may have adverse environmental, social and health effects. The adoption of the risk management framework of 'The Equator Principles' by 111 financial institutions involved with financing projects in developing and emerging economies (Equator Principles, 2020) demonstrates that business acknowledges that environmental and social impacts can ultimately lead to the derailment and failure of large projects. Similarly, the World Bank requires borrowers to conform with 10 Environmental and Social Standards (ESS), of which ESS4 relates to Community Health and Safety, and explicitly states the need to reduce the risk of vector-borne disease and other health risks (World Bank, 2016).

4. LSI2: Localising supply chains in certain products and services to improve national food and energy security, and minimise negative health and environmental impacts

This LSI focuses on a *greater amount of local control over land use, and how it is regulated and controlled*. Currently, nations connected in the global economy rely heavily on global production networks to supply goods and services at the cheapest price and through the most ‘efficient’ operating process. However, there is often a trade-off between cheap production and weak environmental and occupational regulation, resulting in environmental degradation. For example, global brand manufacturers have come under fire for engaging in sweatshop labour practices where workers are forced to work and live in extremely poor conditions, and where there is little attention paid to the environmental pollution that occurs as a result of production or manufacture. Further, small producers in low income nations are often forced to engage in poor industry practices, and having little choice or education to do otherwise as they are often supporting extended families (Brown et al., 2003; Nair, 2016; Zhou, 2017).

In buying cheap goods and services (including holidays) from elsewhere, consumer nations are able to shift the blame for environmental degradation and poor land use regulations to elsewhere—even though their demand for cheap products and services ultimately drives this. The ways in which global production and consumption are currently organised is changing human habitats, creating environmental as well as human health crises. Changes in natural habitats has been highlighted as the driving factor in emerging infectious diseases (EIDs) (Martinus et al., 2020).

We argue for improved regulations and practices in global production chains, as well as support for local production chains particularly in terms of products and services critical for national security. This includes industries related to national security, food and energy where the emphasis is on minimising negative health and environmental impacts. This LSI does not advocate for the dismantling of global production networks, but seeks to provide a mechanism for consumers to make more informed and sensitive choices to reduce their environmental impact. Its local focus responds to shifts in consumer preferences and behaviours that may lead to global change. These consumer shifts are related to more localised consumption patterns, increased environmental activism, local pride and desire to support local business (OECD, 2020; UNWTO, 2020). These changing consumption patterns may generate multiplier effects in producer decisions surrounding land use and environmental management worldwide. This LSI intervenes as a response to the pressures identified in the model, as well as improves outcomes of the state if an EID outbreak occurs in a particular region. There are three points to note in relation to this.

First, this LSI advocates *greater local consumer control over supply chains* as a result of increased awareness of the dangers to human health from environmental degradation and poor land use changes. Unless consumers make different demand choices, then global production networks may continue with industrial land use methods and processes which degrade the environment and exacerbate climate change. These are key pressures (land use change and climate change) leading to the altering of habitats and the increase in human-wildlife interactions, which are well established in increasing the risk of EIDs.

Second, this LSI advocates the greater awareness of consumers regarding the need to properly regulate how corporations use labour and the environment (including working conditions) to minimise the spreading of disease if there is an EID outbreak. This LSI acts to increase the health of the workers and residents, in particular vulnerable persons such as migrant labour, a critical component in influencing human susceptibility and behaviour which is related to the socio-economic and political state of a region. This has been shown to help reduce the number of cases if there is a disease outbreak.

Third, this LSI also provides a mechanism to *ensure to goods and services critical to a nation are not subject to supply shortages* if there is a pandemic. This will essentially reduce effects of the final impact, given the exposed vulnerability of citizens during an outbreak. For example, the disruption of global value chains during COVID-19 was due to an over-dependence on other nations for critical goods and services. There were three reasons for this. Firstly, production was halted due to sickness and economic closures as the pandemic took hold in different nations. Secondly, nations began to hoard supplies of essential goods such as antiseptics, face masks, etc. Thirdly, disruptions to transport networks (local and international) and movement of people (during lock downs) lowered the demand for certain goods and services and increased others. COVID-19 highlighted that national production of essential goods to meet local demand is important to assuring health, energy and food security (OECD, 2020a), which in turn supports the degree of disease and exposure of a local community. This LSI works to reduce the number and distribution of disease cases within a community once an outbreak has occurred.

4.1 Policy levers that may be applied to achieve change

In this LSI, we argue that this increased consumer awareness could be leveraged to improve environmental conditions and prevent future pandemics. Increased national priorities around food, goods and energy security are likely to create a permanent shift in global and local land use structures, specifically those that advance green economies. Indeed, 2020 has seen an increase of articles highlighting the importance of climate change and green economies in post-COVID-19 recovery plan (Dixson-Declève, 2020; Skarbek, 2020).

The shift in how people view their local environment and nature has been an interesting side-effect of COVID-19 social distancing measures, with a global increase in time spent with family, nature, physical exercise, locally-sourced food and local travel (where permitted). Since COVID-19, news reports from around the world document greater engagement in nature in China (Xuejiao, 2020), rise home-grown and local food in the UK (Gladwell, 2020), and changing health habits, growth in family time (Lewis & Rollins, 2020) and domestic tourismin Australia (Pryor, 2020). There are several ways that this can be leveraged strategically.

Firstly, though the direct use of top-down government policy tools such as production subsidies, tariffs, imposing local content requirements and investment restrictions (OECD, 2020a). The use of government policy to direct production towards particular products or services that may be critical is highly important, given the vulnerability associated with different supply chains. For example, during COVID-19, the toilet paper supply was able to adjust far more quickly than disinfectant wipes due to competition of the required disinfectant with personal protective wear (PPE) (Gao, 2020). Another example comes from the increase in penetration of renewable energy production as overall power demand decreased during COVID-19 lockdowns and governments increased fiscal commitments to stimulate the renewable energy sector (Skinner and Elverston, 2020). There is a potential for pandemic conditions to create a tipping point to accelerate growth in the sector, but government has a large role in directing and shaping initiatives to ensure it is future-proofed rather than the ad-hoc use of technologies not appropriate for domestic long-term goals. The former role has been adopted by the Australian government (Thornton, 2020).

Secondly, through the support of bottom-up community led approaches, such as local neighbourhood food production where there is great scope for existing initiatives to be scaled up. Indeed, during the COVID-19 pandemic, some grew vegetables for the first time in fear of a fresh food shortage (Gladwell, 2020). Local food production can provide insurance in crisis situations as well as financial, social and psychological benefits to local communities (Carey et al., 2019; Gaynor, 2020). Examples of community-led initiatives are in local seed banks (such as Seed Savers Networks in Australia) supplying seeds for people to grow their own food in urban areas (including providing for people in need) (Doherty and Osbourne, 2020). Other instances are where community gardens have been prioritised as essential services for food security during the COVID-19 pandemic, rather than a recreational amenity (Lamberink, 2020).

Thirdly, through the support of high tech and innovation in resolving supply chain vulnerabilities and shortages. Agriculture is well placed to do this, with examples of vertical farming within cities (Despommier, 2020), as well as automated harvesting and production facilities such as roboticised abattoirs (Henry, 2020) which reduce human contact (and therefore susceptibility to disease transmissions).

Fourthly, greater engagement of consumers through tourism (budget to high-end) with the natural environment is critical in assigning economic value to protect biodiversity hotspots, as well as in raising awareness of the importance of nature for everyone (Secretariat of the Convention on Biological Diversity, 2015). COVID-19 has changed both tourism and how tourists are perceived as vectors of disease, changing expectations on tourist interactions in local environments with a greater shift towards sustainability (Romagosa, 2020). Shifts to more sustainable tourism is likely done at a global level through institutions such as the United National Environmental Programme, or more regional levels through regional or local governments promoting more eco-based or environmental tourism. Examples of this are the shift by the United Nations World Tourism Organization (2020) towards sustainable tourism, and urgent calls by the OECD (2020) to support a rethinking of tourism.

5. LSI3: Using technology to reconfigure the traditional land intensive business models and enhance resource efficiency

This LSI focuses efforts on using technology and innovation to reconfigure how businesses, consumers and government connect across space. It seeks new ways of thinking about how business operations can be more environmentally sensitive. The traditional business model is one where the producers in one country sell to consumers in another through organised networks of traders and merchants – resulting in limited consumer connection to producer or product of origin. *LSI 3 seeks to reorganise and restructure global production chains and resource efficiency*.

Each point in the value chain requires land to be available for production, storage, logistics and distribution activities at various geographic points. This means that the further products travel to reach consumers, the more land is used for various activities. In addition, the further a product travels, the less connection the consumer has to where that product has come from, understanding of how it is produced, or knowledge of the level of environmental impact attached to the full value chain production. This means the consumer cannot make informed choices regarding the products they buy, and has led to a disconnection in knowing how consumption causes land use change and environmental degradation.

With the aid of technological application and innovations, new business models are emerging that allow products to travel vast distances without the need for traditional modes of storage and distribution. They are enabling producers of goods to link directly to consumers across the globe. This is creating a sense of trust and loyalty that circumvents global value chains through person-to-person transactions, and does not rely on middle-men or brokers. LSI3 is concerned with harnessing the power of technology and allowing consumers to make more informed choices on the goods and services they buy.

This LSI acts as an intervention at three levels of the model. Firstly in the disruption of model drivers, secondly in response to pressures and lastly in minimising impacts of an EID outbreak. These means of intervention are described here.

First, technology and innovations are allowing connections between consumers and producers in ways that were previously unimagined. One of the key ways this has occurred has been in the reinstatement of trust in global supply chains by both better connecting buyers to product source regions and people, as well as allowing the shift away from reliance on intermediaries to sell products. Such changes affect the geographies of production and consumption, and the way that land and resources are used (i.e., driver of global industry production and its distribution). This includes within product source regions as they respond directly to consumer demands, as well as in the cities which house the offices of intermediary organisations (e.g., trading houses or companies, import/export legal or business services). The subsequent reduction in land use needs means more cost efficient production as well as a decrease in environmental impacts which exacerbate climate change.

Second, the decreasing demand for land and other resources translates into decreasing the conversion of natural environments to land uses for human modified environments. Further, decreases in demand for production, storage, logistics and distribution land use may mean spaces currently used for these activities can be shifted towards other activities. This represents a more efficient use of both urban land uses and the natural environment. The continued encroachment of human activity into new areas of the world, as we consume more land for industry and business (land use change) and contribute to climate change through environmental degradation, increases the risk of humans being exposed to novel EIDs.

Third, the capacity to apply technology and innovations in new ways can contribute to the reduction of number and distribution of disease cases once an outbreak occurs. For example, product traceability facilitates the rapid trace back of a contaminated food to its source in the event of a foodborne outbreak. Food traceability along supply chains can also help to anticipate food shortages in emergency situations, reduce or minimise food waste and promote food safety culture on the farms, production facilities and at home (Hahn, 2020; Dingley, 2019). Such enhanced capacities support containment and treatment options after an EID spillover event.

5.1 Policy levers that may be applied to achieve change

This LSI requires government and business to work together to provide the policy environment that encourages technology adoption, as well as facilitate equality in market access through the provision of telecommunications hard infrastructures. Government and business have a key policy and strategic role in ensuring this.

Following this, a key area of transformation brought about through technology application on global consumption and production networks has been in facilitating trust in what has been labelled the trust economy. This is through mechanisms such as blockchain and bitcoin. Deloitte LLP cited the trust economy as relying on a "transacting party's reputation and digital identity – all which can be stored and measured in a blockchain" (Mearian, 2017), and BearingPoint (n.d.) referred to trust as "the real innovation behind Blockchain". For example, blockchain technology is used by Australian beef farmers to sell directly to consumers in China who lacked trust in previous Chinese supplied "Aussie Beef" - being often substituted for cheaper beef. Trust in products can be enhanced by engaging with consumers through social media, school education, transparent reporting on producer websites etc (Dunn, 2020; Fenton, 2019; Relph, 2019).

There is similar potential in other social media apps which connect producers-consumers, such as crowdfunding, and on-line ordering of meal kits or food boxes. Examples of food delivery are myfoodiebox (2020), and youplateit (2020); and of crowdsourcing for specific cuts on a cow (Markovich, 2016; Steen, 2016), or food markets in general (Dunford, 2018). Policy that supports the uptake by businesses and consumers to connect in innovative ways is critical in encouraging the emergence of new models of consumer-producer connectivity.

Related to this, is the emergence of the sharing economy (e.g., businesses such as Uber, AirBnB, Youcamp, GoGet, etc.) which is also unlocking land-use from its traditional private versus business model. The sharing economy has allowed more efficient use of private resources and is decreasing the need for counterpart businesses (e.g. taxis, hotels, campsites). It provides a technology-driven model to address broader issues of climate change and the provision of services for the common good (particularly in areas of a region or city that may miss out otherwise). As noted in Bloomberg (Whitney, 2020), there is also the capacity of the sharing economy to address broader socio-economic and environmental issues. The provision of services in the sharing economy means less demand for non-sharing type land developments associated with the tourism, transport and related sectors, particularly in peri-urban and rural environments where it is often unsustainable to provide specialised services.

Nonetheless, the sharing economy has also been challenged by COVID-19 due to fear of virus transmission through sharing. As such, it will no doubt emerge in a different form given its underlying values of community, sustainability, resourcefulness, and trust (Bond, 2020; Rinne, 2020; Singh, 2020). It is important that government and business work together to create a policy environment for it to thrive, as well as regulations around health and safety that ensure its survival, given its capacity to enhance the efficiency of land and resource use and management.

6. LSI4: Increase public education, engagement and appreciation of the natural world, and willingness to advocate on its behalf

This LSI focuses on public education and engagement for consumer behavioural change to evoke greater awareness of nature and the environment. An outcome of the industrial world has been the disengagement of people from the natural world, and increasingly unsustainable consumption (Miles, 1998). Drawing on theories from the psychologist Bandura (2007), Heald (2017) argues that our general silence on issues such as climate change or environmental degradation emerges from feelings of discouragement, that an individual's actions cannot make a difference.

To explain how humans can damage and exploit the environment even while knowing that these actions will also damage humankind, Bandura (2007) uses 'moral disengagement' and 'self-efficacy' or 'collective efficacy'. Moral disengagement explains how people use various turn-off mechanisms to disengage and harm the natural environment, while still living up to their moral standards which tell them it is wrong. Self-efficacy describes how people are less likely to work to solve a problem if they feel they are ineffective, and that collective and perceived group effort can make a difference. These theories on how we have disengaged from the natural world also provide insight into how we might reengage in the context of a global increased (re)interest and (re)connection to local and natural environments emerging from COVID-19.

Certainly, despite an enormous volume of publically available research which documented the health and well-being impacts of nature long before COVID-19, community and business have been increasingly disengaged from nature and the natural environment. This is most evident in the limited collective actions taken to minimise short or long run impacts of our lives and livelihoods on nature and the environment. Despite rising global concerns on issues such as climate change and environmental degradation, a key aspect to the lack of collective action has been moral disengagement. For example, research has found that pro-environmental persons in positions of management can make decisions that are exploitative and detrimental to the environment, and at the same time perceive the action as a highly attractive opportunity (Shepherd et al., 2013).

Other studies have highlighted the high disengagement among children in the UK, where 12% had not been to a natural environment in a year. The percentage of households that visited nature (between 39% and 78%) was highly dependent on how engaged the adult was (Barkham and Aldred, 2016). A separate commentary on this study (Pitt, 2016) questioned the notion of exactly how respondents interpreted 'nature', challenging perceptions that a small city playground may be considered 'nature' alongside a National Park. Such broad interpretations mean that real engagement by children in the UK in the actual wilderness may be considerably lower. Such findings are concerning as they speak to broader issues surrounding the importance of public education, awareness and appreciation for the natural world, in order to protect it.

This has been one of the interesting outcomes to emerge from the disruptions of COVID-19 lock-downs. Indeed, both BBC News (Kasriel, 2020) and the Scientific American (Smith, 2020) reported that citizens staying at home had meant a rediscovery of the value of spending time in, and advocating for, nature and natural areas. The last time this occurred was around 100 years ago during the 1918 Spanish Flu pandemic, when social distancing methods were also invoked (Kildea, 2020; Strochlic and Champine, 2020). It appears pandemics provide an opportunity for a lifestyle pause and rethink of societal values around nature. It is critical that we understand the importance of this in preventing or minimising the risks of future pandemics.

This LSI acts as an intervention response at three key points of the model – by directly changing demand pressures of model drivers, altering the state of the societal context and minimising impacts of an EID outbreak. These are further illustrated below.

Firstly, *education and engagement with nature is a critical means by which to overcome the issues of moral disengagement and self-efficacy* as highlighted by Bandura (2007). Such theories make it clear that change needs to be done at the community level. The promotion of green and blue space, as well as the increased advocacy by the public for the environment, will lead to more long-term decreases in our impact on the environment. This will occur as consumer demand behaviours shift to be more sustainable with lower local demand for resources. This will in turn alleviate human contributions to land use change and climate change which place certain communities at higher risk of EIDs.

Secondly, *increased public awareness of nature and the natural environment will generate a greater willingness for the public to advocate on its behalf*. Pitt (2016) argues for the benefits of a range of 'nature' environments – from the planned urban to the community or backyard garden to that of more undisturbed environments. Indeed, nature comes in different forms and presents us with a range of opportunities for engagement. This is important if we are to cater to the diversity of societal needs, as well as produce change in human behaviour and society.

Thirdly, whilst public open spaces have long been linked to the improved physical, social and psychological well-being of people (e.g. Koohsari et al., 2015; Wood et al., 2017), there is a significant deficit of greening (vegetation) and blueing (water) in most cities which are largely dominated by infrastructure for vehicles (Mueller et al., 2020). The *increase of natural green and blue environments* will not only improve the health outcomes of neighbourhoods and make them more resistant to disease, but it will reduce the number and distribution of disease cases if there is an outbreak. The COVID-19 pandemic and physical distancing measures have increased government awareness of the importance of access to blue and green infrastructure, as well as exploration on how cities might provide this (Plummer et al., 2020).

With *more public infrastructure converted to green space*, neighbourhoods with lower socio-economic status would likely benefit given evidence of the considerable gap between the socio-economically advantaged and disadvantaged in access to and provision of high-quality public space (cf. Rigolon, 2016). It is often these neighbourhoods that are most at risk of EIDs spread, therefore areas of the city that need particular attention in terms of both minimising spread and maximising residents' well-being and resistance to disease (Abrams and Szefler, 2020).

6.1 Policy levers that may be applied to achieve change

This LSI seeks to use the increased awareness of the importance of a quality environment, for both physical distancing purposes as well as to decrease the risk of EIDs, which has emerged during COVID-19. However, it is likely that people will return to the previous lifestyles which put humankind at risk of another pandemic. The challenge is to sustain local community and individual re-engagement in nature.

There are several ways which this can be done; each entails an element of top-down government incentives and policy as well as bottom-up community led action. Public education and engagement are most effective through the three-way interaction of government, business and the public, given the complexity of economic, environmental and social issues to be tackled. Creating a feeling of community and individual ownership of nature and the environment will produce better levels of engagement. This may be achieved through the following.

Firstly, increased access to quality green and blue natural environments, as well as public open spaces, will promote engagement in nature. This means enhanced efforts towards building sustainable, safe, accessible, equitable, and climate resilient cities through SMART City technological applications, or by rethinking how we see cities in the context of the natural environment. For example, future cities may move beyond merely adding green space to existing grey infrastructure to consider a broad spectrum of ecosystem services (Ahern et al., 2014; Peters, 2020; Plummer et al., 2020; van de Ven et al., 2016;).

There is an opportunity to capitalise on the behavioural changes which have emerged from COVID-19, where people have enjoyed cleaner air and less noise, and rethink how we use and engage with natural and built environments to minimise the risks of future pandemics spaces (Plummer et al., 2020). The greening and bluing of cities provides an indirect means by which to provide educational extension or outreach programs to citizens on the benefits of nature.

Secondly, increased education and public conversations on the drivers of EIDs, including relationship with land use change, climate change and environmental degradation. Several recent, international reports, press releases and interviews with experts have been profiled in the popular media (e.g., Beer, 2020; Taylor, 2020; Vidal, 2020), allowing members of the public to join the dots between land use change, wildlife trade, land degradation, climate change and EIDs (Armstrong et al., 2020; Woolaston, 2020). The experience of other global health challenges, such as maternal and newborn health, has shown that awareness raising among the general public is often the first step in catalysing change (O'Connor et al., 2019). To date, awareness raising campaigns for zoonotic diseases have tended to focus on knowledge of specific diseases and their transmission routes (e.g. rabies, leptospirosis) (e.g., Steneroden et al., 2011; Hasanov et al., 2018); great potential exists to expand public education around the land use drivers of EIDs and more broadly, the 'one health' concept (acknowledging the links between human health, environmental health, and socio-economic systems).

Thirdly, increase research on the public health aspects of EIDs and living in dense cities, given that equating dense living with disease spread is too simplistic. Virus transmission occurs easily across large spatial divides given our highly mobile lifestyles, and shifting to less dense and greater urban sprawl will mean greater urban encroachment in natural areas (Adlakha and Sallis, 2020). Whilst our world may have changed for good, public health debates on what is safe, and what is not, are not well understood. Public transport, for example, has been severely affected as users fear a high risk of potential viral transmission. This is despite research showing that appropriate public health measures and the application of advanced digital technologies can make public transport safe (Ardila-Gomez, 2020; Quiros, 2020). Instead, greater research is needed in the area of public health to understand the factors of greater importance for disease containment and 'flattening the curve' once an outbreak occurs. For example, even in the context of the effectiveness of simple measures such as wearing masks, social distancing in public and regular cleaning.

7. LSI5: Integrated effort to address climate change, pollution and land degradation

Given the demonstrated links between climate change, air and water pollution, land degradation and the emergence of infectious disease (Martinus et al., 2020; Hodges and Tomcej, 2016; Boelee et al., 2019; Short et al., 2017), it would be remiss not to call for an integrated approach across all levels of government, civic society and industry to address these challenges as a key strategy in reducing the potential for future pandemics.

This LSI aims to contribute to the slowing down of land use change and climate change that ultimately drive EID outbreaks. Our proposed interventions stem from an understanding that the choices that we make today around consumption, production, energy use and land use will have a significant impact on the trajectory of climate change, and associated health risks. As such, this LSI works the model in the following ways.

Firstly, it acknowledges that climate change increases the future risk of pandemics directly as well as indirectly through increased extreme events, which alters the landscape that humans normally live in to bring them closer to wildlife and novel viruses. Therefore, renewing the integrated effort across government, business, and civic society to address greenhouse gas emissions, air pollution, and land degradation, all factors linked to human induced climate change (see box 6 Figure 1), is essential to minimising EID risks to humans.

Secondly, land use changes are a major driver of EIDs through impacts on land degradation, biodiversity habitat, and pollution (Keesing et al., 2010). Changes in water and air quality can provide breeding grounds for disease vectors (Boelee et al., 2019). In addition, climate change has complex effects on seasonal weather patterns, shifts in mean temperatures and rainfall, and the occurrence of extreme weather events. These all will, in turn, change the distribution of many mammals or other species, increasing the chances of first encounters between different animals that have not previously shared viruses (Carlson et al., 2020). If this brings these animals in contact with humans, or with domestic animals that are in contact with humans, the risk of EID spilllover events to humans increases.

Thirdly, climate change and air pollution compound the risks associated with EIDs by increasing the severity of EID outbreaks and their impacts (particularly in already-vulnerable regions) (Domingo and Rovira, 2020). That is, conditions under which we live will influence our vulnerability to disease outbreaks. Regions where there is high levels of air pollution or extreme events which displace normal living conditions (floods, droughts, etc.) will impact the health of people living in these regions, and therefore their capacity to withstand disease and contain outbreaks. Activities or strategies to minimise environmental degradation and the occurrence of climate change events will produce better socio-economic living and working conditions, which will decrease the vulnerability of people to disease outbreaks. As such, this LSI works to reduce the number, distribution, and severity of disease cases if a spillover event occurs.

7.1 Policy levers that may be applied to achieve change

There are several ways that an integrated approach to addressing climate change, pollution and land degradation might reduce the overall risk of contact between humans and EIDs.

Firstly, the economic recession caused by the COVID-19 pandemic offers governments a unique opportunity for 'green recovery' stimulus packages aimed at initiatives to lower greenhouse gas emissions, pollution, and land degradation. The global response to the COVID-19 pandemic has already led to a reduction in greenhouse gas emissions and air pollutants (Forster et al., 2020). An economic recovery that consists of investments in coal, oil, and gas could result in significantly higher emissions (and subsequently reducing our chance of meeting Paris Agreement objectives (Forster et al, 2020). Conversely, investments in, for example, higher energy efficiency of buildings, renewable energy industries, industrial development of electric vehicles can aid economic recovery as well as reducing carbon emissions and pollution. The Carbon Brief's 'Green Recovery' tracker provides an interesting overview of what this looks like around the world across several sectors including agriculture, building construction, transport and energy and employment (Evans and Gabbitiss, 2020).

Green recovery includes both short-term fiscal stimulus as well as long-term public spending to support private sector green innovation and infrastructure (including smart grids, mass transit systems, and charging station networks) and pricing reforms (pricing carbon, removing fossil fuel subsidies) to transform to a low-pollution, low-carbon economy (Barbier, 2020). While it may be politically expedient to relax environmental standards to stimulate development and prop up energy-intensive industries, such as construction or transport, doing so without requiring fundamental changes to our economic systems would "*essentially subsidise the emergence of future pandemics*" (Settele et al., 2020). National fossil fuel subsidies present another substantial obstacle to green structural transformation in G20 economies [9], fundamentally undercutting investments in clean energy development (IMF, 2019). As such, COVID-19 has presented a moment of pause to reassess current systems and put into place initiatives to minimise the risk of future EIDs.

[9] The Group of 20 (G20), the world's richest and largest economies.

Secondly, increasing recognition of the linkages between carbon emissions and natural disasters have led to multiple governments' and businesses' emission pledges. On the back of heatwaves, bushfires, and disease outbreaks, Japan and South Korea committed to be carbon-neutral in 2050 (announced on October 26 and 28, 2020), while private and semi-private corporations have also endorsed net zero emission targets (AEC, 2020; ANZ, 2020; The Guardian, 2019; Walmart, 2020). These are changes which will lessen the impact of human induced climate change, thereby reducing the risk of EIDs to humans. Such initiatives need to be encouraged through regulatory incentives (e.g. lower taxes for lower emitters) and platforms where corporations can make their pledge, find information on how to achieve their targets, and report on their progress (e.g. www.theclimatepledge.com; climateaction.unfccc.int). Civil society has a role to play in demanding action from governments and companies, with research showing that society worries deeply about climate change (Quicke and Bennett, 2020). Therefore, as private businesses begin to respond to consumer demands for more sustainably produced goods and services, government policies need to follow the trend.

Thirdly, consumers can reduce everyday resource (carbon, water, land, material) footprints by changing our consumption (see LSI1) and the way in which we conduct businesses. This includes reduced local, national and international travel (Renew Economy 2020), reduced physical business footprints, and transitioning to alternate modes of production and communication. Companies and staff will need to explore alternative ways of conducting business as industry realises the efficiencies and cost savings garnered with greater stay at home workforces, rotating on-site staff, virtual meeting spaces and other forms of connection. The fact many people around the world have continued to be productive (if not more) despite working from home, may lead to a greater work location flexibility post-COVID-19 (Boddy, 2020; Harper, 2020; Schrotenboer, 2020). Indeed, tech giants such as Facebook, MasterCard, Google, Amazon and Twitter are looking to extend working-from-home arrangements long term (Bartleby, 2020; Harper, 2020).

It is predicted that working from home will allow more people to live in rural areas and work from home far from their 'office' (Purtill, 2020), as well as altering leisure and business air travel forever (Reed, 2020). This will change land use patterns, particularly in inner cities, and the infrastructure needs across the city, with consequently lower greenhouse gas emission and pollution.

8. Conclusion

Whilst we may like to think that pandemics are rare events, our vulnerability to novel disease outbreaks has long been predicted. COVID-19 has highlighted large variations in its impact on different populations, with case mortality ratios ranging from 1.5% to 10.1% being dependent on aspects such as health systems, infrastructure, poverty and preparedness (cf. Johns Hopkins University of Medicine, 2020b). In addition, there is the phenomenon of the 'long-COVID' being the development of chronic long term complications to contraction, which will continue to impact populations in the future. The knowledge that new novel viruses continue to emerge has had a sobering effect on humanity, and provided an opportunity to pause and reassess our own role in EID spillover events and global transmission pathways. Therefore, whilst understanding how to *flatten the curve* or contain pandemics, such as COVID-19, and treat patients that contract novel viruses are important, a key strategy is to prevent them in the first place – or at least minimise the risks.

Drawing on previous literature modelling the relationships between human-induced land use change, climate change and the emergence of pandemics, this report focuses on articulating more clearly the link between human activities and increases in novel disease cases at the community level. Drawing on the 'DPSIR' model (Driving Forces, Pressures, State, Impacts and Responses) to understand society-environment interactions, we discuss how alternative behaviours or decision-making by citizen, industry and government across the globe could reduce this risk. These alternative behaviours or decision-making are contextualised within five *land stewardship interventions* (LSIs) which act to disrupt the drivers, pressures and states of the model, thereby alleviating or minimising factors leading to disease case emergence and distribution (the impact). Each LSI affects the model in different ways, but similarly targets the reduction in the risk of human activities exacerbating climate change, land degradation, and land use change – as the key factors linked to EIDs (cf. Martinus et al., 2020).

The model highlights how the *local* decisions of consumers and producers in one part of the world influence land use changes somewhere else. Indeed, intense globalisation and technological development over the past 100 years have transitioned us to be highly connected world-wide through global value chains linking consumption and production across diverse locations, cultural contexts, and economic situations. In this way, the LSIs offer a set of *call to action points* which relate at global, national, city, *and* individual levels, and provide a way to minimise the risk of EID emergence in a globally connected world.

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