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Key policy interventions to limit infectious disease emergence and spread

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The COVID-19 pandemic provides a salient backdrop to consider what many experts across public health, conservation, and biology have long highlighted: that land use change, environmental degradation, habitat loss, and climate change contribute to outbreaks of emerging infectious diseases. Drawing on literature from across a range of disciplines, we present a conceptual model that shows how human-environment interactions and decisions by citizens, industry, and governments can drive disease emergence and spread. We suggest that local consumer and producer decisions at one location can have ramifications that extend around the world and lead to land use changes in other jurisdictions which could amplify or reduce the likelihood of novel disease outbreaks. Moving beyond the immediate health impacts and changes to healthcare systems, we propose that the long-term legacy of COVID-19 could be one that turns global society toward more socially, economically, and environmentally sustainable ways of production, consumption and landscape management through five "Key Policy Interventions."

KEYWORDS

consumer decisions, DPSIR model, economic geography, emerging infectious diseases, pandemics

1 Introduction

COVID-19 has transformed social and economic linkages globally and has heightened awareness of human vulnerability to novel pandemic diseases. Outbreaks of emerging infectious diseases (EIDs[1]) have been linked to human activity, environmental degradation, and climate change (Patz et al., 2008; Lambin et al., 2010; Morse et al., 2012; Rohr et al., 2019; Dobson et al., 2020; Everard et al., 2020; Gibb et al., 2020; Martinus et al., 2020; White and Razgour, 2020). Such links have also been documented for disease spread throughout human history. For example, the bubonic plague or Black Death travelled from Asia along the Silk Route to Europe (Schmid et al., 2015) leading to the fall of Ancient Rome (Harper, 2017). This example provides interesting insights into how the integration of otherwise dispersed societies and communities through trade and migration enabled the spread of disease. The significantly more integrated nature of modern societies has made disease spread a much more *global* event, as exemplified by the COVID-19 pandemic.

1 An EID is a disease which has increasingly infected humans over the past two decades or will do in the near future (van Doorn, 2014). It may be new or previously present having remained undetected and rapidly increasing in terms of numbers or geographic spread (WHO, 2014).

The experience of living with COVID-19 has reminded us of the importance of understanding how human activities at the global scale increase the risk of zoonotic spillover to humans and the spread of EIDs. It has also caused us to consider how alternative behaviours and decision-making at the global scale could reduce this risk (IPBES, 2020; White and Razgour, 2020; Bernstein et al., 2022). Drawing on conceptual understandings from human geography, public health, and environmental science, we show how global consumption and production can amplify local land use changes and environmental degradation, which in turn increases the risk of local spillover events and the geographic spread of zoonotic diseases. Based on our conceptual model, we identify key policy interventions (KPIs) for modifying upstream drivers of land use change, environmental degradation, and climate change, as a platform for policy reform that could reduce future risks of the emergence and spread of novel infectious diseases.

2 Linking local disease outbreaks to global processes: A conceptual framework

Previous studies highlighting the links between land use change, agricultural activities, and EIDs have largely focused on localized human activities, with an emphasis on local or regional drivers, policies, and management actions as a means to reduce disease emergence and spread (e.g., Patz et al., 2004; Lambin et al., 2010; Cumming et al., 2015; Hassell et al., 2017; Mastel et al., 2018; Rohr et al., 2019). Research to date has focused on mitigating land degradation in lower income nations, as this is where spillover events are most often recorded, and where biodiverse habitats are undergoing rapid land-use change (for example, Allen et al., 2017; Brierley et al., 2016; Carlson et al., 2021; Martinus et al., 2020; Morse et al., 2012; White and Razgour, 2020). However, the interconnectedness of economic production and consumption processes across the globe means that the pressures on a small region in a low or lower-middle income nation to produce low-cost agricultural or manufactured goods must be contextualised by global consumption demand and preferences. Accordingly, many authors have argued for greater understanding of global and regional level economic drivers of change (Patz et al., 2004; Wood et al., 2012), as local production is merely one component of broader global production systems (Saxenian, 2002; Coe et al., 2004; Murphy, 2012; Coe and Yeung, 2015). Growing consumer demand for goods and services, economies of scale, and pressure to lower prices influence the spatial distribution and governance of global industry production networks. Product supply chains now require and often inadvertently dictate that land be available for production, storage, logistics, and distribution in different locations across the world.

To help inform decision-makers, we argue that there is a need to visualise how consumption and production decisions contribute to future risks of new EIDs - any of which could be as disruptive or more disruptive than COVID-19. Building upon existing comprehensive research across multiple disciplines, we draw on the widely-understood DPSIR framework (**D**riving Forces, **P**ressures, **S**tates, **I**mpacts and **R**esponses, e.g., Everard et al., 2020) to conceptualise how global processes (driven by the everyday urban consumer, climate change, and land use change) influence the emergence, transmission, and distribution of EIDs in the context of public health (Figure 1). Our model identifies feedback mechanisms and policy interventions which can alter the cause-effect chains linked to EID emergence and spread.

In the sections that follow, we outline and clarify the components of our conceptual model, in turn exploring each of the components of the DPSIR framework, all of which fall within the umbrella of public health. We conceptualise public health as a means to: 1) control and mitigate disease spread and; 2) design landscapes and processes across local and global scales for positive health outcomes and to prevent disease outbreaks. Public health responses need to be tailored to where they can be most effective and embedded across the cause-effects of the model.

2.1 Driving forces

The increasing demand for local resources (e.g., human capital, land, water, energy, and materials) needed for industrial production leads to human encroachment into previously ecologically intact areas of the natural world. This contributes to land degradation and climate change, both of which increase human exposure risk to novel EIDs. Rising global population and *per capita* consumption are therefore some of the important Driving Forces of local land use change and anthropogenic climate change producing Pressures within the system that can lead to disease outbreaks (see also Everard et al., 2020; Bernstein et al., 2022).

2.2 Pressures

Pressures from land use changes through land degradation, habitat fragmentation, deforestation, land and water pollution and urban encroachment into natural habitat alter species habitat and the human-wildlife interface. Anthropogenic climate change is also linked to EIDs through changing wildlife habitats and because 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 (Engelthaler et al., 1999; Epstein, 2001; Semenza and Menne, 2009; Harrigan et al., 2014; Bouchard et al., 2019; Ludwig et al., 2019). Authors who have examined these links (Rogers and Randolph, 2000; Molnár et al., 2013; Parham et al., 2015; Wu et al., 2016; Ryan et al., 2019; Everard et al., 2020) identify some of the socio-economic mechanisms through which human activities drive climate change and, consequently, lead to more (or less) EID events.

2.3 States

Altered habitat and environmental States—such as reduced biodiversity, reduced forest cover, increased contact between species that may have otherwise never met, and altered weather patterns–may increase the risk of local spillover events and be major drivers of EIDs (Keesing et al., 2010). These altered States place human beings at risk of coming in contact with novel diseases. For example, changes in water and air quality can provide breeding

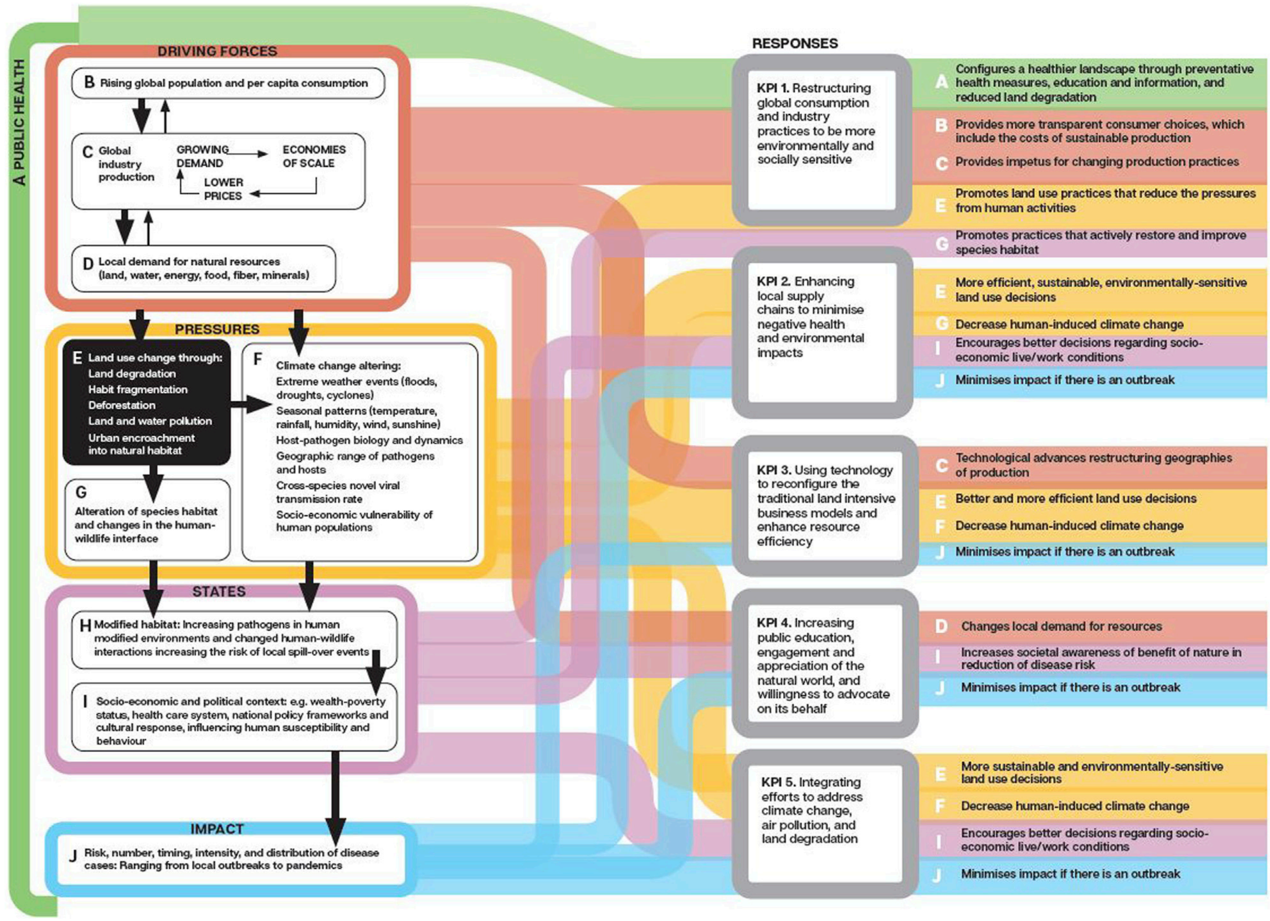

FIGURE 1
A conceptual model illustrating how global processes, climate change and land use change interact to increase the risk of emergence and spread of infectious disease. The model uses the DPSIR (**D**riving Force-**P**ressure-**S**tate-**I**mpact-**R**esponse) framework and shows five key policy interventions as the responses to reduce risk.

grounds for disease vectors (Boelee et al., 2019), and extreme weather events may change species distributions to allow first encounters between animals with different pathogens (Carlson et al., 2021). Furthermore, climate change and air pollution compound the human EID exposure risks by increasing the severity of EID outbreaks and their Impacts, particularly in already-vulnerable regions (Domingo and Rovira, 2020).

2.4 Impacts

The Impact of heightened ***EID risks*** (number of cases and distribution of disease) is associated with an individual's or community's socio-economic and political context (an element of State in Figure 1). Indeed, poverty or socio-economic disadvantage are key social determinants of susceptibility as risk of infectious disease increases with reduced access to safe water and sanitation, education, nutrition, healthcare and housing, employment in more hazardous work (Schneider et al., 2015; Landrigan et al., 2018), higher levels of underlying health conditions, and economic vulnerability (Butler-Jones and Wong, 2016; Rutherford and Unruh, 2019; Platt and Warwick, 2020). It also impedes participation in civil society and political processes, limiting influence to improve communities (Landrigan et al., 2018).

2.5 Responses

The causal links between the Driving Forces, Pressures, State of the environment and Impacton human health have been well-documented for EIDs (Hambling et al., 2011; Boelee et al., 2019; Everard et al., 2020). Thus, enacting Responses—in the form of policies and other actions - at various points within the conceptual model will reduce conditions favouring EID outbreaks and pandemics. In our conceptual model, we frame the Responsesas five Key Policy Interventions, which are expanded below.

3 Key policy interventions

Five key policy interventions (KPIs) are proposed to alter the cause-effect pathways identified in the model, reducing the likelihood and severity of future EID emergence and spread (Figure 1). We explain these KPIs and detail some example policy levers that are open to decision-makers.

3.1 KPI 1: restructuring global consumption and industry practices

Given our global connections through high human mobility and trade, consumption and production decisions made in one location will have effects elsewhere. What occurs through a product's extraction, harvest, or manufacture stages is often opaque, and not easily interrogated by consumers living in an entirely different geographic and cultural context. Consumer choices can drive global production practices, with the collective purchasing power of increased demand providing an incentive to switch to production land use practices that actively restore and improve species habitat, which will reduce EID emergence. KPI 1 emphasises increasing transparency and knowledge around environmentally and socially sensitive global production, to allow more informed consumer choices. Consumers who are more affluent or those concerned with ethical production practices may choose to pay more for certified produce and purchase lower volumes of non-certified goods.

3.1.1 Policy levers

- Targeted research and government campaigns to raise consumer awareness of the impacts of their consumption decisions. Better informed consumer choices have the potential to reduce the environmental footprint of products which lead to the destruction of natural environments, and increase the risk of human contact with novel viruses (Ostfeld et al., 2019; van Noordwijk et al., 2022).
- Improved labelling policies to encourage certification schemes and provenance of goods and services to reduce consumption related to activities which increased EID risk, e.g., reducing demand for trade of live and recently killed wildlife through 'wet markets' (Volpato et al., 2020; Bernstein et al., 2022). Certification schemes work to improve transparency of social and environmental conditions under which commodities are sourced and sold, thus providing guidance to consumers and producers (DeFries et al., 2017; Oya et al., 2018).
- Altered government and businesses initiatives and polices around procurement policies to increase the market share of certified products (e.g., OECD, 2015; White, 2019).

3.2 KPI 2: enhancing local production

Currently, global production networks are key sources of many nations seeking low-cost goods and services. But, there is often a trade-off between cheap production and weak environmental and occupational regulation, resulting in environmental degradation and poor industry practices (Brown et al., 2003; Li and Zhou, 2017). KPI 2 does not advocate for the dismantling of global production networks but suggests policy levers to enable more informed and sensitive consumer choice to reduce environmental impact by encouraging local consumption. During COVID-19, there was shift towards more localised consumption, increased environmental local activism, local pride and desire to support local business (OECD, 2020; WTO, 2020).

The policy levers of KPI2 also encourage a national stock of critical goods and services. This can minimise the impacts of global supply shortages, reducing the exposure of citizens during an outbreak and therefore the final impact of disease emergence. COVID-19 highlighted that national production of essential goods to meet local demand is important to assure health, energy and food security (OECD, 2020) which affect community disease and exposure levels.

3.2.1 Policy levers

- Increased national priorities on securing local food, goods, and energy supply, e.g., via subsidies, encouraging local content requirements, and investment policies (OECD, 2020).
- Greater support for bottom-up community led approaches, such as local neighbourhood food production providing insurance in crisis situations and financial, social and psychological benefits to local communities (Soga et al., 2017; Rose and Gaynor, 2018; Blum et al., 2019; Carey et al., 2019), while local seed banks can supply seeds to communities (Vernooy et al., 2014; Song et al., 2021).

3.3 KPI 3: reconfiguring business land-use and efficiency through technology

The further products travel to reach consumers, the more land is used for various activities, greenhouse gases are emitted during transport, and the less connected a consumer is to where a product has come from, how it is produced, or the full environmental impact of its value chains. This does not allow consumers to make informed choices of the products they buy. KPI 3 focuses on supporting technology and innovation to reconfigure how businesses, consumers, and government connect across space, enabling greater production efficiencies and 'green' choices in business operations.

3.3.1 Policy levers

- Facilitate technology adoption and market access through policy and provision of ICT infrastructure.
- Encourage research in how other technologies and applications can directly connect producers and consumers, such as crowdfunding (Becker, 2016; Markovich, 2016; Dunford, 2018) or on-line food boxes (My Foodie Box, 2022) (You Plate It, 2022).
- Support for the sharing economy such as co-working places or rideshares (e.g., WeWork, GreenWheels, GoGet, Hipcamp), including regulations on health and safety in the context of social distancing (e.g., for public transport), to unlock a more efficient use of private resources and to address issues of climate change (Buheji, 2020; Whitney, 2020; Meenakshi, 2021). This will decrease demand for non-sharing type land developments, increasing sustainable land-use choices.
- Support for production technologies that increase land use efficiencies or reduce human contact (and disease transmissions) such as vertical farming (which decreases

demand for land clearing), automated harvesting, or roboticised abattoirs (Henry, 2020; McClements et al., 2021).

3.4 KPI 4: public education and engagement with the natural world to encourage consumers' behavioural change

The post-industrial era has seen human disengagement from the natural world and unsustainable consumption (Miles, 1998; Heald, 2017), despite publicly available research on the positive impact of nature on health and wellbeing and rising global concerns around climate change and environmental degradation. During COVID-19 lock-downs, citizens reported that staying at home meant a rediscovery of the value of spending time in, and advocating for, nature and natural areas (Smith, 2020; Roll et al., 2021). Pandemics provide an opportunity for a lifestyle pause and rethink of societal values around nature. The promotion of green and blue space, and increased environmental advocacy by the public, can translate into more sustainable consumption behaviours. In the long terms, this will minimise environmental impacts and improve community physical, social, and psychological wellbeing (Koohsari et al., 2015; Wood et al., 2017; Kaplan Mintz et al., 2021).

3.4.1 Policy levers

- Increase community access to quality green and blue natural environments, as well as public open spaces, to promote engagement with nature and indirectly provide educational extension or outreach programs on the benefits of nature. This could involve a quota on public open spaces, "rewilding" of cities, water sensitive urban design, and biodiversity sensitive urban design.
- Encourage education and public conversations on the drivers of EIDs, to promote understanding of the "one health" concept and the links between land use change, wildlife trade, land degradation, climate change and EIDs (Bernstein et al., 2022). Awareness raising among the general public with evidence-based information is often the first step in catalysing change (O'Connor et al., 2019).

3.5 KPI 5: integrating systems and efforts to address pressures

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; Karan et al., 2020; Isphording and Pestel, 2021). Minimising EID risks will require approaches coordinated across government, business, and civic society to jointly address greenhouse gas emissions, land use changes, and land degradation—all which negatively impact the natural environment, potentially created novel human-virus interaction. Activities or strategies to minimise environmental degradation and the occurrence of climate change events will produce better socio-economic living and working conditions, decreasing the human vulnerability to disease outbreaks.

3.5.1 Policy levers

- The use of "green recovery" economic stimulus packages to lower greenhouse gas emissions, pollution, and land degradation (e.g., African Union, 2021). This includes investments in higher energy efficiency of buildings, renewable energy industries, industrial development of electric vehicles (Evans and Gabbatiss, 2020), as well as green innovation and infrastructure (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).
- Facilitating the shift to low footprint workforces and lifestyles to reduce everyday resource use (energy, water, land, material). This includes reduced physical business footprints (more working from home, rotating on-site staff), and transitioning to alternate modes of production and communication (less travel, more virtual meetings). Changing work styles will change lifestyles as more people work and live in rural areas while working from their home offices, leading to changed land use patterns and infrastructure needs (Lee et al., 2014).
- Fund research and technologies on the public health aspects of air quality and disease transmission in densely populated cities. It is well known that air pollution increases the risks of lower respiratory infections and affects the severity of disease (Wu et al., 2020). Additional research is needed to understand the immune response to different sources of air pollution (Horne et al., 2018), while environmental policies and technology investments should target long-term pollution levels (e.g., through alternatives to fossil fuel vehicles or stoves, installation of indoor air purifiers; Isphording and Pestel, 2021).
- Renewal of government and businesses emission pledges given proven linkages between carbon emissions and natural disasters (e.g., AEC, 2020; The Net Zero Asset Managers initiative, 2020; The Investor Agenda, 2022). This is includes 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., theclimatepledge.com; climateaction. unfccc.int).

4 Discussion

Intense globalisation and technological development, particularly over the past century, have generated highly connected global value chains linking consumption and production across diverse locations, cultural contexts, and economic situations. Rising global population and consumer demand are placing increasing pressure on the natural world, with land degradation, climate change, encroachment of natural habitats, and human-wildlife interactions increasing the risk of novel virus emergence. Pandemics, such as COVID-19, provide pause to consider how consumption and production drivers and choices could lead to EID spillover events and global transmission.

A huge wealth of high-quality research exists on the factors that increase the risk of new EIDs. This existing body of research crosses many fields, and can be very technical in nature. We propose that the development of a concise, clear framework linking driving forces, pressures, impacts, states and responses with everyday decisions around consumption and production can aid decision-makers in formulating policies to help build more sustainable and equitable communities, and reduce the risk of future EIDs. Our model provides such a framework, highlighting how global drivers and local consumption decisions are connected and can put pressure on the environment to enable EID spillover events. Our five key policy interventions provide practical decision mechanisms to minimise the risk of future pandemics.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

Author contributions

KM, NP, and MK contributed equally to the conceptualization, writing, revision and graphic design. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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