ISSN 2398-5496

Vol 4, No 2, 2020

the journal of population and sustainability

Information

ISSN 2398-5496

The Journal of Population and Sustainability (JP&S) is an open access interdisciplinary journal exploring all aspects of the relationship between human numbers and environmental issues. The journal publishes both peer reviewed and invited material. It is intended that the JP&S act as an interdisciplinary hub facilitating collaboration and furthering the development of the field. While published by environmental charity Population Matters, the JP&S is editorially independent and welcomes contributions from scholars with a variety of perspectives on the role of population in environmental problems. The views and opinions expressed by authors are their own and do not necessarily reflect those of the editor, the editorial board or publisher.

www.jpopsus.org

Submissions:

We invite contributions from the social sciences, humanities, environmental and natural sciences including those concerned with family planning and reproductive health. We also invite contributions from those working for NGOs with interests in population and environmental issues. We are interested in publishing original research papers, reviews of already published research, opinion pieces and book reviews.

For submission details please see our website: **www.jpopsus.org**

Acknowledgements:

The editor would like to thank Hilary Anderson, Bill Anderson-Samways, Peter Slater and our anonymous reviewers for their help in producing this issue.

Design by Clare Thornhill www.flidesignltd.com

The Journal of Population and Sustainability

Vol 4, No 2, 2020

Contents

Editorial introduction 5
DAVID SAMWAYS

Disaster vulnerability by demographics? 17
ILAN KELMAN

Endangered species condoms: a social marketing tool for starting conversations about population 31
SARAH BAILLIE, KELLEY DENNINGS & STEPHANIE FELDSTEIN

Anticipating urbanization-led land cover change and its impact on local climate using time series model: a study on Dhaka city 45
RIPAN DEBNATH

Measuring net environmental impact from population growth and alternative energy 67
TRAVIS D. EDWARDS & LUIS GAUTIER

Book review: *The urban fix – resilient cities in the war against climate change, heat islands and overpopulation* by Doug Kelbaugh 89
JENNY GOLDIE

Editorial introduction

David Samways – Editor

The eighth issue of the JP&S is published in the midst of the COVID-19 crisis. The JP&S will in due course have a special issue devoted to the role of population in pandemic risk, but for the present it is worth reflecting on how COVID-19 and global pandemics in general relate to population and environmental issues and in particular to some of the themes covered by the papers (mostly written well before the pandemic) in this issue.

The immediate impact of the pandemic and its management have rightly been the focus of concern, but the factors which led to the generation of the pandemic itself are also of great importance given the costs in terms of both human health and disruption to the lives of billions of people. The causes of the pandemic are multiple, but population growth and density are amongst the most significant. Along with specific consumption factors, the globalisation of the world economy and other elements of our socio-technical systems, the ever-growing entanglement of human populations with wild species has played a pivotal role in the generation of the current crisis.

As Ilan Kelman points out in his paper published here, the current pandemic is, like many so-called 'natural' disasters, not 'natural' at all but the result of our societal choices. In the case of COVID-19, the choices which have been significant are not limited to how we have dealt with the spread of the disease, but also include choices made in other spheres such as the economy, international development, socio-technical structures and so on that formed the unacknowledged conditions which facilitated the generation of the pandemic itself. At the micro level, many of these 'choices' may have been passively made, the outcome of deeply embedded social practices and ways of life, the taken-for-granted aspects of everyday life. For many of those whose direct entanglement with the natural world exposes them to zoonotic reservoirs, the social practices in which they are engaged are frequently well beyond the level of active choice. It is often the rural poor of the Global South who are most exposed as population growth and poverty lead them to clear forest and establish subsistence cultivation only to be later displaced by commercial interests (Carr, 2009; Lopez-Carr and Burgdorfer, 2013; Kong et al., 2019).

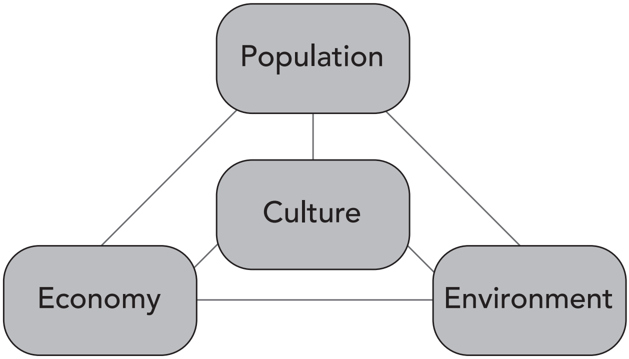
The trade in wildlife for bushmeat, traditional "medicines" and other cultural practices is also a factor in the spread of zoonoses. COVID-19 is believed to have originated in bats with the Malaysian pangolin, trafficked for use in traditional Chinese medicine, as an intermediary species (Ye et al. 2020; Wong et al. 2020). Among the many factors identified as drivers of the illegal wildlife trade, economic growth and globalisation are critical. In more developed countries the combination of population growth, urbanisation and increased affluence has fuelled demand while in poorer regions population growth and rural poverty are drivers of supply. Importantly, supply and demand have been connected by improved roads to formally inaccessible wilderness locations and trade routes to far away markets (Wolfe et al. 2005; Nijman, 2010; Rosen and Smith; 2010).

However, it would be mistaken to regard population, consumption (affluence), and technology (transportation systems)[1] as simple drivers of our entanglement with nature and its associated risks. As Joel Cohen (2017) has argued, culture is a critical factor in how population, the economy and the environment articulate with each other (Fig. 1). Duffy et al. (2016) have argued that in respect of the hunting of endangered wildlife, poverty[2] has been poorly conceptualised and that the motivations of individuals and social groups to hunt have frequently been reduced to an economic rationality. However, as they demonstrate, motivations for hunting often arise from deeply embedded social and cultural factors and that policies aimed at reducing hunting through financial incentives frequently fail or even unintentionally increase the ability to hunt or consume bushmeat.

1 As per Holdren and Ehrlich's (1971) impact = population x affluence x technology (IPAT).

2 Dufy et al. do not connect poverty with population growth, however it is nonetheless a crucial dimension (UNFPA 2014).

Figure 1. Joel E. Cohen's (2010) tetrahedron conceptualising the interactions between population, environment, economy and culture.



As a driver of human entanglement with nature, population growth itself also has important socio-cultural dimensions which are not generally modelled in standard demographic transition approaches where economic development is seen as the primary determinant of reduced fertility. In addition to the availability of sexual health services, female education, and the general reduction in poverty, social norms surrounding family size are an important determinant of fertility (Dasgupta and Dasgupta 2017). Influencing these social norms and fertility choices can take a variety of forms and social marketing methods have been employed successfully by the Population Media Centre (see Ryerson 2018) and are the subject of Sarah Baillie, Kelley Dennings and Stephanie Feldstein's article on the Centre for Biological Diversity's (CBD) Endangered Species Condom project in this issue.

As Baillie et al. show, social marketing is a means of "selling a social good as if it were a commodity". This structured, theoretically informed, approach has been successfully employed to address a range of social problems (notably to increase contraceptive use in India) and is employed by CBD not just as a means of reducing unplanned pregnancy in the US, but also to start a conversation about the impact of population growth on endangered species. Innovatively, Endangered Species Condoms use humour and art to connect sexual health choices with native wildlife species which are threatened directly by population growth. CBD recognises that in the US population growth is largely a consequence of immigration, but while the project is aimed at local reproductive choices the objective is global in that the project elevates the environmental consequences of population growth in public discourses with the aim of ultimately influencing policy makers and, equally importantly, the environmental NGOs which generally choose to ignore the issue.

Ilan Kelman's paper is concerned with the ability of society to cope with disaster. He argues that the vulnerability of a society to the environment or nature is consequent on societal choices which place people in harm's way. Demographic factors including population density can have both positive and negative effects. While high density urban areas are more likely to have emergency services that are experienced and well equipped, larger and more closely confined populations, as in the case of COVID-19, can exacerbate risks. As Jenny Goldie's review of Doug Kelbaugh's *Urban Fix* (published here) makes clear, the redesigning of the city may well offer opportunities for mitigating climate change and overpopulation. However, Kelbaugh's enthusiasm for high density urban living may be in question following the pandemic. With population density being a key factor in the spread of the virus, many who have become acclimatised to home working may well be reassessing the advantages, costs and risks of urban living.

Worldwide, populations are moving from rural to urban locations and it is this internal migration that accounts for the majority of all the world's migration (IOM 2020). Currently, just over half the global population live in urban areas, but it is anticipated that by 2050 this number will rise to 68% (UN, 2018). The COVID-19 pandemic has made the extent of internal migration extremely clear as migrant workers lose their livelihoods and, en masse, have been forced to return to their region of origin. The International Labour Organisation estimates that 1.6 of the 2 billion people who work in the world's informal economy (nearly half the global workforce) have been severely affected by the pandemic lockdown. The majority of these workers are in the Global South with women being disproportionately affected compared to men (ILO, 2020).

This latter aspect of the consequences of the pandemic chimes well with Ilan Kelman's observations regarding the gendered dimensions of disasters. In terms of fatalities men appear to be disproportionately affected by COVID-19 (Jin et al. 2020), but evidence suggests that in social and economic terms women will be disproportionately affected (ILO, 2020; UN, 2020). Kelman argues that it is gender differentiated roles rather than inherent qualities that frequently make women more vulnerable to disasters. This is certainly the case with the consequences of COVID-19: women generally earn less and save less than men, they are often in more insecure employment, are more likely to be heads of single parent households, the burden of unpaid care work largely falls on them, and on top of this they are more likely to experience greater levels of domestic violence during lockdown. From the perspective of population growth the disruption to sexual health services may result in increased fertility. In the Caribbean and Latin America it is estimated that 18 million women will lose regular access to contraception as a result of the pandemic (UN, 2020). The disruption to sexual health services represents an immediate threat, but the economic impact upon women in the Global South represents a longer-term risk of stalling the progress made on increasing fertility choices.

The role of internal migration on urban expansion and population density are themes of Ripan Debnath's contribution to this issue. Exploring the effect of land use change on local climate in Dhaka, Bangladesh, Debnath models the impact of rural to urban migration on the rapid growth in Dhaka city and shows, through the analysis of satellite images and geographic, demographic and climatic data, that such growth will adversely impact the future urban climate. While influenced by global and regional climate change, local land cover change will be an additional exacerbating factor. Land use change from agricultural to urban will result in both heat stress and flooding which will disproportionately affect the most recent and poorest migrants who tend to live in low-lying areas. Like Kelman and Kelbaugh, Debnath argues that the worst effects of such disasters can be avoided with the right urban planning policy choices. However, like Kelbaugh, Debnath sees so called 'smart growth' principles involving, amongst other things, higher density development as a possible solution to Dhaka's population growth. Undoubtedly, Debnath and Kelbaugh are correct about better management and higher density housing being a means of mitigating the impact of climate change, but the COVID-19 pandemic has demonstrated the adage that where it comes to environmental problems "there's no such thing as a free lunch" and the solution to one problem frequently leads to the creation of other unanticipated consequences.

Migration is also a major theme of Travis Edwards and Luis Gautier's article for this issue of the JP&S which examines the relationship between carbon dioxide emissions and population. Where previous studies have concentrated on per capita carbon dioxide emissions, Edwards and Gautier are concerned with how increases in population and the use of alternative energy sources affect total emissions in the USA where immigration is the main driver of population growth. Edwards and Gautier propose a new model where the Demographic Transition Model (DTM) (the idea that as countries develop population growth rises and then falls), and IPAT[3] are integrated into the Environmental Kuznets Curve (EKC) (the inverted U shaped graph that frequently shows that as wealth increases pollution at first rises and then falls). They argue that the concentration on per capita emissions in most of the EKC literature fails to acknowledge population growth can lead to increases in total emissions even when per capita emissions are falling. As a major contributor to the reduction in per capita carbon emissions, Edwards and Gautier go on to estimate a threshold of alternative energy generation after which total emissions may fall. Furthermore, following their proposed DTM-IPAT-EKC model, they argue that the shift in lifestyle that immigrants experience as they move from low/medium income countries into high-income countries may contribute to total emissions growth, however this will depend on the level of alternative energy present in the destination country. They suggest that at present the rate of growth of alternative energy generation in the US is insufficient to offset population growth.

Edwards and Gautier note that, since their study considered total carbon dioxide emissions rather than consumption-based emissions, future research should address this. This would raise some interesting questions since research examining the effect of immigration on CO_2 emissions tends, not unreasonably, to assume that with rising income migrant consumption conforms to the higher levels of the destination country (see for example Weber and Sciubba 2018; Cafaro and Götmark 2019). However, this assumption is open to question since it is well established that remittances from migrants to their country of origin represent around three times the value of official development aid (Ratha et al. 2016) and migrant saving levels are also significant (De et al. 2014). Such income use will have an obvious impact on immigrant consumption levels, but also shifts our understanding of migration towards a global developmental perspective. Remittances represent a significant contribution to development which can have environmentally beneficial effects (Hecht et al. 2006; Jaquet et al. 2016; Oldekop

3 See note 2.

et al. 2018; but see also Davis and Lopez-Carr for a more ambiguous account) and under some circumstances lead to lower fertility (Anwar and Mugha 2016; Green et al. 2019; Paul et al. 2019. See also Ifelunini et al. 2018 for an account of increased fertility with remittance receipt). While the impact of remittances on both environmental impact and fertility is complex and uneven it would appear that the evidence supports a potentially positive impact if other structures (education systems and sexual health services for example) are present. Again, the consequences of the COVID-19 pandemic are pertinent here. As a consequence of the lockdown and probable economic recession in rich countries, remittances to the low and middle-income countries are likely to fall as migrants lose their jobs. The World Bank (2020) estimates that remittance flows to low and middle-income countries are likely to fall by around 20% at a time when need will be greatest and foreign direct investment is likely to fall by around 35%. The longer-term impact on both human wellbeing, population growth and environmental impact will depend on the actions of countries in the Global North. The impact of COVID-19 came after the submission of Edwards and Gautier's paper, but their conclusion is prescient:

> The ability to collectively lower our environmental impact in both advanced and developing economies is vital to the future of the planet. Implementing effective environmental and economic policies which can be strategically enacted for specific stages of development, to reduce overall environmental degradation while maintaining an acceptable standard of living, is crucial to this task.

In the post-pandemic world attention to the welfare of people in developing countries is in the interest of us all.

References

Anwar A.I., Mughal, M.Y., 2016. Migrant remittances and fertility. *Applied Economics*. DOI: 10.1080/00036846.2016.1139676

Cafaro, P., Gotmark, G., 2019. The potential environmental impacts of EU immigration policy: future population numbers, greenhouse gas emissions and biodiversity preservation. *The Journal of Population and Sustainability*. 4(1), pp. 71–101.

Carr, D. 2009. Population and Deforestation: why rural migration matters. *Progress in Human Geography*, 33(3), pp. 355–378.

Cohen, J.E., 2010. Population and climate change. *Proceedings of the American Philosophical Society*. 154(2), pp. 158–182

Cohen, J.E., 2017. How many people can the Earth support? *The Journal of Population and Sustainability.* 2(1), pp. 37–42.

Dasgupta, A., Dasgupta, P., 2017. Socially embedded preferences, environmental externalities, and reproductive rights. *Population and Development Review* 43(3), pp. 405–441.

Davis, J., Lopez-Carr, D., 2010. The effects of migrant remittances on population – environment dynamics in migrant origin areas: international migration, fertility, and consumption in highland Guatemala. *Population and Environment*. 32, pp.216–237. DOI:10.1007/s11111-010-0128-7

De, S., Ratha, D., Yousefi, S.R., 2014. *A note on international migrants' savings and incomes.* [pdf] Washington D.C.: World Bank. Available at: https://blogs.worldbank.org/sites/default/files/Note%20on%20Diaspora%20Savings%20Sep%2023%202014%20Final.pdf [Accessed 15 June 2020].

Duffy, R., St John, F.A.V., Büscher, B., Brockington, D., 2016. Toward a new understanding of the links between poverty and illegal wildlife hunting. *Conservation Biology.* 90(1), pp.14-22. DOI: 10.1111/cobi.12622

Ehrlich, P.R., Holdren, J.P., 1971. Impact of population growth. *Science, New Series.* 171(3977), pp. 1212–17.

Green, S.H., Wang, C., Ballakrishnen, S.S., Brueckner, H., Bearmand, P., 2019. Patterned remittances enhance women's health-related autonomy. *SSM Population Health.* 9, 100370. https://doi.org/10.1016/j.ssmph.2019.100370

Hecht, S.B. Kandel, S., Gomes, I., Cuellar, N., Rosa, H., 2006. Globalization, forest resurgence, and environmental politics in El Salvador. *World Development*. 34(2), pp.308–323. doi:10.1016/j.worlddev.2005.09.005

Ifelunini, I.A., Ugwu, S.C., Ichoku, H.E., Omeje, A.N., Ihim, E., 2018. Determinants of fertility rate among women in Ghana and Nigeria: implications for population growth and sustainable development. *African Population Studies.* 32(2)(S.2).

ILO, 2020. *ILO Monitor: COVID-19 and the world of work. Third edition.* [pdf] Geneva: International Labour Organization. Available at: https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/briefingnote/wcms_743146.pdf [Accessed 4 May 2020]

IOM 2020. *World migration report 2020*. [pdf] Geneva: International Organization for Migration. Available at: https://publications.iom.int/system/files/pdf/wmr_2020.pdf [Accessed 11 June 2020].

Jaquet, S., Shrestha, G., Kohler, T., Schwilch, G., 2016. The effects of migration on livelihoods, land management, and vulnerability to natural disasters in the Harpan Watershed in Western Nepal. *Mountain Research and Development,* 36(4) pp.494-505 https://doi.org/10.1659/MRD-JOURNAL-D-16-00034.1

Jin J.M., Bai P., He W., Wu F., Liu X.F., Han D.M., Liu S., Yang J.K., 2020. Gender differences in patients with COVID-19: focus on severity and mortality. *Frontiers in Public Health* Vol. 8 Article 152. https://doi.org/10.3389/fpubh.2020.00152

Kong, R., Diepart, J., Castella, J., Lestrelin, G., Tivet, F., Belmain, E., Bégué, A., 2019. Understanding the drivers of deforestation and agricultural transformations in the Northwestern uplands of Cambodia. *Applied Geography*, 102(1), pp.84-98.

Lopez-Carr, D., Burgdorfer, J., 2013. Deforestation drivers: Population, migration, and tropical land use. *Environment*, 55(1) pp. 3–11.

Nijman, V., 2010. An overview of international wildlife trade from Southeast Asia. *Biodiversity and Conservation,* 19, pp.1101–1114. https://doi.org/10.1007/s10531-009-9758-4

Oldekop, J.A., Sims, K.R.E., Whittingham, M.J., Agrawala, A., 2018. An upside to globalization: international outmigration drives reforestation in Nepal. *Global Environmental Change*, 52 pp.66–74. https://doi.org/10.1016/j.gloenvcha.2018.06.004

Paul, F.H., Talpur, G.H., Soomro, R., Marri, A.A., 2019. The impact of remittances on fertility rate: evidence from Pakistan. *Sindh University Research Journal (Science Series)*. 51(01), pp.129-134. http://doi.org/10.26692/sujo/2019.01.23

Ratha, D., De, S., Plaza, S. Schuettler, K., Shaw, W., Wyss, H., Yi, S. 2016. *Migration and Remittances – Recent Developments and Outlook*. Migration and Development Brief 26, April 2016, Washington, DC: World Bank. DOI: 10.1596/978-1-4648-0913-2

Rosen, G.E., Smith, K.F., 2010. Summarizing the Evidence on the International Trade in Illegal Wildlife. *EcoHealth* 7, pp.24–32. https://doi.org/10.1007/s10393-010-0317-y

Ryerson, W. N., 2018. The hidden gem of the Cairo consensus: helping to end population growth with entertainment media. *The Journal of Population and Sustainability*. 2(2), pp. 51–61.

UN, 2018. *68% of the world population projected to live in urban areas by 2050, says UN.* [online] New York: United Nations. Available at: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html [Accessed 13 June 2020].

UN, 2020. *Policy brief: the impact of COVID-19 on women.* [pdf] New York: United Nations. Available at: https://www.un.org/sexualviolenceinconflict/wp-content/uploads/2020/06/report/policy-brief-the-impact-of-covid-19-on-women/policy-brief-the-impact-of-covid-19-on-women-en-1.pdf [Accessed 13 June 2020]/

UNFPA (United Nations Population Fund), 2014. *Population and poverty.* [online] New York: UNFPA. Available at: https://www.unfpa.org/resources/population-and-poverty [Accessed 12 June 2020]

Weber, H., Sciubba, J.D., 2018. The effect of population growth on the environment: evidence from European regions. *European Journal of Population,* [e-journal] April 9, 2018. https://doi.org/10.1007/s10680-018-9486-0

Wolfe, N. D., Daszak, P., Kilpatrick, A. M., & Burke, D. S., 2005. Bushmeat hunting, deforestation, and prediction of zoonoses emergence. *Emerging infectious diseases, 11*(12), pp.1822–1827. https://doi.org/10.3201/eid1112.040789

Wong, G., Bi, Y-H., Wang, Q-H., Chen, X-W., Zhang, Z-G., Yao, Y-G., 2020. Zoonotic origins of human coronavirus 2019 (HCoV-19 / SARS-CoV-2): why is this work important? *Zoological Research*. doi: 10.24272/j.issn.2095-8137.2020.031

World Bank, 2020. *COVID-19 crisis through a migration lens. Migration and development brief 32.* [pdf] Washington D.C.: World Bank Group. Available at: http://documents.worldbank.org/curated/en/989721587512418006/pdf/COVID-19-Crisis-Through-a-Migration-Lens.pdf [Accessed 2 June 2020]

Ye, Z. W., Yuan, S., Yuen, K. S., Fung, S. Y., Chan, C. P., Jin, D. Y., 2020. Zoonotic origins of human coronaviruses. *International journal of biological sciences*, *16*(10), 1686–1697. https://doi.org/10.7150/ijbs.45472

INVITED ARTICLE

Disaster vulnerability by demographics?

Ilan Kelman[1]

Institute for Risk & Disaster Reduction, University College London, UK
Department of Global Development and Planning, University of Agder, Kristiansand, Norway

Abstract

This article provides a brief overview of the relationship between disaster vulnerability and demographic variables. Population numbers and densities are examined along with using a gender focus as illustrative of individual characteristics. For the most part, people's and society's choices create vulnerabilities based on demographics rather than specific demographic characteristics inevitably conferring vulnerability.

Keywords: disaster risk reduction; gender; population; vulnerability

Defining disaster

The question "What is a disaster?" is not straightforward to answer, having been the subject of books as well as debates over synonyms and the use of terminology (Britton, 1986; Quarantelli, 1998; Perry and Quarantelli, 2005; Leroy, 2006). Concatenating the academic literature, dictionaries, and professional glossaries (e.g. UNISDR, 2017), a straightforward suggestion encompassing these ideas is that a disaster is defined as "A situation requiring outside support for coping".

The key is the element of coping. Many environmental phenomena and processes occur, from volcanic eruptions to droughts to space weather, but not everyone

1 ilan_kelman@hotmail.com. Ilan Kelman's latest book is *Disaster by choice: how our actions turn natural hazards into catastrophes.*

is affected by them or is affected in the same way. If a house is flood-resistant, including being resistant to contaminants in the water such as salt and petrol, then a family might be able to move back in a few days after the water subsides, compared to several months for many dwellings without flood resistance (Lamond et al., 2011). Similarly, dwellings built and maintained to resist earthquakes might not require evacuation unlike those which collapse and kill the occupants (Coburn & Spence, 2002).

The ability of a society to cope with the environment indicates aspects of its vulnerability. However, a society's vulnerability is itself the result of societal processes which set up people, groups within society, and communities so that they are harmed by environmental activity and nature becomes hazardous. It is these vulnerabilities which are the fundamental cause of disasters rather than natural hazards. The phrase "natural disaster" is therefore preferably avoided as a misnomer, since disasters themselves are not natural and instead should simply be referred to as "disasters". Choices are available to better deal with the environment, but often we live or are forced to live in places and in ways which subject us to harm (Hewitt, 1983, 1997; Lewis, 1999; Wisner et al., 2004), such as not having flood-resistant or earthquake-resistant infrastructure.

Examples of created vulnerabilities are:

- Where we live or are forced to live, in places such as floodplains, over earthquake faults, on unstable slopes, or near volcanoes. Any location has advantages and potential environmental hazards, so understanding them will indicate how to act to avoid a disaster, provided that resources and opportunities are available.

- How we live or are forced to live, such as with few livelihood options, without education, and with little opportunity to accumulate assets or savings which could assist with safer and healthier living.

- Who we are and the population groups to which we belong, such as population numbers and densities as well as individual characteristics.

This article summarises some aspects of this last point, exploring how vulnerabilities are not inherent to individuals and groups, but people are made to be vulnerable by their choices or, more commonly, by the choices of others.

Population numbers and densities

By definition, a disaster cannot occur without people and society being affected, with a disaster's scale defined according to these impacts. How do population numbers and densities influence the potential effects? Are higher numbers more worrying? As always, the straightforward answer is "it depends". It depends on which numbers are considered and the specific context, with no single figure providing a complete answer.

Consider population numbers. The more people who are affected, the worse a disaster is generally assumed to be. But absolute numbers of people paint only part of the picture, because proportional numbers also need to be considered (Lewis, 1999).

In 1995, the Caribbean island of Montserrat had a population of approximately 12,000 people when the volcano comprising the island starting erupting, settling down only in the past few years. During the two decades of eruptions, most of the island's infrastructure was destroyed and the entire population fled their homes, some to rebuild in the island's north and up to 2/3 of the population to other countries, with many but not all of them eventually returning (Pattullo, 2000). On June 25, 1997, at least nineteen people were killed in pyroclastic flows.

All Montserratians directly experienced this disaster, with 100% of lives being upended and possible long-term impacts from continual inhalation of volcanic ash still to be determined (Baxter et al., 2014). Yet the number of immediate deaths was small and even the total number of people affected in Montserrat was less than half the death toll of the 26 December 2003 earthquake in Bam, southern Iran (Ghafory-Ashtiany, 2004). Comparatively, though, 0.16% of Montserrat's population was killed by the volcano in 1997 compared to 0.038% of Iran's population killed by the earthquake in 2003 – a far higher percentage in Montserrat.

Examining absolute numbers makes Montserrat's disaster appear irrelevant compared to Bam's. Examining proportions makes Montserrat's disaster appear to be far worse than Bam's. Both were disasters in their own right, but each had different characteristics in terms of population numbers affected, meaning that it is not straightforward to compare them. Neither should necessarily be made out to be a worse disaster than the other; both were devastating, could have had their impacts reduced through prevention, and required major responses and reconstruction. Proportional vulnerability and absolute vulnerability each provide different but important disaster-related perspectives (Lewis, 1999).

Similar aspects of "it depends" emerge for population density. One often-heard mantra is that urbanization worsens disasters due to higher population densities. Cities expanding means larger population numbers concentrated within the same agglomeration, augmenting disaster risk and making disasters worse.

The flipside is that more people are available to assist. High-density urban areas sometimes have the most experienced, best equipped, and highest concentration of emergency services (e.g. Reames et al., 2009 for emergency physicians in Oklahoma), including healthcare facilities, as well as shorter transportation times to the nearest one (e.g. Fleischman et al., 2011 for paediatrics in Oregon). Logistics and planning personnel are likely to be dealing with larger and more closely confined populations in cities, and this is certainly a major factor in the high infection and death rates in London and New York during the 2020 Covid-19 pandemic. They are also dealing with smaller areas and typically more options for supply chains, transportation, distribution networks, and nearby skilled people – although this does not necessarily translate into improved or easier disaster responses (Kovács and Spens, 2012). Urban areas without formal or well-maintained roads, as often exist in informal settlements, are a logistical nightmare for emergency services and supply chains.

Another disadvantage of cities is that, if multiple hospitals or fire stations are put out of action by the disaster, then the emergency services will be overloaded and the non-urban areas in the vicinity are not likely to be able to take up the slack. In addition, many examples exist of rural areas with better disaster prevention and response than larger centres; for instance, Johnston (2015) found that more isolated communities in Fiji had received less disaster aid in previous cyclones and so were more prepared than their larger counterparts who had previously received, and therefore expected to receive, external aid. Moreover, much is contextual: rural rescuers are likely to be more familiar with isolated mountain rescue than their urban counterparts, while the latter probably know large building collapse rescue better.

Similarly, the siting of a city or other settlement can be selected to reduce (or increase) the possibility of environmental hazards, irrespective of population numbers and densities. If a large city develops in a country's least hazardous location while a village is placed in a canyon subject to flash floods, rockfalls, avalanches, and more, then the overall disaster risk might be more for the village, despite the large difference in population-based vulnerability and depending how hazard and vulnerability are quantified for calculating disaster risk.

Conversely, cities tend to be paved over much more than less urban locales, meaning that rain runs off and pools in low-lying areas, flooding them, rather than being absorbed by the ground. Green spaces and permeable paved surfaces, though, can prevent flooding (e.g. Webber et al., 2020 for Melbourne, Australia). Siting, designing, planning, and landscaping – irrespective of population numbers and densities – affect many aspects of possible disasters.

Even for disaster evacuation and sheltering, locations with high population density can enact swift and effective measures through planning, training, suitable routes, and sufficient vehicles and organisation (Renne, 2018). People in non-urban areas have frequently been trapped when a wildfire is burning across their only escape road or a flood or earthquake severs it – or if information flow for warnings is inhibited, so residents decide not to evacuate, as documented for the Philippines and Dominica (Yore and Faure Walker, 2020). The safety and success of disaster evacuation is determined more by preparation and readiness than by population numbers and densities.

Some cities offer a form of evacuation rarely available in non-urban areas: vertical evacuation up tall buildings. Provided that the building will remain standing and not be overwhelmed by a hazard, the quickest, safest, and easiest evacuation in floods, tsunamis, avalanches, and many types of slides, might be heading to upper floors (Mostafizi et al., 2019). Even for pyroclastic flows – which are hot, fast ash and gas clouds from some volcanoes – inner rooms in large buildings might provide survival spaces against the heat and ash which would be unavailable in smaller structures (Spence et al., 2007). The key is that the structures need to withstand the environmental forces and energies to keep people safe, which is not a function of population numbers or densities (and which is not always easy to know in advance).

Disasters are certainly influenced by population numbers and densities, yet much emerges from societal choices on how to deal with the people in a location. We can and should make choices to prevent disasters, no matter what the population numbers.

Individual characteristics: A gender focus

Disasters are also about individual demographic characteristics – such as age, gender, sex, sexuality, disabilities, medical conditions, ethnicity, race, caste, religion, belief systems, education, communication abilities including languages spoken, livelihoods, and wealth among others – playing roles in how vulnerability is determined by and for individuals. These variables have a range of dependencies and the interplay among them produces complex analyses, correlations, causations, and chains of influence. Detailed work has covered many of these variables, such as religion (Gaillard and Texier, 2010) and disability (Bennett, 2020), while others, such as prisoners (Gaillard and Navizet, 2012) and homeless people (Wisner, 1998), have only received sporadic study. Combinations are now being more fully explored through intersectionality, based on Crenshaw (1989), where multiple individual characteristics intersect to create, augment, or diminish vulnerability.

To exemplify individual demographic characteristics, this section addresses vulnerability differences in males and females, meaning sex-differentiated vulnerability which, in the literature, tends to be termed gender. 'Sex' and 'gender' are not interchangeable, since they depict characteristics which are different and the male-female binary division is not how many people regard or live their gender. Disaster fatality data has tended to be reported through a division of women/girls and men/boys (Neumayer and Plümper, 2007) with more thorough approaches starting to be explored (Gaillard et al., 2017). For now, gender-differentiated vulnerability generally means comparing girls/women and boys/men, so the phrase is used here, even though 'sex-based vulnerability' would be more correct.

For instance, following the 26 December 2004 Indian Ocean tsunami, fatality data from villages in Sri Lanka, India, and Indonesia found that female deaths were consistently higher than male deaths (Oxfam, 2005). When examining why this difference emerged, the pattern became clear that the reason was gender-differentiated roles in society, not that women were inherently more vulnerable to tsunamis than men. As two examples documented in the report showed, when the tsunami appeared:

- In an area of Sri Lanka, it was the time at which women bathed in the sea; a few hours difference would have meant that the women were not in the water.

- In some Acehnese villages, the women were waiting on the shore for their fisher husbands to come in from the sea with the catch; again a few hours difference would have changed the situation.

These gender-based roles and the societal separation of the genders creates gender-based vulnerability leading to gender-differentiated death tolls (Enarson and Morrow, 1998).

In many of the tsunami-hit locations and other places around the region, further similarly artificial factors disadvantage women and girls in dealing with water hazards, including river and coastal floods. Females are typically not taught how to swim, are not always allowed to leave their home (such as for evacuating) without a male relative, are expected to be carers which makes evacuation harder and slower, wear clothes which inhibit running or swimming (and they would never remove their clothes to survive), and tend to be more malnourished and hence physically weaker than men. Such points explain why far more females than males died in the 1991 cyclone in Chittagong, Bangladesh across all age groups (Begum, 1993; Chowdhury et al., 1993).

Many more factors that lead to women and girl's vulnerabilities become manifest through examining gender-based data and experiences (e.g. Bates, 2014; Criado Perez, 2020), but are under-researched. They represent the typical, day-to-day gender-based marginalisation and the normalisation of gender-based discrimination and violence which reduces options for education, health, and initiative, thereby augmenting vulnerability on the basis of gender alone. Examples are ostracising menstruating women, a legitimate fear of violence and assault when evacuating or in shelters, the objectification of women's bodies, not considering women's bodies when designing clothes and equipment, and devaluing the importance of girls for rescue and evacuation. In all these instances, the vulnerabilities are socially constructed.

The same occurs for men and boys, with their vulnerability being socially constructed through expected cultural roles for them (Enarson and Pease, 2018). More men than women are recorded as dying in floods in the USA (Doocy et al., 2013) and Australia (Coates, 1999). The reasons are generally attributed to risk-taking behaviour, such as driving through floodwater and being in rescue-related professions. More fundamentally, expectations regarding risk-taking behaviour are typically foisted on men, especially within contexts of toxic masculinities, hypermasculinity, assumptions of machoism/machismo, and culturally engrained mantras such as 'women and children first' for rescue when ships sink (Mosher, 1991). Sexual and physical violence against boys and men occurs and is not often admitted (Zalewski et al., 2018), suggesting that males could also decide to avoid safe evacuation and sheltering out of fear of being assaulted.

The evidence shows that the demographic categorisation of being male or female is not the causation of gender-differentiated mortality. Women/girls or men/boys are not intrinsically or genetically less intelligent, less capable of surviving floods, or more attuned to water than the other. Instead, gender-based cultural roles are created, leading to gender-based disaster vulnerabilities and abilities to overcome these vulnerabilities which, in turn, produce the observed differences in male-female flood and tsunami mortality – and the same with other hazards and disasters (Neumayer and Plümper, 2007; Kinnvall and Rydstrom, 2019). Irrespective of females and males having differences in physiology, they are made by society to have different vulnerabilities due to cultural, not physiological, constructions.

Disaster by choice

Ultimately, vulnerability is typically not inherent to certain people, populations, or subgroups. Instead, vulnerability is created by society, usually by some population groups for others; that is, individuals and groups are made to be vulnerable by the choices of others. Even where demographic features do influence vulnerability directly, we could make choices to reduce this influence and to reduce vulnerabilities in other ways, showing that "natural disasters" rarely exist.

Yet no situation is ever as simple as it appears in a short paragraph: "we could make choices" is the crux in terms of why people often cannot make choices, even if they theoretically could (and would). Considering the influence of population size on disasters, one approach among many is to seek population stabilisation by reducing the world's population growth rate to a negative value in the short-term followed by a growth rate of zero over the long-term, once a suitable population size is agreed and achieved.

Who must agree and how will they agree? Who is permitted to make these policy choices and to enact the subsequent actions, how they are made, and how they are implemented leads to labyrinthine political entanglements intersecting with ethics, belief systems, and ideologies (Coole, 2018). The political philosophy of this decision is particularly troublesome for reaching consensus and consistency, in terms of balancing how much individuals should have choices regarding reproduction compared to national governments or international organisations. Science fiction writers have even speculated about why people have the right to breed at will, with contraception often government controlled, rather than contraception being the norm with governmental permission required to have a child – leading to tortuous ethical consequences of either approach.

The difficulties of managing population stabilisation without neglecting all the other contributors to disaster vulnerability (and to wider social and environmental challenges) pushes 'disaster by choice' into the realm of 'yes, but whose choice'? The majority of the world's population has little prospect for fully tackling the deep-rooted, systemic structures which make choices for them while denying their own abilities to choose. The focus on choice, therefore, deserves critique through examining:

(i) Similarities and differences among choice, free will, agency, and other notions (Holton, 2006).

(ii) The contrasting adages that everyone always has some level or modicum of choice and that everyone is always highly constrained

> by the norms, rules, and regulations governing our opportunities and behaviour (Giddens, 1979, 1984; Mouzelis, 1995; Stones, 2005).

If disasters fundamentally come down to choices – namely, someone's choices – then much more work is needed to drill down into what choices really are and the processes by which choices are and should be made, such as when irreconcilable societal and individual philosophies and values conflict (Baron, 1993; Findlay, 1961).

Nonetheless, there is so much more which those with power and resources could choose to do more immediately to avert disasters. Even a comet or asteroid, heading towards the Earth to generate a cataclysmic explosion threatening all demographic groups within humanity, would not induce a "natural disaster". We already have some space monitoring networks and some readiness to deflect or destroy dangerous objects, but we have a long way to go to safeguard ourselves fully (Schmidt, 2019). It is our choice to provide only some surveillance and response capability, rather than ensuring that we could avert a major impact under all circumstances. Irrespective, some natural hazards might be unstoppable and could indeed represent true natural disasters, such as gamma-ray bursts (Palmer et al., 2005) or supernovae from nearby stars (Wallner et al., 2016), ice ages due to orbital cycles (Hodell 2019), and basaltic flood volcanic eruptions (Courtillot and Fluteau, 2014).

Apart from these extremes, disasters are not natural because we make choices to create or tackle vulnerabilities, as illustrated by this brief exploration of demographics. We need to learn more from the successes to change 'disaster by choice' into 'no disaster by choice'.

References

Baron, J., 1993. *Morality and Rational Choice*. Dordrecht: Kluwer.

Bates, L., 2014. *Everyday sexism*. London: Simon & Schuster.

Baxter, P.J., Searl, A.S., Cowie, H.A., Jarvis, D. & Horwell, C.J., 2014. Evaluating the respiratory health risks of volcanic ash at the eruption of the Soufrière Hills Volcano, Montserrat, 1995 to 2010. *Geological Society of London, Memoirs*, 39, pp. 407–425.

Begum, R., 1993. Women in environmental disasters: the 1991 cyclone in Bangladesh. *Gender and Development*, 1 (1), pp. 34–39.

Bennett, D., 2020. Five years later: Assessing the four priorities of the Sendai Framework to increase resiliency among people with disabilities. *International Journal of Disaster Risk Science*, 11 (2), forthcoming.

Britton, N.R., 1986. Developing an understanding of disaster. *Journal of Sociology*, 22 (2), pp. 254–271.

Chowdhury, A., Mushtaque, R., Bhuyia, A.U., Choudhury, A.Y. & Sen, R., 1993. The Bangladesh cyclone of 1991: why so many people died. *Disasters*, 17 (4), pp. 291–304.

Coates, L., 1999. Flood fatalities in Australia, 1788-1996. *Australian Geographer*, 30 (3), pp. 391–408.

Coburn, AW. & Spence, R.J.S., 2002. *Earthquake protection*. London: John Wiley & Sons.

Coole, D., 2018. *Should we control world population?* Cambridge: Polity Press.

Courtillot, V. & Fluteau, F., 2014. A review of the embedded time scales of flood basalt volcanism with special emphasis on dramatically short magmatic pulses. *GSA Special Papers*, 505, pp. 301–317.

Crenshaw, K., 1989. Demarginalizing the intersection of race and sex: a black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics. *University of Chicago Legal Forum*, 1, pp. 139–167.

Criado Perez, C., 2020. *Invisible women: exposing data bias in a world designed for men*. London: Chatto and Windus.

Doocy, S., Daniels, A., Murray, S. & Kirsch, T.D., 2013. The human impact of floods: a historical review of events 1980-2009 and systematic literature review. *PLoS Currents*, [e-journal] 5. doi:10.1371/currents.dis.f4deb457904936b07c09daa98ee8171a.

Enarson, E. & Morrow, B.H., eds., 1998. *The gendered terrain of disaster: through women's eyes*. Connecticut: Greenwood Publications.

Enarson, E. & Pease, B., eds., 2016. *Men, masculinities and disaster*. Abingdon: Routledge.

Findlay J.N., 1961. *Values and intentions: a study in value-theory and philosophy of mind*. London: Allen & Unwin.

Fleischman, R.J., Yarris, L.M., Curry, M.T., Yuen, S.C., Breon, A.R. & Meckler, G.D., 2011. Pediatric educational needs assessment for urban and rural emergency medical technicians. *Pediatric Emergency Care*, 27 (12), pp. 1130–1135.

Gaillard, JC & Navizet, F., 2012. Prisons, prisoners and disaster. *International Journal of Disaster Risk Reduction*, 1, pp. 33–43.

Gaillard JC & Texier, P., 2010. Religions, natural hazards, and disasters: an introduction. *Religion*, 40 (2), pp. 81–84.

Gaillard, JC, Sanz, K., Balgos, B.C. & Dalisay, S.N.M., Gorman-Murray, A., Smith, F., & Toelupe, V., 2017. Beyond men and women: a critical perspective on gender and disaster. *Disasters*, 41 (3), pp. 429–447.

Ghafory-Ashtiany, M., 2004. Editorial summary: Bam earthquake of 05:26:26 Of 26 December 2003, MS6.5. *Journal of Seismology and Earthquake Engineering*, 5-6 (4-1), pp. 1–3.

Giddens, A., 1979. *Central problems in social theory*. Basingstoke: Macmillan

Giddens, A., 1984. *The constitution of society*. Cambridge: Polity Press.

Hewitt, K., ed., 1983. *Interpretations of calamity from the viewpoint of human ecology*. London: Allen & Unwin.

Hewitt, K., 1997. *Regions of risk: a geographical introduction to disasters*. London: Routledge.

Hodell, D.A., 2019. The smoking gun of the ice ages. *Science*, 354 (6317), pp. 1235–1236.

Holton, R., 2006. The act of choice. *Philosophers' Imprint*, 6 (3), pp. 1–15.

Johnston, I., 2015. Disaster management and climate change adaptation: a remote island perspective. *Disaster Prevention and Management*, 23 (2), pp. 123–137.

Kinnvall, C. & Rydstrom, H., 2019. *Climate hazards, disasters, and gender ramifications*. Abingdon: Routledge.

Kovács, G. & Spens, K.M., 2012. *Relief supply chain management for disasters: humanitarian, aid and emergency logistics*. Hershey, Pennsylvania: IGI Global.

Lamond, J., Booth, C., Hammond, F. & Proverbs, D., eds., 2011. *Flood hazards: impacts and responses for the built environment*. London: CRC Press.

Leroy, S.A.G., 2006. From natural hazard to environmental catastrophe: past and present. *Quaternary International*, 158 (1), pp. 4–12.

Lewis, J., 1999. *Development in disaster-prone places: studies of vulnerability.* London: Intermediate Technology Publications.

Mosher, D.L., 1991. Macho men, machismo, and sexuality. *Annual Review of Sex Research*, 2 (1), pp. 199–247.

Mostafizi, A., Wang, H., Cox, D. & Dong, S., 2019. An agent-based vertical evacuation model for a near-field tsunami: choice behavior, logical shelter locations, and life safety. *International Journal of Disaster Risk Reduction*, 34, pp. 467–479.

Mouzelis, N., 1995. *Sociological theory: what went wrong?* London: Routledge.

Neumayer, E. & Plümper, T., 2007. The gendered nature of natural disasters: the impact of catastrophic events on the gender gap in life expectancy, 1981–2002. *Annals of the Association of American Geographers*, 97 (3), pp. 551–566.

Oxfam, 2005. *Oxfam briefing note: the tsunami's impact on women*. Oxford: Oxfam International.

Palmer, D.M., Barthelmy, S., Gehrels, N., Kippen, R.M., Cayton, T., Kouveliotou, C., Eichler, D., Wijers, R.A.M.J., Woods, P.M., Granot, J., Lyubarsky, Y.E., Ramirez-Ruiz, E., Barbier, L., Chester, M., Cummings, J., Fenimore, E.E., Finger, M.H., Gaensler, B.M., Hullinger, D., Krimm, H., Markwardt, C.B., Nousek, J.A., Parsons, A., Patel, S., Sakamoto, T., Sato, G., Suzuki, M. & Tueller, J., 2005. A Giant γ-ray flare from the magnetar SGR 1806220. *Nature*, 434, pp. 1107–1109.

Pattullo, P., 2000. *Fire from the mountain: the tragedy of Montserrat and the betrayal of its people*. London: Constable and Robinson.

Perry, R. & Quarantelli, E.L., 2005. *What is a disaster?* New York: Xlibris.

Quarantelli, E.L., 1998. *What is a disaster?* New York: Routledge.

Reames, J., Handel, D.A., Al-Assaf, A. & Hedges, J.R., 2009. Rural emergency medicine: patient volume and training opportunities. *The Journal of Emergency Medicine*, 37 (2), pp. 172–176.

Renne, J.L., 2018. Emergency evacuation planning policy for carless and vulnerable populations in the United States and United Kingdom. *International Journal of Disaster Risk Reduction*, 31, pp. 1254–1261.

Schmidt, N., ed., 2019. *Planetary defense: global collaboration for defending Earth from asteroids and comets*. Switzerland: Springer.

Spence, R., Kelman, I., Brown, A., Toyos, G., Purser, D. & Baxter, P., 2007. Residential building and occupant vulnerability to pyroclastic density currents in explosive eruptions. *Natural Hazards and Earth Systems Sciences*, 7 (2), pp. 219–230.

Stones, R., 2005. *Structuration theory*. Basingstoke: Palgrave Macmillan.

UNISDR, 2017. *Terminology on disaster risk reduction*. Geneva: UNISDR (United Nations Office for Disaster Risk Reduction). https://www.unisdr.org/we/inform/terminology

Wallner, A., Feige, J. , Kinoshita, N., Paul, M., Fifield, L.K., Golser, R., Honda, M., Linnemann, U., Matsuzaki, H., Merchel, S., Rugel, G., Tims, S.G., Steier, P., Yamagata, T. & Winkler, S.R., 2016. Recent near-Earth supernovae probed by global deposition of interstellar radioactive 60Fe. *Nature*, 532, pp. 69–72.

Webber, J.L., Fletcher, T.D., Cunningham, L., Fu, G., Butler, D. & Burns, M.J., 2020. Is green infrastructure a viable strategy for managing urban surface water flooding? *Urban Water Journal*, forthcoming.

Wisner, B., 1998. Marginality and vulnerability: why the homeless of Tokyo don't 'count' in disaster preparations. *Applied Geography*, 18 (1), pp. 25–33.

Wisner, B., Blaikie, P., Cannon, T. & Davis, I., 2004. *At risk: natural hazards, people's vulnerability and disasters*, 2nd ed. London: Routledge.

Yore, R. & Faure Walker, J., 2020. Early warning systems and evacuation: rare and extreme vs frequent and small scale tropical cyclones in the Philippines and Dominica. *Disasters*, forthcoming.

Zalewski, M., Drumond, P., Prügl, E. & Stern, M., 2018. *Sexual violence against men in global politics*. Abingdon: Routledge.

PRAXIS

Endangered species condoms: a social marketing tool for starting conversations about population

Sarah Baillie[1], Kelley Dennings and Stephanie Feldstein

Center for Biological Diversity, Tucson, Arizona, USA

Abstract

The Endangered Species Condoms project was launched 10 years ago to bring the discussion of human population growth back into the environmental movement with a focus on human rights and reproductive justice. In that time, more than 1 million condoms have been distributed by thousands of volunteers. The principles of social marketing are used through the Endangered Species Condoms project to create a national discourse around the population issue. They are introduced in both formal teaching settings like high school and university classrooms as well as informal settings like community events and after-hours programing at zoos and museums to reach a broad, diverse audience.

Keywords: endangered species; outreach; overconsumption; social marketing

Introduction

Human population growth is at the root of our most pressing environmental issues. The number of people on the planet drives up the demand for resources which in turn propels climate change, fossil fuel use, habitat destruction, and biodiversity loss.

1 Corresponding author: sbaillie@biologicaldiversity.org

However, this topic is rarely discussed within the environmental movement. The Center for Biological Diversity, a national environmental non-profit based in the USA, recognizes that it is crucial to have conversations around the effects of population growth on the environment and wildlife in order to address the problem. The Center only supports ethical, non-coercive solutions to combat unchecked human population growth, including comprehensive sex education and universal access to contraceptive resources and reproductive health care. Using creative social marketing techniques has helped break down barriers to bring this important topic back into the environmental discourse.

Social marketing is used to address "wicked problems" – those that are complex with no easy solution – and unplanned pregnancies are just that. Decreasing unplanned pregnancies involves improving contraception and sexual education through policy and infrastructure, along with changing cultural norms around family size and talking about reproductive health. The social marketing framework facilitates choosing a behavioral objective along with a priority audience and then campaigns are designed around this. The objective could be upstream to change policy with elected officials as the audience or downstream where the objective is to use contraception and the audience is individuals of reproductive age.

This paper will discuss the importance of talking about population within the environmental movement, why the Center focuses on domestic reproductive rights and choices, and how we use a social marketing framework in our creative outreach to effect change. The Endangered Species Condoms are a unique tool to start a conversation about the negative impacts of unchecked population growth. They provide people with a literal tool to prevent unintended pregnancies and additional information about the ethical solutions we advocate for. We have developed and grown this program over the past ten years to expand our reach to new audiences.

Resistance to discussing population as an environmental issue

We are currently in the sixth mass extinction and losing species at an unprecedented rate, an estimated 1 million species are at risk of extinction (UNSDG, 2019). There is a very clear correlation between the growth of the human population and the extinction rate of species (Scott, 2008; McKinney, 2001; McKee, Chambers and Guseman, 2013). North America has lost 29 percent of its total bird population in the past 48 years (Rosenberg, et al., 2019). Large apex predators adjust their hunting patterns based on the presence of humans (Suraci *et al.*, 2019), as do mesocarnivores (Clinchy, et al., 2016). As our population grows, every new individual needs resources such as food, water, shelter, energy and land, and as demand on natural resources grows we are negatively impacting wildlife through destruction of habitats and other changes to the ecosystem.

Despite population being intrinsically connected to the most urgent environmental crises of our time, it is rarely directly addressed by the environmental community. Some organizations and individuals may have different strategic or philosophical reasons for ignoring the topic. For example, some groups have chosen to focus on industrial practices and polluting infrastructures rather than individual behavior. These groups may view the solutions to population such as reproductive rights and education as outside of their missions or expertise. But we have also found that many people distance themselves from population discussions because of cultural taboos around sex or stigma from past transgressions where proposed solutions for population growth have targeted vulnerable, marginalized communities. In some cases, groups may support equality, education and healthcare with an emphasis on other co-benefits like resilience, while excluding language around population growth to avoid potential negative associations.

In 2009 the Center for Biological Diversity recognized that all our other work to save species would ultimately be undermined if human population growth was not addressed. Since it can be a challenging topic for many people to talk about, we knew we had to be creative if we were going to bring population back into the environmental movement in a positive, productive way. The award-winning Endangered Species Condoms project was created to use humor and art to make the topic of population and family planning easier to approach.

The colorful condom packages include original artwork featuring North American species threatened by population growth and slogans like "Before it gets any hotter, think of the sea otter." Inside the package is more information about the featured species, how population pressure negatively effects wildlife, recommended human-rights solutions, and two condoms.

In addition to learning about population and proposed solutions, recipients literally receive a tool enabling them to have safe sex and help prevent unplanned pregnancies. The condoms included in the packages are fair-trade, vegan, nitrosamine-free and sourced from sustainable rubber plantations.

The Endangered Species Condoms help people make a direct link between population growth and imperiled wildlife that they care about. Each species featured on the condom packages was chosen because of its connection to the threats from our growing human population. For example, monarch butterflies are disappearing due to corn and soybean crops replacing the native plants they need to survive. There is also the additional threat of the pesticides used on those crops, most of which are grown to feed to livestock. Hellbender salamanders are declining because of increased water pollution from runoff coming from cities and agriculture. Polar bears have become powerful symbols of climate change and the effects of greenhouse gas emissions from our ever-growing population. By starting the conversation with the featured animal, people are reminded of what they want to save before broaching a potentially uncomfortable topic. As discussed in more detail below, the Center has successfully used this approach to start more than a million conversations about the impact of population growth on wildlife and the environment.

Focusing on population pressure in the U.S.

Since the United States has one of the largest carbon footprints per individual, Americans have a disproportionate impact per person compared to other countries. Americans are also responsible for a disproportionate amount of habitat loss, pollution and waste. The Endangered Species Condoms – and the Center's Population and Sustainability program as a whole – work to provide a local context for how wildlife are affected by the twin threats of population growth and overconsumption. By focusing on these issues side-by-side, we've been able to demonstrate how they're intertwined and overcome the false dichotomy that only one or the other is to blame for global pressure on the planet. Although many population groups focus their work in higher-fertility countries, the Center chooses to focus our efforts domestically to increase awareness among high-consuming populations and advance positive solutions to address this global issue.

We acknowledge that U.S. population is growing more from immigration than it is from the birth rate (Adamy and Overburg, 2019), but we believe that national immigration policy is not an appropriate or effective solution to address a global problem. Furthermore, immigration policy has often been used in the United States to violate human rights and worsen environmental damage (CBD, n.d.).

Where we do see opportunities for solutions is in addressing reproductive rights. While the United States is below replacement rate fertility, about 45 percent of all pregnancies in the country are unintended (Finer and Zolna, 2016). This is high for a developed country, but it becomes less surprising after learning only 39 states mandate sex education. Of those, only 17 mandate that it be medically accurate (Guttmacher Institute, 2019). Thirty nine states stress abstinence, and only 20 states include information about condoms and contraception (Guttmacher Institute, 2019). In addition, recent federal policies restricting the Affordable Care Act and Title X clinics are decreasing access to contraception and health services. Improving access to family planning and education is crucial to slowing population growth to more sustainable rates.

How social marketing can help change the population narrative

In a previous article published in this journal, William Ryerson (2018) wrote about entertainment education. He discussed how, when the framework is rooted in social and behavior-change communications theory, results can be substantial and cost-effective. Social marketing used by the Center for Biological Diversity is another successful social and behavior-change framework. The social marketing process applies marketing principles and techniques to create, communicate, and deliver value in order to influence behaviors that benefit society as well as the priority audience (Lee and Kotler, 2011).

The concept emerged in the 1950s when sociologist G.D. Wiebe (1951), in an article in Public Opinion Quarterly, asked “Why can’t we sell brotherhood like we sell soap?” and explored the challenges of selling a social good as if it were a commodity. However, it was not until 1971 that Kotler and Zaltman (1971) coined the term “social marketing” and developed a framework from which to work. One of the first social issues tackled by social marketing was that of attempting to increase contraceptive use in India in the 1960s. The effort involved selling subsidized Nirodh condoms with the assistance of major private sector marketers like Unilever and Brooke Bond Tea, which helped support distribution of the product (Harvey, 1999). This trend continued into the 1980s when condoms emerged as an effective tool to combat the spread of HIV/AIDS (Manoff, 1985).

Like entertainment education, social marketing is rooted in theories of behavior change including the Social Ecological Model, Stages of Change or Transtheoretical Model, Theory of Planned Behavior, Social Cognitive Theory, and Diffusion of Innovation Theory. These theoretical approaches are used to help outline research, create a campaign strategy and/or track evaluation metrics. Social marketing is frequently used in the health sector and is commonly applied to some environmental issues, such as energy efficiency. It can be used with any social issue where there's a beneficial behavior-change component, such as family planning.

Social marketing is a targeted, step-by-step and data-driven process with the objective of removing the barriers an audience may have to a desired action and enhance the benefits and motivations to engage in the behavior. There is a focus on outcomes and impact, and monitoring and evaluation are important components to track results.

The number and type of social marketing steps can vary, but the following seven steps show how the Center for Biological Diversity uses the framework for the Endangered Species Condoms Project (Dennings, 2018):

1. Outcome – Campaign outcomes might be dictated by management, costs, local government, etc. and should include goals for short and long-term success. Our long-term outcome is to decrease population pressure on wildlife and associated habitat by increasing access to family planning and contraceptive resources. The Endangered Species Condoms serve the short-term outcome of increasing visibility and engagement for these issues in support of long-term behavior and policy change.

2. Action or Behavior – The desired behavior identified for a campaign's priority audience should be helpful and have a high likelihood of the audience engaging in the action. Some behaviors are made up of sub-actions which may require creating a behavioral map prior to choosing the behavior the campaign will promote. While the Endangered Species Condoms facilitate safe sex, the primary purpose of the colorful, fun packages is as a conversation tool. The desired action is to spur conversations about population that

will inspire people to choose whichever birth control method is right for them and get engaged in supporting access to all forms of contraception, comprehensive sex education and reproductive healthcare equality.

3. Segment – Although many social issues would benefit from "everyone" changing their behavior, segmenting people by factors such as perceived barriers, difficulty of the action, demographics and receptiveness to different messaging can be used to create more effective, tailored campaigns. (Lee and Kotler, 2011). While anyone inspired by the Endangered Species Condoms' message can help influence society and the political system, the project's target audience is people of child-bearing age. Particularly those who have not yet made family planning decisions or who are environmentally-minded but may be unaware of the intersection between the increase in population and environmental degradation.

4. Barriers – The reasons why people are not already engaging in the desired behavior – including internal barriers like motivation, knowledge, attitudes, beliefs and abilities as well as external barriers like infrastructure, economics, access, convenience and social situations – needs to be researched for each audience and incorporated into campaign strategies (McKenzie-Mohr, 2011). The humor, artwork and informational packaging of the Endangered Species Condoms helps overcome taboos and stigma by providing an approachable way to frame an often-challenging conversation and clear information on the problem and positive rights-based solutions.

4. Strategy – Many behavior-change strategies are informed by social science such as the use of prompts, norms, defaults, commitment, diffusion, feedback, framing, heuristics, incentives, etc. (Michie, Atkins and West, 2014). Using some of these social science strategies, the Endangered Species Condoms are an effective way to prompt a conversation about population and its impact on wildlife. By talking openly about family planning as a climate change solution we help normalize the conversation.

5. Implement – After planning and testing a strategy, it is then implemented and the results monitored. The Endangered Species Condoms are distributed through a large volunteer network, with a focus on particular holidays and events discussed in more detail below.

6. Evaluate – The campaign should be assessed on a regular basis and adjusted as needed as this is an iterative process. A logic model can be a useful tool to help think about outputs, outcomes and impact. The Center evaluates each major condom distribution in addition to an annual review of the project as a whole.

Another way to build a campaign strategy is with marketing's four Ps: Product, Price, Place and Promotion (Lee and Kotler, 2011). The Endangered Species Condoms project provides an attention-grabbing product that's related to the message and given away for free. Place is determined by the focus of each distribution – for example, some distributions focus on specific geographic locations tied to holidays or species, while the Pillow Talk program targets institutions such as zoos, museums and science centers. Finally, the condom package itself and the use of prompts, norms and framing all contribute to the promotion, which is enhanced by traditional and social media outreach and, occasionally, advertising such as posters or billboards.

How the Endangered Species Condoms project works

The Endangered Species Condoms are distributed by hundreds of volunteers nationwide every year. Around 100,000 condoms are disseminated annually, and in July 2019 we celebrated giving out our millionth condom. The condoms are shared three key ways:

1) People submit their ideas year-round for how they want to give out the condoms, and we send the condoms free of charge to where we think there are good opportunities for volunteers to have conversations about population. Volunteers hand out the condoms in a variety of settings, such as classrooms, health clinics, churches, community events and college campuses. While we may offer support and tips for individual distributions, this peer-to-peer strategy is focused on volunteers choosing where they would like

to hand out the condoms, allowing us to reach different audiences in a wide range of communities that we might not otherwise have access to.

2) The Center organizes several coordinated distributions each year where thousands of condoms are sent out to be given away within a particular timeframe or following a theme. Volunteers are recruited around holidays that are particularly relevant, like Valentine's Day and Earth Day. We have also recognized World Population Day, Earth Overshoot Day and World Contraception Day. Additionally, we send condoms to strategic decision-makers. For example, in 2017 we sent the Endangered Species Condoms to all 100 U.S. Senators for World Population Day connected to a vote on the Affordable Care Act. We also sent them to President Trump's appointees to Health and Human Services.

   By using both traditional and social media to promote these distributions, we're able to extend the reach of the condoms. This is done by placing op-eds, blog posts, and targeted local outreach. These allow the conversations to go beyond just those people who are receiving the Endangered Species Condoms. For example, a tweet one senator posted with a picture of the condoms received more than 4,700 likes, 1,600 retweets, and 170 comments as well as attracting attention from online alternative news outlets.

3) The interactive Pillow Talk program gives away condoms at special events held at zoos, museums, science centers and other science center locations (described in more detail below).

Over the ten years the Endangered Species Condoms project has been active, there have been three iterations of six condom package designs highlighting different species. The artwork has been updated to keep the designs contemporary and different species have been included to represent a broad range of wildlife affected by human population growth. Some species, like the polar bear and hellbender, have been present in multiple sets. We also incorporated four Spanish-language designs in 2017, translating the polar bear and monarch butterfly packages and adding the vaquita porpoise and Mexican gray wolf. The intention was to expand our reach by being more inclusive with our messaging.

The Endangered Species Condoms project also expanded in 2017 to include an environmental education and outreach program called Pillow Talk. This program uses engaging activities to discuss the relationship between population and patterns of consumption, and how Americans' disproportionate impact per individual is an important component of our unsustainable population growth.

This program started with zoo, museum, and science center adult-only event audiences but can be adapted for other settings. We started with these particular audiences because studies show that people who visit these institutions are more interested than the average person in ways they can reduce their individual impact (Falk, 2014)(Falk *et al.*, 2007). Often, they are unaware of the greenhouse gas emissions impact that having a child has and now can add family planning to their emissions reduction toolkit (Wynes and Nicholas, 2017)which records the aggregation of billions of individual decisions. Here we consider a broad range of individual lifestyle choices and calculate their potential to reduce greenhouse gas emissions in developed countries, based on 148 scenarios from 39 sources. We recommend four widely applicable high-impact (i.e. low emissions).

In the past two years, the Center has worked with 53 different institutions and participated in 100 events around the country. We estimate that we've reached tens of thousands of individuals through these events that host anywhere from 100 to 3,000 visitors. Volunteers represent the Center at these events to help explain the message behind the Endangered Species Condoms, answer questions and facilitate environmental education activities.

The activities provided for Pillow Talk events are designed to also address the consumption side of the population equation. A game called Carbon Budget Monopoly helps participants gain a better understanding of the components of their carbon footprint. Players start with an amount of money to represent the amount of carbon dioxide that the average American is responsible for annually. They are then asked a series of questions about their daily life related to diet, transportation, energy use and having children. Potential answers are broken down into categories to simplify the responses and calculations. The higher the environmental impact of an answer, the more money is owed. For example, someone who eats meat every day would pay more than a vegetarian or vegan. The amount of money left over at the end of the game gives the player an idea of how they compare to the average American and understanding of what actions make up the biggest parts of their carbon footprint.

Evaluating success

There are challenges in assessing the behavior change of a large national audience, particularly around long-term issues such as having children or contraceptive use. Since the condoms are given away at a variety of events by volunteers, we aren't able to follow up with the recipients to learn if the condoms changed their perceptions, influenced their family planning decisions or prompted them to have additional conversations. As a result our evaluation focuses on measuring the number of conversations between volunteers and condom recipients, the quality of conversations, social media and earned media.

High-quality conversations are those where we're reaching the intended audience and the message of the condoms is discussed beyond just the novelty of the packaging. This is built into the model for Pillow Talk events. For individual distributors, we are selective in opportunities when screening the requests for the Endangered Species Condoms. Distributors with a specific plan and audience are preferred. For example, an environmental science professor at Bellevue College uses the condoms in her lesson plan. She talks about the connection between population and species decline and then gives the condoms to her students with an assignment to share the condoms with someone else and tell them about the connection. The students then write a paper about how the conversation went.

Though we aren't able to track how every volunteer conversation goes, we do receive feedback from volunteers and event coordinators from Pillow Talk events, which helps us evaluate the events and refine our training materials as needed. A volunteer from an event in Florida describes visitors' reactions to the condoms:

> *"As a volunteer, I immediately saw positive changes in people's expressions and increases in enthusiasm for listening to our message when I mentioned the condoms. People seemed much more engaged by the unusual topic and were genuinely excited about getting to take the packages home to show people."*

An event coordinator in Texas emphasizes the importance of drawing these connections for visitors:

> *"The Endangered Species Condoms proved a strong attraction for our guests and a wonderfully playful gateway into connecting the dots between human behavior and its larger consequences on the environment. The mission of increasing awareness of our impact on the globe – from climate change to infringing on natural habitats – can and should be a part of our daily consciousness."*

We continue to solicit feedback from individual volunteers, event volunteers, and event coordinators so that we can continually better understand how our message is received.

Conclusion

Endangered Species Condoms present a unique way to discuss human population growth and its impacts on our environment. They function as both a messenger and tool for our recommended solutions. Based on the principles of social marketing, the condoms serve as an eye-catching form of advocacy, helping people make the connection between wildlife and family planning and, by extension, between conservation and reproductive rights. This project makes these issues more approachable, which we hope continues to inspire both individuals and other environmental groups to recognize the importance of tackling population as the urgent issue it is.

References

Adamy, J. and Overburg, P., 2019. Immigrants propel population growth in 10% of U.S. counties. *Wall Street Journal*. [online] Available at: <https://www.wsj.com/articles/immigrants-propel-population-growth-in-10-of-u-s-counties-11555560061> [Accessed: 23 October 2019].

CBD, n.d.. *Statement on Immigration and Population*. [online] Available at: <https://www.biologicaldiversity.org/programs/population_and_sustainability/immigration_statement.html> [Accessed: 29 October 2019].

Clinchy, M. et al., 2016. Fear of the human "super predator" far exceeds the fear of large carnivores in a model mesocarnivore. *Behavioral Ecology*. 27 (6), pp. 1826-1832. doi: 10.1093/beheco/arw117.

Dennings, K., 2018. Changing behaviors. In: Social Marketing Association of North America. *Missouri Recycling Association 2018 annual conference: creating connections*. Kansas City, MO. 11-13 September 2018.

Falk, J. H. et al., 2007. *Why zoos & aquariums matter: assessing the impact of a visit to a zoo or aquarium.* [online] Association of Zoos and Aquariums. Available at: <www.aza.org> [Accessed: 16 October 2019].

Falk, J. H., 2014. Evidence for the educational value of zoos and aquariums. [online] *World Association of Zoos and Aquariums Magazine*, 15. Available at: <www.waza.org> [Accessed: 16 October 2019].

Feldstein, S., 2015. A long-overdue burial for the population vs. consumption question. [online] Ensia. Available at: <https://ensia.com/voices/a-long-overdue-burial-for-the-population-vs-consumption-question/> [Accessed: 29 October 2019].

Finer, L. B. and Zolna, M. R., 2016. Declines in unintended pregnancy in the United States, 2008-2011. *New England Journal of Medicine*, 374 (9), pp. 843–852. doi: 10.1056/NEJMsa1506575.

Guttmacher Institute, 2019. *Sex and HIV education.* [online] Guttmacher Institute. Available at: <https://www.guttmacher.org/state-policy/explore/sex-and-hiv-education> [Accessed: 22 October 2019].

Harvey, P. D., 1999. *Let every child be wanted: how social marketing is revolutionizing contraceptive use around the world.* Westport, CT: Auburn House.

Kotler, P. and Zaltman, G., 1971. Social marketing: an approach to planned social change. *Journal of Marketing*, 35(3), p. 3. doi: 10.2307/1249783.

Lee, N. and Kotler, P., 2011. *Social marketing: influencing behaviors for good.* 4th edition. London: SAGE Publications.

Manoff, R. K., 1985. *Social marketing: new imperative for public health.* Westport: Praeger Publishers.

McKee, J., Chambers, E. and Guseman, J., 2013. Human population density and growth validated as extinction threats to mammal and bird species. *Human Ecology*, 41 (5), pp.773–778. doi: 10.1007/s10745-013-9586-8.

McKenzie-Mohr, D., 2011. *Fostering sustainable behavior: an introduction to community-based social marketing*. Gabriola Island, BC: New Society Publishers.

McKinney, M. L., 2001. Role of human population size in raising bird and mammal threat among nations. *Animal Conservation*, 4 (1), pp. 45–57. doi: 10.1017/S1367943001001056.

Michie, S., Atkins, L. and West, R., 2014. *The behaviour change wheel: a guide to designing interventions*. London: Silverback Publishing.

Nations, U., 2019. *Growing at a slower pace, world population is expected to reach 9.7 billion in 2050 and could peak at nearly 11 billion around 2100* [online] UN DESA United Nations Department of Economic and Social Affairs. Available at: <https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html> [Accessed: 22 October 2019].

Rosenberg, K. V. et al., 2019. Decline of the North American avifauna. *Science*, p. eaaw1313. doi: 10.1126/science.aaw1313.

Ryerson, W. N., 2018. The hidden gem of the Cairo consensus: helping to end population growth with entertainment media. *The Journal of Population and Sustainability*. 2 (2), pp. 51–61.

Scott, J. M., 2008. *Threats to biological diversity: global, continental, local.* U.S. Geological Survey, Idaho Cooperative Fish and Wildlife, Research Unit, University of Idaho.

Suraci, J. P. et al., 2019. Fear of humans as apex predators has landscape scale impacts from mountain lions to mice. *Ecology Letters*. 22 (10). pp. 1578–1586.

UNSDG, 2019. *UN report: nature's dangerous decline 'unprecedented'; species extinction rates 'accelerating'.* [online] Sustainable Development Goals. Available at: <https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/> [Accessed: 2 October 2019].

UNESCO, 2010. *Population continues to grow*. [online] Available at: <http://www.unesco.org/education/tlsf/mods/theme_c/popups/mod13t01s001.html> [Accessed: 22 October 2019].

Wiebe, G. D., 1951. Merchandising commodities and citizenship on television. *Public Opinion Quarterly*, 15 (4), p.679. doi: 10.1086/266353.

Wynes, S. and Nicholas, K. A., 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. *Environ. Res. Lett*, 12 (7), p. 74024. doi: 10.1088/1748-9326/aa7541.

PEER REVIEWED ARTICLE

Anticipating urbanization-led land cover change and its impact on local climate using time series model: a study on Dhaka city

Ripan Debnath[1]

Department of Environmental Science and Management,
North South University, Dhaka, Bangladesh

Abstract:

Urbanization-led changes in natural landscape often result in environmental degradation and subsequently contribute to local climate variability. Therefore, apart from global climate change, Dhaka city's ongoing rapid urban growth may result in altering future local climate patterns significantly. This study explores transition relationships between urbanization (population), land cover, and climate (temperature) of Dhaka city beginning in 1975 through to forecast scenarios up to 2035. Satellite image, geographic, demographic, and climatic data were analyzed. Change in core urban land cover (area) was regarded as a function of population growth and was modeled using linear regression technique. The study developed and validated a time series (ARIMA) model for predicting mean maximum temperature change where (forecasted) land cover scenarios were regressors. Throughout the studied period, the city exhibited an increasing urbanization trend that indicated persistent growth of core urban land cover in future. As a result, the city's mean maximum temperature was found likely to increase by around 1.5-degree Celsius during 2016–2035 on average

1 dbn.ripan@gmail.com

from that of observed 1996–2015 period. It is expected that findings of this study may help in recognizing urbanization-led climate change easily, which is crucial to effective climate change management actions and urban planning.

Keywords: urbanization; land cover; climate change; time series model; Dhaka city

1. Background

Urbanization is the process of growth in the proportion of a country's total urban population (Thomas, 2008). The majority of the global population currently live in urban areas, in 2018 this amounted to more than 4 billion people (UN DESA, 2019) and this number is growing at an annual rate of nearly 2% (World Bank, 2018). By 2050, proportion of the global urban population is likely to rise to 68% which will be mostly contributed by countries in Asia and Africa where the rate of urbanization is most rapid (UN DESA, 2019). Relevantly, it has been predicted that Dhaka will have more than 28 million people by 2030 (UN DESA, 2019). Dhaka is the capital of Bangladesh and the center of political, cultural and economic life. After liberation in 1971, the population of Dhaka started to rise sharply and since 1991 Dhaka has experienced remarkable urban growth (Rahman, et al., 2008). The previous annual population growth rate of Dhaka city of 4.2% (Biswas, et al., 2010) has recently shrunk to 3.48% (BBS, 2012). A study conducted by the World Bank revealed that sprawl intensity and coverage were increasing day by day within the Dhaka Statistical Metropolitan Area (World Bank, 2011). The probable reasons for this trend are population boom, very high land price in planned areas, development management inefficiency, etc. Therefore, historical change and urban growth pattern monitoring of Dhaka Metropolitan Area using remote sensing technologies (Ahmed, et al., 2013; Ahmed & Ahmed, 2012; Dewan & Yamaguchi, 2009a; Dewan & Yamaguchi, 2009b) have been of great interest to the scientific community.

Urbanization is always accompanied by several changes in socio-economic, cultural and demographic settings (Khoury, 1982). When characterized by rapid population growth, sprawl, poverty, etc., it creates stress in the urban environment, triggering environmental problems and risks for urban inhabitants (WHO, 2000). In this regard, Dhaka city is anticipated to be affected in two major ways; heat stress and flooding (multiplied by drainage congestion) as consequences of ongoing climate change (UN-HABITAT, 2008; Alam & Rabbani, 2007). A slight rise in sea level may engulf large parts of the city and negative consequences are likely to be felt by a large number of people; especially the urban poor who live in flood-prone and waterlogged areas (UN-HABITAT, 2008). Thus, the city needs to develop advanced knowledge of potential climate change, its impact and the mechanisms to overcome the situation.

Climate change has forced many rural people in Bangladesh to migrate to cities and this has caused a sharp rise in the slum population of Dhaka (Aulakh, 2013). Climate change is a global issue with great importance requiring adaptation and mitigation (United Nations, n.d.) otherwise a cascade of naturally triggered disasters will devastate the known forms of life on earth. "Climate change impacts and consequences can wipe out development gains and significantly reduce the standard of living" (Prasad, et al., 2009 p.10). Yet, cities can take active steps to minimize climate change induced or other natural disaster risks/impacts by improving planning, creating effective infrastructure and establishing disaster preparedness. In this regard, climate change prediction can help in developing local prevention, mitigation and adaptation strategies to minimize probable loss.

Due to urbanization, the increased demand for land for non-agricultural purposes (e.g. for urban residential and industrial use) is the main driver of land use and land cover[2] change (LULCC) (Coskun, et al., 2008). Evidence shows that LULCC has effects on climate change (Dale, 1997; Thompson, et al., 2011). As with the production of greenhouse gases, LULCC has significant effects on atmosphere, climate and sea level in both global and local systems (Meyer & Turner, 1992; Pielke, 2005; Hong Kong Observatory, 2012). Land cover change by new city elements and their surface materials alters energy, water exchanges and airflow. Urban climate also varies with these factors in a conjunction with direct anthropogenic emissions of heat, CO_2 and pollutants (Grimmond, 2007). For instance, "…small changes of 100 square kilometers in urban development or deforestation can change local rainfall patterns and trigger other climate disruptions" (Climate Future Group, 2006).

2 Land-use and land cover terms are often used interchangeably. However, the underlying difference between those is land-use stands for the particular use (e.g. residential / commercial etc.) of land whereas the land cover means the surface cover (e.g. urban area/ vegetation etc.) on the ground (Coffey, 2013).

From the above discussion, it is clear that Dhaka city is at risk of facing negative environmental consequences propelled by ongoing rapid urbanization. Migrating population, voluntary and forced (e.g. environmentally displaced), is adding pressure to the city at a significantly higher rate (6%) than the country's overall rate of internal migration (4.5%) (Xinhua, 2013; Khan, 2012). These migrants, typically unskilled and having lost their livelihoods, merge into the urban poor and often become even poorer than before migrating (Stojanov, 2005). They generally settle in low-lying flood prone areas in cities and gradually transform urban ecosystems and landscapes (UNU-IHDP, 2015) resulting in environmental degradation. Given predicted climatic vulnerability, it is necessary to anticipate urbanization-induced land cover change and associated future climate change so that proper adaptation and mitigation measures can be planned and initiated.

2. Objectives and scope

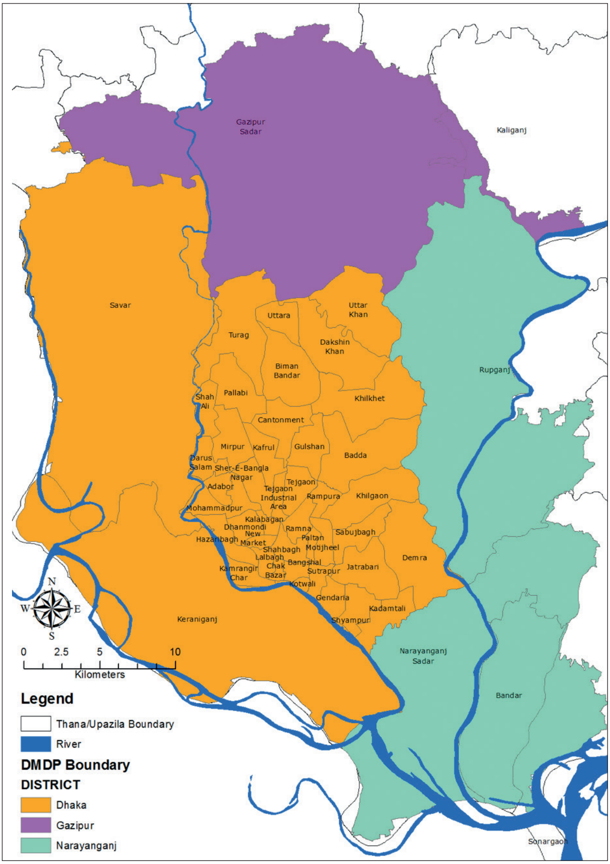
The objective of this study is to ascertain changes in future climate of Dhaka city in relation to the predicted land cover change using long term observational data. The study assumes that land cover change due to future urbanization is likely to bring changes on climate pattern of the study area. Hence, it targets to understand and explore the underlying relationships among urban population, land cover, and climatic parameter based on historical evidences. For performing the study, Dhaka Metropolitan Development Planning (DMDP) area is taken into consideration. It includes city corporation areas and other some peripheral urban centers and localities, which is governed by the *Rajdhani Unnayan Kartripakkha* (RAJUK) i.e. capital city development authority. The extent of the DMDP area is around 1439 km^2 (RAJUK, 2011) which is shown in Figure 1 along with local administrative Thana[3] and Upazila[4] boundaries.

Among different factors of urbanization economic growth, industrialization, exports, residential GNP per capita, agricultural productivity, size of total population, start date of modernization etc. are very dominant (Bairoch & Goertz, 1986). However, the study does not investigate the factors behind Dhaka's urbanization but examines its trends. The study recognizes change in urban population and land cover as the consequences of change in social, economic

3 Thana: administrative area/region in urban area controlled by a police station.

4 Upazila: the sub-division of a District, i.e. sub-district.

Figure 1: Administrative Map of the Study Area



and policy aspects as well as the management efficiency or inefficiency of the concerned authorities.

3. Method

Most commonly, remote sensing and Geographic Information System (GIS) are used to monitor and measure land-use changes. Numerous researchers have worked with multi-temporal digital satellite imagery and GIS database for comparing and assessing LULCC (Coskun, et al., 2008; Reis, 2008; The World Bank, 2012; Malaque & Yokohari, 2007; Gregorio & Jansen, 2005; Thompson, et al., 2011; Long, et al., 2007).

In climate change prediction/research, time series data and autoregressive integrated moving average (*ARIMA*) model has been frequently employed (Piwowar & Ledrew, 2002; Romilly, 2005; Ye, et al., 2013; Afrifa-Yamoah, 2015). This study has followed a similar method by developing a time series (1975–2015) database and ARIMA model with regressors for predicting climate change. Notably, regional climate change measurement accounts for maximum temperature trends only (Pielke, 2005). Therefore, the study attempts to predict change in mean maximum temperature of Dhaka city to ascertain probable climate change. This study's urban population, land cover, and maximum temperature predictions follow the timeframe (2016–2035) of the DMDP's second Structure Plan[5] (RAJUK, 2015). The study's detailed methodological aspects are described in the following sub-sections.

3.1 Land cover data

The study collected historical Landsat images (multispectral only) of the Dhaka region for 1975, 1989, 1999 & 2006 from the official data archive of the U.S. Geological Survey (USGS, n.d.). It worth mentioning that available images for 1975, 1989, and 1999 in the archive did not cover the DMDP (area of interest) entirely, consequently the next available years' data were collected (Table 1). The downloaded data, having less than 10% cloud coverage, were then projected to the Universal Transverse Mercator (UTM) – Zone 46 North with the World Geodetic System (WGS) – 1984 datum. Spatial resolution of these images was 30 × 30 meters except for 1975 images (Table 1) which were resampled to this specification. Apart from this, no further pre-processing was performed. Seasonality was ignored as all images were captured between November and March, which broadly falls in winter. As greeneries/vegetation, open space, and waterbodies contribute greatly in regulating local climate (Bolund & Hunhammar, 1999), the study has extracted land cover data under the following four categories:

1. Dense/Core Urban: densely developed urban lands areas within the study area.

2. Underdeveloped (Non-Urban & Agriculture): rural settlement, vacant/ open space, agricultural lands, services/ institutional area, proposed urban area, etc..

5 It is the long-term (20-year) strategic planning document of the DMDP area, which provides urban development strategies and planning proposals for the area.

3. Green/Reserved: homestead vegetation, forests, parks, restricted and reserved lands/ playgrounds, etc..

4. Waterbody: marshland, river, canal, pond, etc. areas.

Table 1: Particulars of collected Landsat images from the USGS archive

Data year (as regarded)	Acquisition Date	Path/ Row	Coverage of the study area	Sensor	Pixel size (meters)
1975	27-Mar-75	147/43	85%	MSS	60 x 60
	08-Feb-77	147/44	15%		
1989	04-Nov-89	137/44	85%	TM	30 x 30
	26-Nov-91	137/43	15%		
1999	24-Nov-99	137/44	85%	ETM+	30 x 30
	28-Feb-00	137/43	15%		
2006	27-Jan-06	137/43 and 137/44	100%	ETM+	30 x 30

Supervised Classification method, where user/analyst selects representative samples for each land cover category in the digital image, was applied during image analysis. To test accuracy of classified outputs, a total 100 stratified random samples were taken from four land cover classes. The Urban Area Plan (1995-2005) (RAJUK, 1995) and Detailed Area Plan[6] (DAP) (RAJUK, 2010) maps as well as high resolution Google Earth images were used while checking representativeness of actual land cover in the classification outputs. The overall accuracy of 1975, 1989, 1999, and 2006 classified images were 85%, 90%, 88%, and 91% with Kappa coefficients of 0.80, 0.86, 0.84, and 0.88 respectively. As the accuracy figures met the standard requirement for LULCC studies (Dewan & Yamaguchi, 2009a), no further actions to improve these classification outputs was taken. Total area under different land cover categories from the analyzed four image sets were calculated, summarized, and stored. Furthermore, recent land cover statistics from 2013 were extracted from generalized land use data used in the structure plan (RAJUK, 2015)

6 It is third and last tier of Development Plan for DMDP area, which provides further detailed urban planning proposals for specific sub-areas in the lights of the Structure Plan and the Urban Area Plan.

preparation work. At the end of this stage, land cover information of five different periods (1975, 1989, 1999, 2006 and 2013) were prepared and accumulated for further analyses.

3.2 Demographic data

The study has collected population census data from the years 1981 (BBS, 1981), 1991 (BBS, 1991), 2001 (BBS, 2001) and 2011 (BBS, 2012) for Dhaka, Gazipur and Narayanganj Districts (falling within the DMDP area). Here, enumerated population under corresponding Thanas and Upazilas (administrative regions) were considered. For calculating partial population at the periphery, overlying Upazila area (part) was multiplied by the gross population density of that particular Upazila as no other spatially distributed demographic data for that area were found.

3.3 Climatic information

Climatic information, recorded at Dhaka station, were collected from Bangladesh Meteorological Department (BMD, 2017) for the 1975–2015 period. Monthly maximum temperature values, in degree Celsius (°C), were arithmetically averaged to obtain the yearly mean maximum temperature (hereafter referred as temperature).

3.4 Time series database

At this stage, Underdeveloped (Non-Urban & Agriculture) and Green/Reserved land covers are aggregated into one category named 'Potential Urban' as lands under those categories are believed to be most suitable for urban functions and uses (Naab & Dogkubong, 2013). Finally, a time series database, starting from 1975, has been developed by combining three land cover (core urban, potential urban & waterbody) categories, population, and temperature data. To obtain in-between population and land cover figures of two base years, linear interpolation method was applied.

3.5 Forecasting method and ARIMA model

Population to the year of 2035 was projected using graphical method (FHWA, 2001). Moreover, exponential forecasting method (using F1 and F2) (George, et al., 2004) was applied since Dhaka experienced a near exponential growth trend in recent decades (Iqbal & Khan, 2005). The study compared those two outcomes and considered the lowest figure as the minimum probable population by the predicting year for further analyses.

Population of forecasted year $P_2 = P_1 \times e^{r*(t_2-t_1)}$ (F1)

The study followed formula F2 for computing population growth rate where P_2 and P_1 were the population of last (t_2) and first (t_1) assessment year respectively.

Population growth rate $r = \frac{\ln P_2 - \ln P_1}{t_2 - t_1}$ (F2)

As the prepared land cover statistics were not originally time series (but sample) data, a linear regression model was applied to predict its future change. Here, population growth in the DMDP area has been viewed as a key contributor to core urban land cover change. Thus, forecasted population was used as the only regressor in building a linear model for core urban area prediction. Average annual gain/loss rate of waterbodies (land cover) has been used in forecasting their future status. Potential urban land cover area was calculated by deducting the sum of core urban and water-body areas from the total DMDP area. Land cover change rate(s) within the considered periods was assessed with the following formula F3 (Long, et al., 2007) where LC_2 and LC_1 were present and past land cover area respectively for a time interval (t).

Land cover change rate $LC_r = \frac{LC_2 - LC_1}{LC_1 \times t}$ (F3)

The study developed and applied an ARIMA (time series) model for predicting temperature change by the year of 2035. Before executing ARIMA, Augmented Dickey-Fuller test for unit root was performed on collected temperature records for a stationarity check of the time series. Since the temperature records were yearly data, seasonality test was not necessary. To identify the appropriate ARIMA model structure, Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) were tested. Finally, Akaike Information Criterion (*AIC*) and Bayesian Information Criterion (BIC) tests, where lower values signify the best-fitting model, were performed to determine goodness of fit of the tested ARIMA model(s). Notably, in the temperature change model, all (predicted) land cover categories were considered as regressors, since this study aimed to explore the impact of urban land cover change on the city’s temperature by 2035.

Figure 2: Proportion and area (in km²) of different land-cover categories during collected data periods

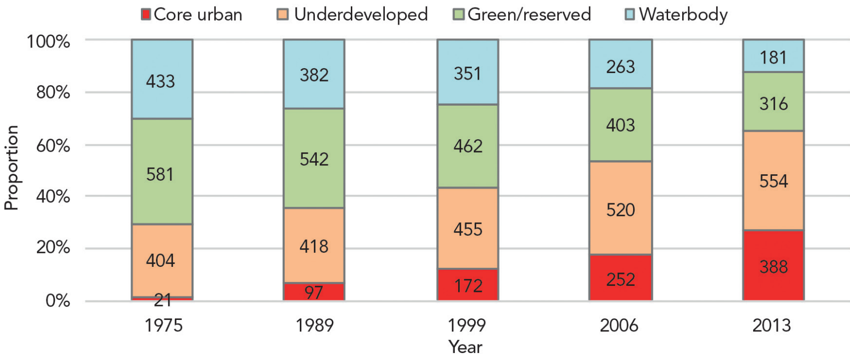


Table 2: Observed land-cover change rate over the periods

Land-cover category	1975–1989	1990–1999	2000–2006	2007–2013	Weighted Average
Core Urban	26.1%	7.7%	6.7%	7.7%	12.0%
Underdeveloped	0.2%	0.9%	2.1%	0.9%	1.0%
Green/ Reserved	-0.5%	-1.5%	-1.8%	-3.1%	-1.7%
Waterbody	-0.8%	-0.8%	-3.6%	-4.5%	-2.4%

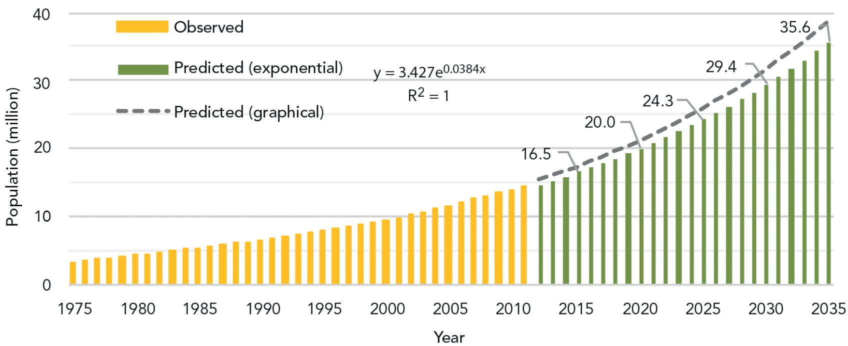
4. Results

Land cover statistics obtained from analyses are shown in Figure 2 from which change rates were calculated for different periods under corresponding land cover categories (Table 2). During the period 1975–2013, core urban and underdeveloped land covers were found growing annually at 12% and 1% rate respectively. However, in contrast, both green and waterbody land (cover) areas were found decreasing at around and above a rate of 2% per annum respectively. Total adjusted population of the study area in 2011 was found to be 14.2 million (Figure 3). During 2001–2011 period, population in Gazipur District was growing at nearly twice the rate (5.4%) per annum compared to the other two Districts. Interestingly, the population in the peripheral Districts was observed to be growing at a faster rate than central (below Dhaka District) region. With the help of forecasting methods discussed in section 3.5, probable population, land cover and temperature changes for the study area by 2035 (year) were estimated. The following sub-sections highlight different forecasted results.

4.1 Future population

The exponential method offered lower population figures than graphical method (Figure 3). While considering the lowest probable population, the model predicted the possibility of the study area having around 24.3 million inhabitants by the year 2025. Relevantly, it has been claimed that Dhaka city might have 23.6 million (Parvin, 2013) to 25 million (Davis, 2006) residents by 2025 which were close to the study's projection. Thus, the study considered forecasted population reliable and extended it to 2035, which resulted in an estimated population of above 35 million for the study area by that time.

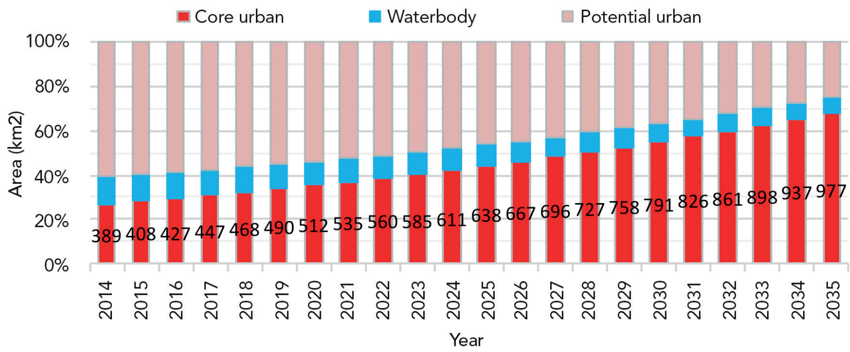
Figure 3: Observed and forecasted population of the study area



4.2 Imminent land cover change

Using liner regression model (see model summary in Appendix 1), core urban land cover of the study area by 2035 was approximated to be around 977 km^2 i.e. nearly 68% of the study area (Figure 4). Waterbody (land cover) area was estimated, using its annual average loss rate i.e. (-) 2.4% (see Table 2), to extend over only around 106 km^2 (7% of total) area. The remaining 25% (356 km^2) area was found likely to remain as potential urban space. In a related study, Ahmed and Bramley (2015) concluded that, in the absence any spatial development strategies, by 2025 more than 60% of total DMDP area would possibly be urbanized. However, they also observed that restrictions on reserved land may save around 15% from conversion into (core) urban land cover.

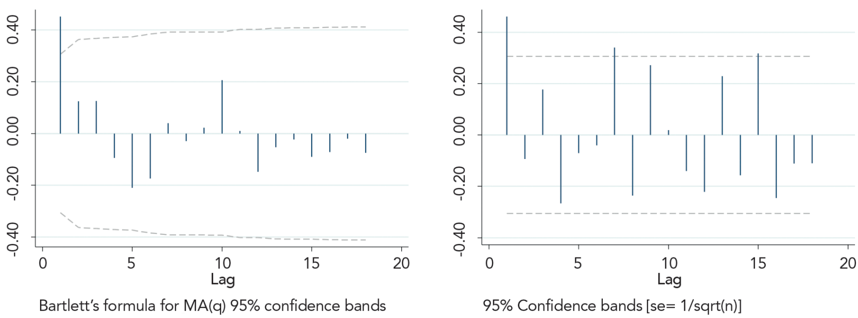
Figure 4: Predicted land cover scenario (using linear model) of the study area by 2035



4.3 Probable temperature change

The Dickey-Fuller test, performed on collected temperature (1975–2015) records, found the time series stationary ($p = 0.0029$). Hence, ACF and PACF of temperature records were checked (Figure 5) to build an appropriate ARIMA model. The ACF graph set a clear indication of moving average (MA) and the model's suitability for temperature change assessment. Therefore, this study considered testing ARIMA(0,0,1) and $MA_{(1\ 10)}$ for lags 1 and 10 models with constant (series mean). Additionally, looking into the shape of PACF, an autoregressive $AR_{(1\ 7\ 15)}$ model for significant lags 1, 7 and 15 with constant (series mean) was also rendered.

Figure 5: ACF and PACF graphs of collected mean maximum temperature data

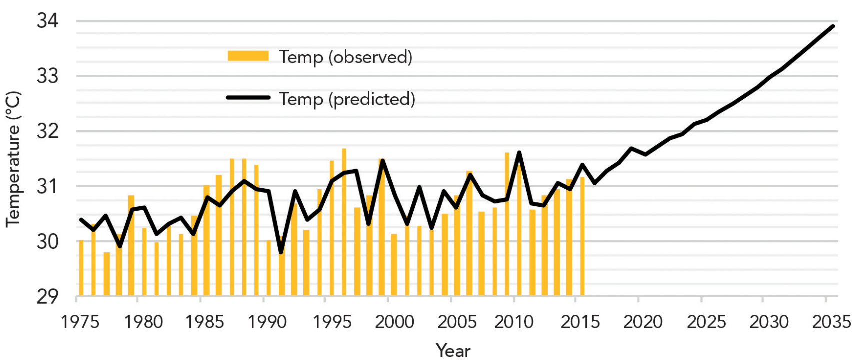


It was found that ARIMA(0,0,1) failed to pass probability test as its probability (> chi^2) value was above acceptable 0.05 (Table 3) range. From the remaining tests, $MA_{(1\ 10)}$ model was found to be the best fit for maintaining lower AIC and BIC values (Table 3). Later, the same $MA_{(1\ 10)}$ model (see model summary in Appendix 2) was applied to forecast temperature to the year 2035 where the previously predicted land covers were input as regressors. The resulting prediction (Figure 6) showed that between 2016 and 2035 the study area is likely to experience a nearly (+)1.52°C increase in mean maximum temperature compared to the 1996–2015 period.

Table 3: Test result of considered temperature (ARIMA) models

Summary	Temperature (1975–2015)		
	$AR_{(1\ 7\ 15)}$	ARIMA(0,0,1)	$MA_{(1\ 10)}$
Number of observations		41	
Probability > chi2	0.0093	0.517	0.0001
AIC	62.20853	55.44885	55.32161
BIC	75.91711	64.01671	67.31661

Figure 6: Observed and predicted temperature (using $MA_{(1\ 10)}$ model) of the study area



5. Discussion

The study area has exhibited a sharply increasing urbanization trend throughout the examined period resulting in rapid land use and land cover change (LULCC).

During 1981-2011 period, population in the Dhaka Metropolitan Development Planning (DMDP) area was found to be growing at an average annual rate of 3.84% as opposed to the country's overall rate of growth of 2.04% (World Bank, 2013) rate. Dhaka's population growth predominantly consists of migrants from rural areas attracted by the advantages of urban life (Hossain, 2008; Islam, 1999; Alam & Rabbani, 2007). In line with the general predictions relating to Dhaka city in respect of climate change vulnerabilities (UN-HABITAT, 2008; Alam & Rabbani, 2007), the study has revealed predicted increases in mean maximum temperature in the period 2016-2035. Such temperature rise may be the consequence of global and regional environmental change as well as local land cover change. To mitigate and adapt to the consequences of climate change or natural disasters, it is important to foresee the probable scenario. This study has communicated information relevant to such probable scenarios based on future urban population, probable land cover changes, and associated temperature (climate) change by 2035 for the DMDP area.

Considering the study's prediction, the expansion of core urban land cover in this area may significantly increase the volume of surface runoff while retentions and water channels (to retain and transfer rainwater to the surrounding outfalls (rivers)) were being depleted or insufficiently maintained. During monsoon (May to October), the level of surrounding rivers remains higher than the city's internal drainage level (Mowla & Islam, 2013). Consequently, the drainage capacity of those rivers reduces, and the city faces severe waterlogging from medium to high showers of rain. Over previous decades the city authority replaced many canals and low-lying runoff channels with roads and other infrastructure developments (Mowla & Islam, 2013). Moreover, illegal encroachment by influential people has led to the disconnection of many water drainage channels, drastically reducing their carrying capacity. Poor management of surface drainage network exacerbates waterlogging which may lead to flooding following prolonged rainfall.

In the light of the study's findings, it is apparent that urban (population) growth management can contribute to minimizing temperature increases in Dhaka city. Dhaka's inexorable growth is the reflection of extreme centralization of decision-making and political authority (Rahman, 2012). In this connection, '*smart growth*' principles (Corrigan, et al., 2004) like limiting outward expansion, encouraging higher density development, promoting mixed-use zoning, revitalizing older areas, etc. can be adopted. This study revealed a comparatively higher population growth rate in peripheral (fringe) areas characterized by sprawl development patterns (Rahman, et al., 2008). Improved governance with strict control and monitoring of the urban area plan, conservation and restoration of protected lands, etc. can reduce loss of climate control sinks e.g. greeneries, open space and waterbodies.

The urban system is a complex mosaic of climate, land use, biophysical, and socio-economic variables. In this study, land cover and climate change prediction work at city scale examined historic observational data and applied linear and time series model respectively. The study's considered parameters are very dynamic in nature and established models are not simple, precise, and always mathematical. Moreover, temperature (climate) change prediction used local parameters only where the impact of anticipated global/regional climate change (IPCC, 2014) on the study area was overlooked. However, it is commonly understood that the worst consequences of ongoing global climate change e.g. extreme weather conditions, seaward hazards, etc. would be felt by low-lying coastal cities like Dhaka (UNU-IHDP, 2015; UNFCCC, 2018). The study has analyzed five datasets to assemble 1975-2015 land cover scenarios, this can be improved by inputting more evidence from intermediate years. The observed mean annual degradation rate of waterbodies has been used in predicting future scenarios, which may vary in practice. Indeed, change in protected lands e.g. waterbodies and public spaces may not follow the observed pattern as their conservation greatly depends on the operational and management efficiency of the local government/authorities.

Urbanization is always accompanied by multiple changes in the socio-economic, cultural and demographic setting (Khoury, 1982). The relationship between socio-economic development and changes in land use that determines LULCC in both urban and rural areas is dynamic (Long, et al., 2007). This study has not evaluated social factors and their dynamics, investigation of these factors would form a valuable focus for future research. Setting aside these limitations, the predictions can still contribute in formulating development guidelines that are responsive to climate change. Concerned city planners and decision makers need to focus on managing the growth of both population and core urban land cover for climate change management of the DMDP area. The study's implications can be employed to mitigate and minimize climate change related negative externalities of Dhaka city notwithstanding any artificial or natural interventions large enough to alter the observed pattern. As a final point, this study may help to understand the underlying dynamism of similar contexts, as well as to quantify the future degree/level of change in maximum temperature for other urban areas.

Appendix 1: Summary of core urban land cover prediction model (linear regression)

Source	SS	df	MS
Model	407937.023	1	407937.023
Residual	1783.30564	37	48.1974497
Total	409720.329	38	10782.1139

Number of obs =	39
F(1, 37) =	8463.87
Prob > F =	0
R-squared =	0.9956
Adj R-squared =	0.9955
Root MSE =	6.9424

Core urban	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
Population	29.77811	0.3236775	92	0	29.12227	30.43394
_cons	-84.8169	2.848425	-29.78	0	-90.58836	-79.04544

Appendix 2: Summary of $MA_{(1\ 10)}$ temperature prediction model (time series)

Sample: 1975 - 2015
Log likelihood = -20.6608

Number of obs =	41
Wald $chi^2(5)$ =	27
Prob > chi^2 =	0.0001

Temperature	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Urban_linear	0.0113777	0.031017	0.37	0.714	-0.0494146	0.07217
Potential_urban	0.0059544	0.0379652	0.16	0.875	-0.0684559	0.0803648
Waterbody	0.0111241	0.0295961	0.38	0.707	-0.0468833	0.0691314
_cons	19.49265	49.57308	0.39	0.694	-77.6688	116.6541
ARMA ma						
L1.	1.056285	0.2801433	3.77	0	0.5072141	1.605356
L10.	0.1880118	0.1236563	1.52	0.128	-0.05435	0.4303736
/sigma	0.3658156	0.0871539	4.2	0	0.1949971	0.5366341

References

Afrifa-Yamoah, E., 2015. Application of arima models in forecasting monthly average surface temperature of Brong Ahafo region of Ghana. *International Journal of Statistics and Applications*, 5(5), pp. 237–246.

Ahmed, B. & Ahmed, R., 2012. Modeling urban land cover growth dynamics using multi temporal satellite images: a case study of Dhaka, Bangladesh. *ISPRS International Journal of Geo-Information*, 1(1), pp. 3–31.

Ahmed, B. et al., 2013. Simulating land cover changes and their impacts on land surface temperature in Dhaka, Bangladesh. *Remote Sensing*, Volume 5, pp. 5969–5998.

Ahmed, S. & Bramley, G., 2015. How will Dhaka grow spatially in future?- modelling its urban growth with a near-future planning scenario perspective. *International Journal of Sustainable Built Environment*, 4(2), pp. 359–377.

Alam, M. & Rabbani, M. G., 2007. Vulnerabilities and responses to climate change for Dhaka. *Environment and Urbanization*, 19(1), p. 81–97.

Aulakh, R., 2013. Climate change forcing thousands in Bangladesh into slums of Dhaka. [Online] Available at: http://www.thestar.com/news/world/2013/02/16/climate_change_forcing_thousands_in_bangladesh_into_slums_of_dhaka.html[Accessed 14 May 2014].

Bairoch, P. & Goertz, G., 1986. Factors of urbanisation in the nineteenth century developed countries: a descriptive and econometric analysis. *Urban Studies*, Volume 23, pp. 285–305.

BBS, 1981. *Community tables of dhaka district, Gazipur District and Narayanganj District,* Dhaka: Ministry of Planning.

BBS, 1991. *Community series – Dhaka Zilla, Gazipur Zilla and Narayanganj Zilla*, Dhaka: Ministry of Planning.

BBS, 2001. *Community series – Dhaka Zilla, Gazipur Zilla and Narayanganj Zilla,* Dhaka: Ministry of Planning.

BBS, 2012. *Community report – Dhaka Zila, Gazipur Zilla and Narayanganj Zilla*, Dhaka: Ministry of Planning.

Biswas, S. K., Mahtab, S. B. & Rahman, M. M., 2010. Integrated water resources management options for Dhaka City. *Proceedings of International Conference on Environmental Aspects of Bangladesh (ICEAB10)*, Japan, Sept. 2010 Kitakyushu, Japan, pp. 179–181.

BMD, 2017. *Bangladesh climate data portal*. [Online] Available at: http://bmd.wowspace.org/team/homex.php [Accessed 12 April 2017].

Bolund, P. & Hunhammar, S., 1999. Ecosystem services in urban areas. *Ecological Economics*, Volume 29, pp. 293–301.

Climate Future Group, 2006. *Causes of climate change*. [Online] Available at: www.climatefuture.org/menu/climate/causes/index.htm[Accessed 25 October 2019].

Coffey, R., 2013. *The difference between "land use" and "land cover"*. [Online] Available at: http://msue.anr.msu.edu/news/the_difference_between_land_use_and_land_cover. [Accessed 5 November 2013].

Corrigan, M. B. et al., 2004. *Ten principles for smart growth on the suburban fringe*, Washington, D.C.: ULI–the Urban Land Institute.

Coskun, H. G., Alganci, U. & Usta, G., 2008. Analysis of land use change and urbanization in the Kucukcekmece Water Basin (Istanbul, Turkey) with temporal satellite data using remote sensing and GIS. *Sensors*, Volume 8, pp. 7213–7223.

Dale, V. H., 1997. The relationship between land-use change and climate change. *Ecological Applications*, 7(3), pp. 753–769.

Davis, M., 2006. *Planet of slums*. London: Verso.

Dewan, A. M. & Yamaguchi, Y., 2009a. Land use and land cover change in Greater Dhaka, Bangladesh: using remote sensing to promote sustainable urbanization. *Applied Geography*, 29(3), pp. 390–401.

Dewan, A. M. & Yamaguchi, Y., 2009b. Using remote sensing and GIS to detect and monitor land use and land cover change in Dhaka Metropolitan of Bangladesh during 1960–2005. *Environmental Monitoring and Assessment*, Volume 150, pp. 237–249.

FHWA, 2001. *Population forecasting methods: a report on forecasting and estimating methods*, Washington, DC: Urban Planning Division, Bureau of Public Roads.

George, M. V., Smith, S. K., Swanson, D. A. & Tayman, J., 2004. Population projections. In: J. S. Siegel & D. A. Swanson, eds. *The methods and materials of demography*. 2nd ed. San Diego: Elsevier Academic Press, pp. 561–602.

Gregorio, A. D. & Jansen, L. J., 2005. *Land cover classification system – classification concepts and user manual*. 2nd ed. Rome: Food and Agriculture Organization (FAO).

Grimmond, S., 2007. Urbanization and global environmental change: local effects of urban warming. *The Geographical Journal*, 173(1), pp. 83–88.

Hong Kong Observatory, 2012. *Urbanization effect*. [Online] Available at: http://www.hko.gov.hk/climate_change/urbanization_e.htm [Accessed 22 April 2013].

Hossain, S., 2008. Rapid urban growth and poverty in dhaka city. *Bangladesh e-Journal of Sociology*, 5(1), pp. 1-24. [pdf] Available at: http://www.bangladeshsociology.org/BEJS%205.1%20Rapid%20Urban%20Growth%20and%20Poverty%20final.pdf?q=dhaka [Accessed 1 March 2020].

IPCC, 2014. *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Geneva, Switzerland: IPCC.

Iqbal, A. & Khan, M. H., 2005. *Tall buildings in the urban context of Dhaka City.* New York: Council on Tall Buildings and Urban Habitat, pp. 3–11.

Islam, N., 1999. *Urbanization, migration and development in Bangladesh: recent trends and emerging issues*, Dhaka: Centre for Policy Dialogue.

Khan, S., 2012. Arresting decline of a worst livable city. [Online] Available at: http://www.thefinancialexpress-bd.com/more.php?date=2012-08-23&news_id=140750 [Accessed 2 November 2013].

Khoury, N. F., 1982. *Interrelationship between urbanization and socio - economic changes in Syria, Beirut: population and labour policies.* Regional Programme for the Middle East.

Long, H., Heilig, G. K., Li, X. & Zhang, M., 2007. Socio-economic development and land-use change: analysis of rural housing land transition in the transect of the Yangtse River, China. *Land Use Policy*, 24(1) pp. 141–153.

Malaque, R. I. & Yokohari, M., 2007. Urbanization process and the changing agricultural landscape pattern in the urban fringe of Metro Manila, Philippines. *Environment and Urbanization*, 19(1), pp. 191–206.

Meyer, W. B. & Turner, B. L., 1992. Human population growth and global land-use/cover change. *Annual Review of Ecology and Systematics*, Volume 23, pp. 39–61.

Mowla, Q. A. & Islam, M. S., 2013. Natural drainage system and water logging in Dhaka: measures to address the problems. *Journal of Bangladesh Institute of Planners*, Volume 6, pp. 23–33.

Naab, F. Z. & Dogkubong, R., 2013. Urbanisation and its impact on agricultural lands in growing cities in developing countries: a case study of Tamale in Ghana. *Modern Social Science Journal*, 2(2), pp. 256–287.

Parvin, M., 2013. Projecting the population size of Dhaka city with migration using growth rate method. *IOSR Journal of Mathematics*, 8(5), pp. 29–37.

Pielke, R. A., 2005. Land use and climate change. *Science*, 310(5754), pp. 1625–1626.

Piwowar, J. M. & Ledrew, E. F., 2002. ARMA time series modelling of remote sensing imagery: a new approach for climate change studies. *International Journal of Remote Sensing*, 23(24), pp. 5225–5248.

Prasad, N. et al., 2009. *Climate resilient cities, a primer on reducing vulnerabilities to disasters*. Washington, DC: The World Bank.

Rahman, G., Alam, D. & Islam, S., 2008. City growth with urban sprawl and problems of management. *Dalian: International Society of City and Regional Planners (ISOCARP)*, pp. 1–11.

Rahman, H. Z. ed., 2012. *Bangladesh urban dynamics.* Dhaka: Power and Participation Research Centre (PPRC).

RAJUK, 1995. *Dhaka metropolitan development plan (1995-2015) volume – ii: urban area plan (1995–2005)*, Dhaka: Dhaka Metropolitan Development Planning (DMDP).

RAJUK, 2010. *Preparation of detailed area plan (dap) for Dhaka metropolitan development plan (dmdp) area*, Dhaka: Bangeladesh Govenment Press.

RAJUK, 2011. *Detailed area plan – DAP*. [Online] Available at: http://www.rajukdhaka.gov.bd/rajuk/dapHome [Accessed 12 May 2013].

RAJUK, 2015. *Dhaka structure plan 2016-2035 (final draft)*, Dhaka: Rajdhani Unnayan Kartripakkha (RAJUK).

Reis, S., 2008. Analyzing land use/land cover changes using remote sensing and GIS in Rize, North-East Turkey. *Sensors*, Volume 8, pp. 6188–6202.

Romilly, P., 2005. Time series modeling of global mean temperature for managerial decision-making. *Journal of Environmental Management*, 76(1), pp. 61–70.

Stojanov, R., 2005. *Environmental refugees between development and poverty - case study of the Three Gorges Dam area*. Bonn, European Association of Development Research and Training Institutes (EADI), pp. 1–19.

The World Bank, 2012. *Historical assessment of spatial growth of the metropolitan areas of Delhi, Mumbai and Dhaka*. [Online] Available at: http://go.worldbank.org/5A2EGEFL90 [Accessed 6 April 2013].

Thomas, S., 2008. Urbanization as a driver of change. *The Arup Journal*, 43(1), pp. 58–67.

Thompson, J. R., Foster, D. R., Scheller, R. & Kittredge, D., 2011. The influence of land use and climate change on forest biomass and composition in Massachusetts, USA. *Ecological Applications*, 21(7), pp. 2425–2444.

UN DESA, 2019. *World urbanization prospects 2018: highlights (ST/ESA/SER.A/421)* , New York: Department of Economic and Social Affairs, Population Division, United Nations.

UNFCCC, 2018. *Global sea level rise is accelerating – study*. [Online] Available at: https://unfccc.int/news/global-sea-level-rise-is-accelerating-study [Accessed 15 October 2019].

UN-HABITAT, 2008. *State of the world's cities 2008/2009, case study: Dhaka's extreme vulnerability to climate change*, Nairobi: United Nations Human Settlements Programme (UN-HABITAT).

United Nations, n.d. *Climate change*. [Online] Available at: https://www.un.org/en/sections/issues-depth/climate-change/ [Accessed 25 October 2019].

UNU-IHDP, 2015. *Coastal zones and urbanization: summary for decision-makers.* Bonn: International Human Dimensions Programme on Global Environmental Change (UNU-IHDP).

USGS, n.d. *EarthExplorer*. [Online] Available at: https://earthexplorer.usgs.gov/ [Accessed 3 June 2019].

WHO, 2000. *Issue paper on: urban environment management in Asia and the Pacific*, Hangzhou, Peoples Republic of China: Regional Office for Western Pacific of the World Health Organization (WHO).

World Bank, 2011. *Historical assessment of spatial growth of the metropolitan areas of Delhi, Mumbai and Dhaka.* [Online] Available at: http://go.worldbank.org/5A2EGEFL90 [Accessed 6 April 2013].

World Bank, 2013. *Data: Bangladesh.* [Online] Available at: http://data.worldbank.org/country/bangladesh [Accessed 7 March 2013].

World Bank, 2018. *World Bank staff estimates based on the United Nations Population Division's world urbanization prospects: 2018 revision*. [Online] Available at: https://data.worldbank.org/ [Accessed 28 February 2019].

Xinhua, 2013. *Dhaka suffers from over population*. [Online] Available at: http://www.clickittefaq.com/in-the-news/dhaka-suffers-from-over-population/ [Accessed 22 October 2013].

Ye, L., Yang, G., Ranst, E. V. & Tang, H., 2013. Time-series modeling and prediction of global monthly absolute temperature for environmental decision making. *Advances in Atmospheric Sciences*, 30(2), pp. 382–396.

PEER REVIEWED ARTICLE

Measuring net environmental impact from population growth and alternative energy

Travis D. Edwards[1]

Department of Economics, University of Kansas, USA

Luis Gautier

Department of Social Sciences, The University of Texas at Tyler, USA

Abstract

Existing research on the relationship between economic growth and environmental impact has produced mixed results. Also, there has been a lack of attention on the effect of population, and per capita measures are used rather than total pollution. To address this gap, we analyze the role of population and alternative energy on the environment using total carbon dioxide emissions (CO_2) in the United States. We propose a new model integrating population demographics into the Environmental Kuznets Curve, and then apply this framework to an empirical analysis. The effect of population and immigration on total CO_2 is estimated, as well as the level of alternative energy use required to overcome increasing environmental pressure. Results suggest population and immigration growth may lead to an increase in total CO_2 growth, but alternative energy may lower total CO_2 growth after a threshold. Further, immigration and total CO_2 growth exhibit a nonlinear relationship.

JEL: Q56; Q53; O13

Keywords: environmental forecasting; environmental impact; green economics; population growth; renewable energy.

1 Corresponding author: travis.edwards@ku.edu

1. Introduction

The impact of population on environmental degradation is a comparatively underexplored causal link in environmental economics. There is also an emphasis on per capita pollution rather than total pollution e.g., carbon dioxide emissions (CO_2). We have two main objectives in this note: (1) to propose a new model wherein the Demographic Transition Model (DTM)[2] and net migration, in conjunction with the I=PAT equation[3], are incorporated into the Environmental Kuznets Curve (EKC), and (2) to investigate the effect of population, immigration and technology on the environment through an empirical analysis of total CO_2 in the United States (US).

The link between population and environmental degradation has been discussed as far back as Malthus (1798).[4] More recently, Ehrlich and Holdren (1971) introduced the concept of the I=PAT equation to measure the environmental impact of economic activity in relation to population, affluence, and technology.[5] Ehrlich and Holdren (1971) argue that pressure from population growth has a disproportionate effect on environmental degradation. Because of the expected rise in population globally and the resulting pressure on resources via demand/supply factors (e.g., Baldwin, 1995), along with flows of migration becoming the main source of population growth in the near future (Vespa, Armstrong, and Medina, 2018), looking at population in the context of environmental degradation is relevant.

2 The Demographic Transition Model explains the shift in population structure during five phases: high death rates/high birth rates; falling death rates/high birth rates; low death rates/falling birth rates; low death rates/low birth rates; low death rates/stable birth rates near the replacement rate (Roser, 2017).

3 I=PAT stands for Environmental Impact = Population X Affluence X Technology.

4 Other early contributions include David Ricardo's theory on land rent, Arthur Pigou's work on tax policy to improve resource allocation, and Nicolas de Condorcet's proposal that air pollution was a negative externality from economic activity (Sandmo 2015).

5 Perhaps the most robust application of the I=PAT equation is the extended formulation by Dietz, Rosa, and York (2003) known as the STIRPAT project. The STIRPAT project assessed environmental impact with the I=PAT equation, using stochastic estimation through regression analysis, while converting the variables to natural logarithms and placing T as an error term (by arguing there is not an appropriately agreed-upon measurement for this variable) (Dietz, Rosa, and York, 2003). The study concluded that modernization leads to an overall negative impact on environmental degradation, with no evidence to support the widely held belief that economic growth eventually leads to declining environmental impact, such as predicted by the EKC (Dietz, Rosa, and York, 2003).

A second widely-used approach to capture the link between environmental degradation and economic activity is the EKC (Carson, 2010). The EKC was developed based on the theory concerning the relationship between increasing wealth in an economy and the corresponding environmental degradation of the ecosystem (Stern, 2003). There is a large body of empirical work regarding the EKC, yet no general consensus exists and few papers incorporate demographic factors into their analyses.[6] Given the lack of consensus and growing importance of population on environmental degradation, exploring the role of population and migration in the context of the EKC is pertinent for the formulation of policy.

Our contribution is at the intersection of two branches of the literature. First, demographic factors are often overlooked when analyzing possible environmental impacts (e.g., Curran and Sherbinin 2004). However, there has been some recent research incorporating demographic variables to better understand the relation between population and the environment (e.g., Galeotti et al., 2011; Franklin and Ruth, 2012; Roser, 2017). Our work is closest to Galeotti et al. (2011) where they consider the demographic transition in a sample of countries and find evidence for an "enriched" EKC.[7] We build on the work of Galeotti et al. (2011) in three ways. First, we examine the role of immigration in explaining total CO_2 by estimating changes in total population arising specifically from immigration and arguing that immigration may exert an upward pressure on CO_2 growth. Second, we complement Galeotti et al. by developing a model which incorporates the DTM into the EKC. Third, we show that the relationship between immigration and the rate of the growth of total CO_2 is nonlinear, an analysis not present in Galeotti et al (2011), but with important implications for policy formulation.

Our second contribution to the literature rests on what has been a lack of attention to total CO_2, an important area specifically absent from the EKC literature but with important policy implications (e.g., determination of carbon budgeting and

6 e.g., Atasoy, 2017; Carson et al., 1997; Franklin and Ruth, 2012; Grossman and Krueger 1995; Holt-et al., 1992; List and Gallet, 1999; Meadows et al. 1972; Mitchell 2012; Rupasingha et al., 2004; Shafik and Bandyopadhya 1992; York et al., 2003.

7 Baldwin (1995) points to the implications arising from demographic factors and argues that in order to reach environmental sustainability the majority of the world must move past the second phase of the demographic transition, while moving as quickly as possible through the ecological transition. Galeotti et al. (2011) builds on Baldwin (1995) using CO2 data for 17 Organisation for Economic Co-operation and Development (OECD) countries.

pricing policies). An issue with past analyses is the almost universal use of per capita emissions as the measure of pollution. Our main concern is the lack of attention to total CO_2, since an increasing population may produce higher total CO_2 even as CO_2 per capita declines.[8] However, this is not to dismiss using per capita measures altogether. For example, Jones and Warner (2016) used per capita measures to derive projections for future energy demands and CO_2 trajectories.

We also examine the role of alternative energy (defined as energy that does not produce carbon dioxide, including hydropower, geothermal, nuclear, wind, and solar power, among others) in the population-environmental degradation nexus and estimate a threshold level of alternative energy after which total CO_2 may fall. This is particularly important since alternative energy sources have increased in recent years (U.S. Energy Information Administration, 2019) and so identifying such a threshold can guide policy formulation.

Our contribution also extends to the role of the DTM in the EKC by extending demographic transition factors into the EKC and testing some of the results using US data. Even though the US does not necessarily face over-population issues vis-à-vis low-income countries, the US is considered as a case study because it has arguably experienced all the phases present in the DTM and at the same time the full range of income levels proposed in the EKC. An important consideration, absent from the DTM, is concern for levels of net migration. Any shift in lifestyle, related to ecological footprint, as migrants shift into high-income countries may be relevant. Our results suggest that immigration may play a role in explaining total CO_2 growth. Additionally, the literature suggests that the level of renewable energy usage and energy consumption patterns in the economy are responsible for any possible mitigation of pollution (e.g., Dogan and Ozturk, 2017; Soytas, Sari, and Ewing, 2007) and therefore we explore the role of alternative energy and migration on total CO_2 growth in the case of the US.

The literature on the demographic transition argues that such transition is driven by an increase in urbanization and industrialization, with potentially negative effects on the environment. These effects range from the population age structure and its implications on the demand for goods and services, to

8 A notable exception is Franklin and Ruth (2012), who argued that although CO2 per capita has leveled out in recent years, total CO2 continues to increase.

migration patterns (Franklin and Ruth, 2012; United Nations, 2015). O'Neil et al. (2012) consider demographic changes with regard to CO_2 by considering various household characteristics such as age, size, and urban/rural data. O'Neill et al. (2012) concluded aging populations have a lower overall environmental impact in comparison to younger populations as a result of labor productivity. Also, urbanization can lead to an increase in projected CO_2 (O'Neil et al., 2012; Weber and Sciubba, 2016). Conversely, Zhou and Liu (2016) argued urbanization led to decreased levels of CO_2 in China. Still, both Zhou and Liu (2016) and O'Neill et al. (2012) found urbanization to decrease overall energy use. Although results in the literature vary, all found population growth to have a significant impact on CO_2. And although our results are consistent with the literature, our contribution relies on the study of immigration and its impact on the environment.

The literature also examines the rebound effect (e.g., Franklin and Ruth 2012; Sorrell, Gatersleben, and Druckman, 2020; Madlener and Alcott, 2009; Baldini and Jacobsen, 2016).[9] The rebound effect, in which energy consumption increases as technology improves efficiency, is estimated to be anywhere from 0% to 50% (Madlener and Alcott, 2009). However, Gilligan, Rapson, and Wagner (2016) make the case that even though rebound effects exist, the overall gains from implementing energy-efficient policy outweigh these effects. This result is consistent with our estimates, but our analysis focuses on total CO_2 rather than per capita.

The structure of this paper is as follows. Section two describes the US energy mix and population structure. Sections three and four, respectively, introduce a hypothesized model and describe the data. Sections five, six, and seven explain the benchmark model, present an empirical analysis, and describe the robustness check, respectively. Section eight concludes with a few remarks on policy implications, limitations of the analysis, and future lines of research.

2. The US energy mix and population structure

The energy mix in the US is an important consideration since CO_2 is directly tied to the type of energy consumed. Currently, the US uses a mixture of energy technologies including natural gas, crude oil, coal, nuclear, natural gas

9 Rebound effects were first hypothesized by Jevons (1866) regarding improvements in the efficiency of coal use in steam engines leading to their expansion.

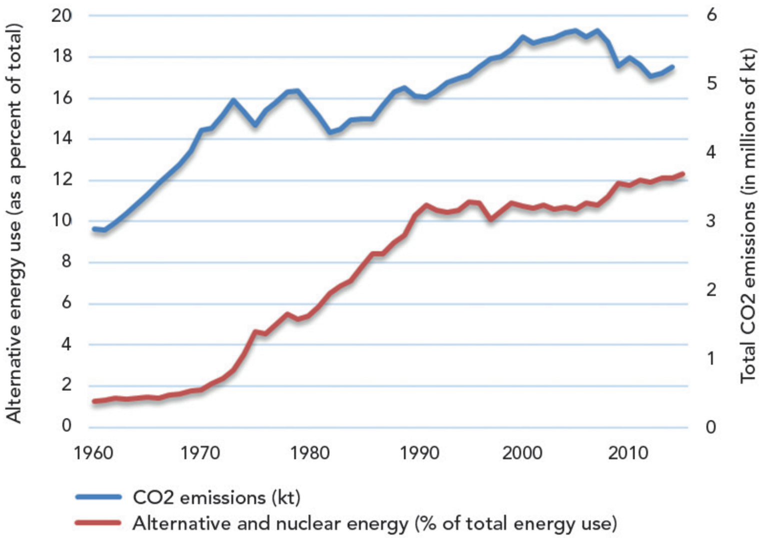
plant liquids, biomass, hydroelectric, solar, wind, and geothermal. Of these, petroleum comprises the largest share of total energy consumption, while natural gas makes up the largest share when considering energy for electricity generation (U.S. Energy Information Administration, 2019; BP Statistical Review, 2019). Renewables such as hydroelectric, solar, wind, and geothermal comprise the lowest four energy sources in terms of percentages, although their use has continued to increase in recent years (U.S. Energy Information Administration, 2019). Nuclear energy increased each year from 1960 to 1990 but has leveled off since 2000 (U.S. Energy Information Administration, 2019). The amount of coal used for energy production has been on a steady decline, while the use of natural gas and crude oil has been increasing (U.S. Energy Information Administration, 2019; BP Statistical Review, 2019).

Since our analysis focuses on alternative energy as a measure of technological advancement, we pay particular attention to its usage. It should be noted that alternative energy use can be broken into two distinct periods, 1960–1990 and 1990–2016, where different energy technologies played key roles in total CO_2. Specifically, the increase in nuclear energy use was prevalent for the 1960–1990 period, whereas increases in renewable energy (e.g., solar, wind, geothermal) were significant for the 1990–2016 period (see figure 1).[10]

In terms of policy, Jacobson et al. (2017) argue that 139 countries across the world can achieve 80% conversion to zero-emitting energy, defined as energy from wind, water, and sunlight (WWS), by 2030, and 100% zero-emitting energy by 2050. More specifically, Jacobson (2015) made the same case for each state in the US. Considering that the level of alternative energy use in the US was only approximately 12.3% as of 2015 (World Bank, 2018), Clark et al. (2017) warned policymakers to remain cautious over plans which call for the use of WWS exclusively and, instead, recommended a more balanced approach, which includes a range of energy technologies in the economy.

10 The models presented in this paper were also formulated with nuclear and renewable energy as separate variables during these two time periods, each being statistically significant for each respective period.

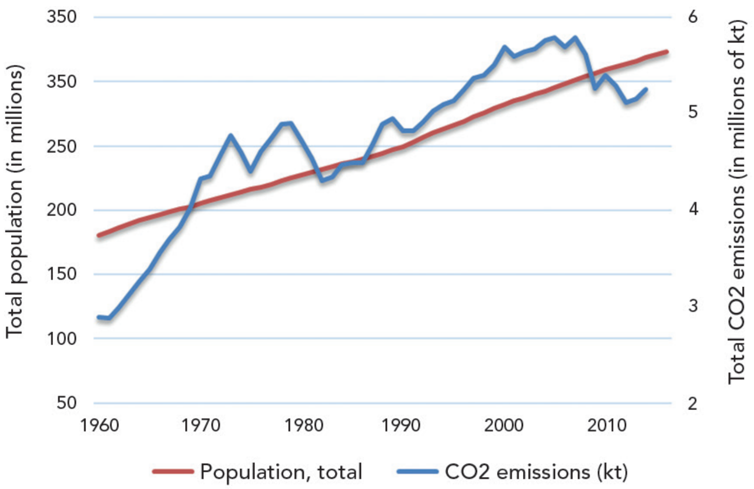
Figure 1 – United States Alternative Energy Use and Total CO2 Emissions



Although the US had a 11.5% increase in natural gas production in 2018, the use of non-hydro renewable energy grew by 9.8% and coal production fell by 1.9% (BP Statistical Review, 2019). Carbon emissions grew by 2.8%, while carbon intensity continued declining at a rate of 0.9% (BP Statistical Review, 2019). Further, energy consumption grew by 3.5% (BP Statistical Review, 2019). These figures suggest that the US is seeing improvements in the use of renewable energy, but as the demand for energy increases natural gas and coal remain as the primary sources of energy for electricity generation.

Galeotti et al. (2011) argue that for long-term environmental sustainability, both economic growth and policy for lowering population are needed. The increased global total CO_2 resulting from cross-country migration is a major concern (Cafaro and Staples, 2009). At the same time Cafaro and Götmark (2019) show, in the case of the European Union, that minor changes in annual net migration can lead to large changes in future population. And in the case of the US, immigration has become the main driver of population growth (Cafaro and Staples, 2009). Although fertility rates in the US are below the replacement rate of 2.1 births per woman, the increase from positive net migration has a larger impact on population than this decline in fertility (figure 2) (World Bank, 2018). Therefore, the US population is projected to increase for the foreseeable future. The implication is that even if CO_2 per capita is declining a net increase in total CO_2 may be expected as each additional person contributes to the sum.

Figure 2 – United States Population and Total CO2 Emissions



3. A Model

Figure 3 illustrates an overview of the relationship between the demographic transition and the I=PAT equation from the standard theory, factoring in net migration levels (positive for the US). The arrows in front of the variable signal the effect on environmental impact, I, not the rate of increase in the variable itself. For example, an increase in technology, T, has an upward pressure on environmental impact, I, during phase one of the demographic transition, but an increase in technology, T, has downward pressure on environmental impact, I, during phase three of the transition process.

Figure 3 – PAT Equation & DTM Integration

I = PAT Equation & DTM Integration

with positive net migration in phase 3-5

Phase 1: $\uparrow I = P \uparrow AT$

Phase 2: $\uparrow I = \uparrow P \uparrow AT$

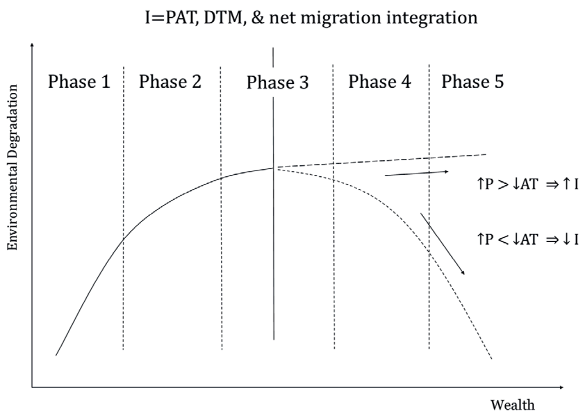
Phase 3-5: $I = PAT$

$\text{if } \uparrow P > \downarrow AT \Rightarrow \uparrow I$

$\text{if } \uparrow P < \downarrow AT \Rightarrow \downarrow I$

Figure 4 presents a preliminary integration of the I=PAT equation and DTM into the EKC, including net migration. This model illustrates environmental impact from population, affluence, and technology through the five stages of the demographic transition. A key point to this proposed model is the consideration of positive net migration as advanced economies have significantly larger levels of energy/goods consumption. Although the demographic transition will drive down population growth as an economy develops, and thus environmental impact, immigration may offset this decline as overall population in developed countries continues to grow. An empirical analysis of this hypothesis follows.

Figure 4 – Hypothesized EKC for Total Pollution



4. Data

Annual data for the US from years 1960-2016 was obtained from the World Bank. We use total CO_2 (total emissions in kt) as the measure of environmental impact, total population, and real GDP as a control to capture changes in economic activity. Time dummies were constructed to capture period-specific effects such as recessionary periods and global oil shocks. Alternative energy, as a percent of total energy use, is used as a measure for technological advancement to capture increasing technology in an economy while avoiding high correlation with population. As noted earlier, this will incorporate the effects of all near-zero-emissions energy use from 1960-2016.

In addition to population we look at the role of immigration. Even though there is total immigration data available for the US, we focus on cumulative immigration instead. The reason for this is threefold. First, total immigration is measured on an annual basis and thus represents a relatively small share of total population: the US population is over 326 million and approximately 41 million have immigrated since 1960, while total immigration has averaged 722 thousand annually (World Bank, 2018). As a result, any changes in CO_2 explained by immigration are likely to be offset by the variability explained by total population. Second, cumulative immigration is defined as immigration at time t, plus all previous immigration from 1960. Thus, cumulative immigration arguably captures the potential cumulative effects of immigration on CO_2 while accounting for changes in consumption behavior once migrants settle in the US. Third, net migration growth (net migration defined as either total population minus total immigration or total population minus total cumulative immigration) mirrors total population growth over time and exhibits a Pearson correlation coefficient of just over 0.92.

To test for stationarity we rely on Dickey-Fuller and Phillips-Perron tests, where total CO_2, total population, alternative energy and real GDP are I(1), whereas cumulative immigration is I(0).

5. Benchmark Model Specification

We estimate the following benchmark model in first differences using Ordinary Least Squares (OLS):

$$d(lnCO_2total_t) = \alpha + \beta_1 d(lnPOP_t) + \beta_2 d(lnALN_t) + \beta_3 Z + \epsilon_t \qquad (1)$$

where $d(\ln CO_2total_t)$ denotes the first-differenced natural log of total CO_2 (in kt) at time t, $d(\ln POP_t)$ first-differenced natural log of total population at time t, $d(\ln ALN_t)$ first-differenced natural log of alternative energy use at time t, and ε_t the residuals. We model residuals following an autoregressive-moving-average (ARMA) structure when applicable.[11] The term *Z* in (1) denotes a set of controls such as the one-period lagged first-differenced natural log of real *GDP* (constant 2010 USD), a linear time trend and time-specific dummies to capture, for example, recessionary periods in the US.

It is noteworthy that real GDP is arguably correlated with population and CO_2. As a result, alternative energy is used to avoid issues of correlation with population, but also the one-period lag for real GDP was used to avoid issues of endogeneity. In any case, Pearson correlation coefficients do not suggest a high degree of correlation between real GDP, alternative energy, total population and cumulative immigration.

6. Results

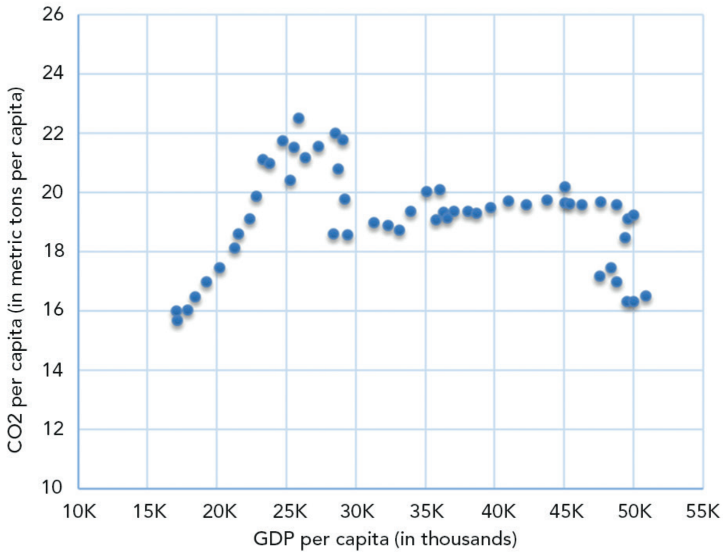
Estimation of (1) suggests that higher growth rates of population imply higher growth rates of total CO_2. The estimated coefficient, β_1, is positive and statistically significant, implying a 1 percentage point increase in the growth rate of population results in an approximately 1.92 percentage point increase in total CO_2 growth (see summary table in the appendix). The alternative energy coefficient, β_2, is negative and statistically significant, which implies that increasing the rate of growth of alternative energy use by 1 percentage point results in an approximately 0.15 percentage point decrease in total CO_2 growth. Estimates also suggest that the inclusion of alternative energy into the model may reduce the upward pressure population has on CO_2, thereby pointing to the key role of alternative energy in explaining variations in CO_2.

To explore the potential interaction between population and alternative energy, a second model specification is considered:

$$d(lnCO_2total_t) = \alpha + \beta_1 d(lnPOP_t) + \beta_2 d(lnALN_t) + \gamma_2 d(lnPOP_t) * d(lnALN_t) + \beta_3 Z + \epsilon_t \qquad (2)$$

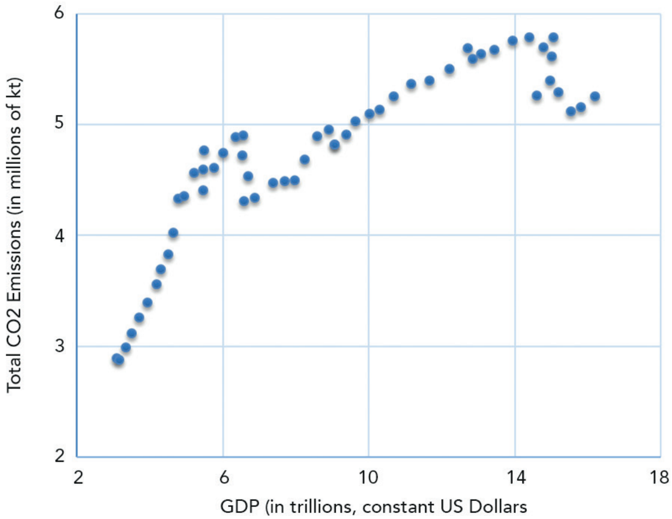
Estimation of (2) points to two important results. First, population may have a larger increasing effect (i.e. increase in the growth rate of CO_2) vis-à-vis the decreasing effect (i.e., decrease in the growth rate of CO_2) of alternative energy use on the growth rate of total CO_2. This indicates that although CO_2 per capita is in decline (figure 5), the effect of population can be larger so there is a net increase in total CO_2 (figure 6). This increase is consistent with our hypothesized EKC (figure 4). Second, the model suggests that the growth rate in the share of alternative energy required to achieve the turning point predicted in the EKC is approximately 23%.[12] As of 2015, the level of alternative energy use in the US was 12.3% (World Bank, 2018). This indicates that total CO_2 growth may continue rising until alternative energy use is expanded. It is noteworthy that we were also able to identify such a result for the 1990–2016 period, where the population growth rate in the US shows a clear downward trend, but also a fairly stable use of alternative energy, particularly in renewables.

Figure 5 – United States GDP per capita and CO2 per capita



12 The approximation for the level of alternative energy use required, as a percent of total, is obtained from $\beta 1 + \gamma 2ALNt$ in summary table, column 6.

Figure 6 – United States GDP and Total CO2 Emissions



A third model is estimated to analyze the effect of cumulative immigration on total CO_2:

$$d(lnCO_2total_t) = \alpha + \delta_1 lnCIMM_t + \delta_2 lnCIMM_t^2 + \beta_2 d(lnALN_t) + \beta_3 Z_t + \epsilon_t \quad (3)$$

where $lnCIMM_t$ denotes the natural log of cumulative migration at time *t*. Results indicate (i) a nonlinear inverted-U relationship between cumulative immigration and the growth rate of total CO_2, and (ii) alternative energy, consistent with (1), puts a downward pressure on the growth rate of total CO_2. These results are important because immigration will become the main source of population growth by the year 2030 as the natural rise from population momentum begins to slow (Vespa et al., 2018).

The non-linear relationship between cumulative immigration and growth in total CO_2 growth indicates that the growth in cumulative migration can have an upward pressure on CO_2 if cumulative migration remains on average just under 1.5 million a year. Since this threshold has been exceeded, the analysis suggests that the growth rate of total CO_2 may likely slowdown via immigration.

7. Robustness Check

We employ a two-stage least squares estimation technique with the dual purpose of addressing potential issues of endogeneity between population and CO_2, but also account for variations in population arising specifically from immigration. Results from previous sections hold indicating that (i) population growth explained by growth in immigration may exert an upward pressure on total CO_2 growth, and (ii) there is an alternative energy use threshold level after which total CO_2 growth falls. The result in (i) suggests that variations in immigration play a role in explaining total CO_2 growth and thus should be kept in mind when formulating policy, albeit the effects on the level of total CO_2 are likely relatively small given the small share of immigration with respect to total population in the US.

The two-stage least squares estimation consists of first estimating population growth as follows:

$$d(lnPOP_t) = \alpha + \gamma_1 d(lnCIMM_{t-1}) + \gamma_2 d(lnIMM_{t-1}) + \gamma_3 \Delta + u_t \quad (4)$$

where *d(lnIMM)* denotes the growth rate of immigration, and Δ a set time dummies and linear and non-linear time trends. The specification in (4) considers one-period time lags to avoid issues of endogeneity since total population incorporates immigration in its measurement. On the second stage, the estimated growth in total population obtained from (4), $d(\widehat{lnPOP_t})$, is used to re-estimate (1) and (2). Results are shown in the Appendix.

8. Conclusion and Policy Implications

After controlling for economy-wide and time-specific effects, estimates suggest evidence against an inverted-U EKC for total CO_2 growth in the US. Population growth increases total CO_2 growth, which may surpass the downward pressure from increased technology measured through alternative energy. This result indicates that although CO_2 per capita is in decline, the effect of population is greater, thus leading to a net increase in total CO_2. Results also point to a threshold level of alternative energy growth after which growth in total CO_2 may fall.

While we provide some evidence that total CO_2 is increasing as a result of population growth, there are areas which need further consideration. First, expanding the analysis to include the effect of population on pollution apart from CO_2 (e.g., NOx) would be an improvement, particularly if connections to the energy sector are sought. Second, broadening the analysis to include a range of countries in various stages of the demographic transition, while increasing the number of observations, would help in understanding the effect of population as an economy develops. Third, the analysis considers total CO_2, not total consumption-based CO_2. Thus, checking whether results hold using total consumption-based CO_2 would give a better sense as to whether immigration is having a significant effect on total CO_2. In this sense our results should be taken with caution.

While our research focuses on alternative energy sources, recent trends are moving away from nuclear energy and towards renewable energy sources. We should note that renewable energy use has increased, reaching record highs in 2019 (U.S. Energy Information Administration, 2019). Also, alternative energy was chosen for the measure of technology to avoid high correlation with population, but the relation to CO_2 should be noted. There is the concern that CO_2 affects the level of alternative energy in a country, which would need further investigation to rule out issues of endogeneity (i.e., is increasing renewable energy use driving down CO_2, or is increasing CO_2 causing faster implementation of renewable energy?). Exploring other measures of technology and comparing results would be worthwhile as robustness checks.

Improving our understanding of the impact of human population and economic growth on the environment is invaluable for policymakers. This is equally important for both economically advanced and developing regions. The ability to collectively lower our environmental impact in both advanced and developing economies is vital to the future of the planet. Implementing effective environmental and economic policies which can be strategically enacted for specific stages of development, to reduce overall environmental degradation while maintaining an acceptable standard of living, is crucial to this task.

Appendix – Regressions: Summary Table

Appendix – Regressions: Summary Table. Dependent variable d(lnCO_2total).

									TWO-STAGE LEAST SQUARES				
	1	2	3	4	5	6	7	8	9	10	11	12	13
constant	.03	.06	.08	.05	.06	.01	-3.70	7.20	.02	.06	.07	.05	-.003
	(2.33)*	(4.20)*	(6.7)*	(3.71)*	(8.52)*	(.50)	(-2.43)*	(1.56)	(1.76)	(3.59)*	(4.13)*	(3.01)*	(-.17)
dlnPOPt	1.92	.34	-.95	.80		3.22							
	(2.27)*	(.36)	(-1.14)	(.82)		(2.97)*							
dlnALNt		-.14	-.61		-.49					-.16	-.83		
		(-2.93)*	(-2.93)*		(-2.35)					(-2.99)*	(-3.01)*		
dlnPOPt* dlnALNt			39.53	-12.38	34.21								
			(1.92)**	(-2.76)*	(1.68)**								
dlnPOPt* ALNt						-.14							
						(-2.52)*							
dlnGDP(t-1)	.09	.003	-.04	-.001	-.04	-.004	.03	.15	.11	.03	.03	.03	.12
	(.48)	(.03)	(.62)	(-.001)	(-.35)	(-.04)	(.26)	(2.81)	(.84)	(.22)	(.26)	(.27)	(1.08)
lnCIMMt							.54	-.83					
							(2.48)*	(-1.52)					
lnCIMM²t							-.02	.02					
							(-2.47)*	(1.47)					
lnCIMMt* dlnALNt								-.23					
								(-5.21)*					
D79_82;D09;D12;D73;D01;D08;D70							YES						
D79_82;D90_91;D09;D97;D88;D12 D73;D70;D01								YES					
$dln\widehat{POP}t$									2.27	.46	-.84	.95	4.61
									(2.29)*	(.67)	(-.72)	(.82)	(2.77)*
$dln\widehat{POP}t$* dlnALNt											63.47	-13.01	
											(2.44)*	(-2.53)*	
$dln\widehat{POP}t$* ALNt													-.18
													(-1.84)**
D73_75; D79_82; D90_91; D09_11; D09	YES	YES							YES	YES			
D_79_82; D_90_91; D_09			YES										
D73_75; D79_82; D90_91; D09_11; D09; D12				YES							YES	YES	
D73_75; D79_82; D90_91; D09; D12					YES								YES
D73_75; D79_82; D90_91; D09; D08						YES							
Linear time trend	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
AR ; MA terms -residuals	1;2	1;2	1;2	1;2	1;2	1;2	NO	3;7	1;2	1;2	1;2	1;2	1;2
R^2	0.83	0.86	0.86	0.85	0.86	0.88	0.85	0.94	0.82	0.86	0.88	0.85	0.83
Durbin Watson	2.01	2.06	2.02	2.01	2.04	2.03	2.01	2.05	2.04	1.99	1.98	1.99	2.09
N	52	52	52	52	52	52	53	50	50	50	50	50	50

*5% significance level; **10% significance level

References

Atasoy, B., 2017. Testing the environmental Kuznets curve hypothesis across the U.S.: evidence from panel mean group estimators. *Renewable and Sustainable Energy Reviews*. 77, pp. 731–47.

Baldini, M. and Jacobsen, H.K., 2016. Optimal trade-offs between energy efficiency improvements and additional renewable energy supply: a review of international experiences. In: Institute of Electrical and Electronics Engineers, 2016 13th International Conference on the European Energy Market (EEM). Porto, Portugal , 6-9 June 2016. New York, NY: IEEE.

Baldwin, R., 1995. Does sustainability require growth?. In: I. Golden and L.A. Winters eds. *The Economics of Sustainable Development*. Cambridge: Cambridge University Press. pp. 51–78.

Beckerman, W., 1992. Economic growth and the environment: Whose growth? whose environment?. *World Development*. 20(4), 1992, pp. 481–96.

BP, 2019. *Statistical Review-2019-The US energy market in 2018*. [pdf] London: British Petroleum Co. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-us-insights.pdf [Accessed 20 February 2020].

Cafaro, P. and Gotmark, G., 2019. The potential environmental impacts of EU immigration policy: future population numbers, greenhouse gas emissions and biodiversity preservation. *The Journal of Population and Sustainability*. 4(1), pp. 71–101.

Cafaro, P. and Staples, W., 2009. The environmental argument for reducing immigration into the United States. *Environmental Ethics*. 31(1), pp. 5–30.

Carson, R., 2010. The Environmental Kuznets Curve: Seeking empirical regularity and theoretical structure. *Review of Environmental Economics and Policy*. 4(1), pp. 3–23.

Carson, R., Jeon, Y. and McCubbin, D., 1997. The relationship between air pollution emissions and income: US Data. *Environment and Development Economics*. 2(4), pp. 433–50.

Casey, G. and Galor, O., 2017. Is faster economic growth compatible with reductions in carbon emissions? The role of diminished population growth. *Environmental Research Letters*. 12, doi:10.1088/1748-9326/12/1/014003.

Caviglia-Harrisa, J., Chambersa, D. and Kahn, J., 2009. Taking the "U" out of Kuznets: a comprehensive analysis of the EKC and environmental degradation. *Ecological Economics*. 68(4), pp. 1149–59.

Chowdhury, R. and Moran, E., 2012. Turning the curve: a critical review of the Kuznets approaches. *Applied Geography*. 32(1), pp. 3–11.

Clack, C., Qvist, S., Apt, J., Bazilian, M., Brandt, A., Caldeira, K., Davis, S., Diakov, V., Handschy, M., Hines, P., Jaramillo, P., Kammen, D., Long, J., Granger M., Morgan, Reed, A., Sivaram, V., Sweeney, J., Tynan, G., Victor, D., Weyant, J. and Whitacre J., 2017. Evaluation of 100% wind, water, and solar power. *Proceedings of the National Academy of Sciences*. 114(26), pp. 6722–27.

Curran, S. and Sherbinin, A., 2004. Completing the picture: the challenges of bringing "consumption" into the population-environment equation. *Population and Environment*. 26(2), pp. 107–31.

Dogan, E. and Ozturk, I., 2017. The influence of renewable and non-renewable energy consumption and real income on CO_2 emissions in the USA: evidence from structural break tests. *Environmental Science and Pollution Research International*. 24(11), doi:10.1007/s11356-017-8786-y.

Ehrlich, P.R. and Holdren, J.P., 1971. Impact of population growth. *Science, New Series*. 171(3977), pp. 1212–17.

Figge, F., Young, W. and Barkemeyer, R., 2014. Sufficiency or efficiency to achieve lower resource consumption and emissions? The role of the rebound effect. *Journal of Cleaner Production*. 69, pp. 216–24.

Franklin, R.S. and Ruth, M., 2012. Growing up and cleaning up: the environmental Kuznets curve redux. *Applied Geography*. 32, pp. 29–39.

Galeotti, M., Lanza, A. and Piccoli, M.C.L., 2011. *The demographic transition and the ecological transition: Enriching the Environmental Kuznets Curve*. IEFE Working Paper No. 44. [online] Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1922594 [Accessed 10 October 2019].

Gillingham, K., Rapson D. and Wagner, G., 2016. The rebound effect and energy efficiency policy. *Review of Environmental Economics and Policy*. 10(1), pp. 68–88.

Grossman, G.M. and Krueger, A.B., 1991. *Environmental impacts of a North American Free Trade Agreement*. National Bureau of Economic Research Working Paper No. 3914. [online] Available at: https://www.nber.org/papers/w3914 [Accessed 10 October 2019].

Grossman, G.M. and Krueger, A.B., 1995. Economic growth and the environment. *The Quarterly Journal of Economics.* 110(2), pp. 353–77.

Holtz-Eakin, D. and Selden, T., 1992. *Stoking the fires? CO2 emissions and economic growth.* National Bureau of Economic Research Working Paper No. 4248. [online] Available at: https://www.nber.org/papers/w4248 [Accessed 10 October 2019].

Jacobson, M., Delucchi, M., Bauer, Z., Goodman, S., Chapman, W., Cameron, M., Bozonnat, C., Chobadi, L., Clonts, H., Enevoldsen, P., Erwin, J., Fobi, S., Goldstrom, O., Hennessy, E., Liu, J., Lo, J., Meyer, C., Morris, S., Moy, K., O'Neill, P., Petkov, I., Redfern, S., Schucker, R., Sontag, M., Wang, J., Weiner, E. and Yachanin, A., 2017. 100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world. *Joule*. 1(1), pp. 108–21.

Jacobson, M., Delucchi, M., Bazouin, G., Bauer, Z., Heavey, C., Fisher, E., Morris S., Piekutowski, D., Vencill, T. and Yeskoo, T., 2015. 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States. *Energy Environmental Science*. 8, doi.org/10.1039/C5EE01283J.

Jevons, W.S., 1866. The Coal Question. 2nd ed. London: Macmillan.

Jones, G. and Warner, K., 2016. The 21st century population-energy-climate nexus. *Energy Policy.* 93, pp. 206–12.

Kuznets, S., 1955. Economic growth and income inequality. *The American Economic Review.* 45(1), pp. 1–28.

List, J. and Gallet, C., 1999. The environmental Kuznets curve: Does one size fit all?. *Ecological Economics.* 31(3), pp. 409–23.

Madlener, R. and Alcott, B., 2009. Energy rebound and economic growth: a review of the main issues and research needs. *Energy*. 34(3), pp. 370–76.

Malthus, T., 1798. An essay on the principle of population. Reprint, 2nd ed., 1992. Edited with an introduction by Donald Winch. Cambridge: Cambridge University Press.

Meadows, D.H., Meadows, D.L., Randers, J. and Behrens III, W., 1972. *The limits to growth.* New York: Universe Books.

Mitchell, R., 2012. Technology is not enough: climate change, population, affluence, and consumption. *The Journal of Environment and Development.* 21(1), pp. 24–27.

O'Neill, B.C., Liddle, B., Jiang, L., Smith, K.R., Pachauri, S., Dalton, M. and Fuchs, R., 2012. Demographic change and carbon dioxide emissions. *The Lancet.* 380(9837), pp. 157–64.

Roser, M., Ritchie, H. and Ortiz-Ospina, E., 2019. World Population Growth., 2019. *Our World in Data.* [online] Available at: https://ourworldindata.org/world-population-growth [Accessed 10 October 2019].

Rupasingha, A., Coetz, S., Debertin, D. and Pagoulatos, A., 2004. The environmental Kuznets curve for US counties: A spatial econometric analysis with extensions. *Papers in Regional Science.* 83(2), pp. 407–24.

Sandmo, A., 2015. The early history of environmental economics. *Review of Environmental Economics and Policy.* 9(1), pp. 43–63.

Shafik, N. and Bandyopadhya, S., 1992. *Economic growth and environmental quality: Time-series and cross-country evidence.* The World Bank *Policy Research Working Paper* Number 904. [online] Available at: https://ideas.repec.org/p/wbk/wbrwps/904.html [Accessed 10 October 2019].

Sorrell, S., Gatersleben, B. and Druckman, A., 2020. The limits of energy sufficiency: A review of the evidence for rebound effects and negative spillovers from behavioural change. *Energy Research & Social Science.* 64, doi.org/10.1016/j.erss.2020.101439.

Soytas, U., Sari, R. and Ewing, B., 2007. Energy consumption, income, and carbon emissions in the United States. *Ecological Economics.* 62, (3–4), pp. 482–89.

Stern, D., 2003. *The Environmental Kuznets Curve.* [pdf] Internet Encyclopaedia of Ecological Economics. International Society for Ecological Economics. Available at: https://www.researchgate.net/profile/David_Stern/publication/237780646_International_Society_for_Ecological_Economics_Internet_Encyclopaedia_of_Ecological_Economics/links/0deec52743a9796717000000/International-Society-for-Ecological-Economics-Internet-Encyclopaedia-of-Ecological-Economics.pdf [Accessed 10 October 2019].

The World Bank, 2018. *World Development Indicators, United States.* [online] Available at: https://data.worldbank.org/country/united-states?view=chart [Accessed 10 October 2019].

United Nations, 2015. *International Migration Report.* [pdf] New York: United Nations Department of Economic and Social Affairs. Available at: https://www.un.org/en/development/desa/population/migration/publications/migrationreport/docs/MigrationReport2015_Highlights.pdf [Accessed 10 October 2019].

U.S. Energy Information Administration, 2019. *Energy Facts*. [online] Washington D.C.: U.S. Energy Information Administration. Available at: https://www.eia.gov/energyexplained/us-energy-facts/ [Accessed 20 February 2020].

Vespa, J., Armstrong, D. and Medina, L., 2018. *Demographic Turning Points for the United States: Population Projections for 2020 to 2060.* [pdf] Washington D.C.: United States Census Bureau. Available at: https://www.census.gov/content/dam/Census/library/publications/2018/demo/P25_1144.pdf [Accessed 10 October 2019].

York, R., Rosa, E. and Dietz, T., 2003. A rift in modernity? Assessing the anthropogenic sources of global climate change with the STIRPAT model. *International Journal of Sociology and Social Policy.* 23(10), pp. 31–51.

Weber, H. and Sciubba, J.D., 2018. The Effect of Population Growth on the Environment: Evidence from European Regions. *European Journal of population.* 35(2), pp. 379–402.

Zhou, Y. and Liu, Y., 2016. Does population have a larger impact on carbon dioxide emissions than income? Evidence from a cross-regional panel analysis in China. *Applied Energy.* 180, pp. 800–09.

BOOK REVIEW

The urban fix – resilient cities in the war against climate change, heat islands and overpopulation

by Doug Kelbaugh

New York and London: Routledge 2019. £29.99 (GBP). 308pp.
ISBN: 9780367175702

Jenny Goldie – Sustainable Population Australia

As climate change bears down on us, some are moving to the country to attempt self-sufficiency and reduce their carbon footprint. Yet Doug Kelbaugh's *Urban Fix* sees urbanization as a solution to, not only climate change, but extreme heat and overpopulation as well.

The book's cover shows a streetscape dominated by mature trees with terraced houses built directly on to the street. This is the kind of city street that Kelbaugh regards as the ideal – side and front gardens, especially lawns, are a waste of space, suburbs are anathema. Trees, however, are good. They are part of a well-designed cityscape that can provide a solution to many problems including urban heat islands (UHIs), which are heating up cities twice as fast as their surrounding countryside.

"Global warming is upon us, with accelerating and profound changes to our civilization and our lives," (p.xi) Kelbaugh writes. "… Another mega-narrative lurking in the background is global population growth, that other hockey-stick curve of the last few centuries. It is of course connected to climate change, because total energy use tracks the number of humans" (p.xii).

Cities are the centres of civilization. They "make our societies more productive, more livable, more diverse, culturally richer and wealthier," (p.xvi) he writes. And yet the impressive benefits of urbanism are "all put at risk by the simple arithmetic of too many people consuming too many resources too fast, and producing too much pollution and waste for the earth to handle" (p.xvi).

Kelbaugh, who is Professor of Architecture and Urban and Regional Planning at the University of Michigan, has a quarter century's involvement in sustainable cities, urban design, New Urbanism and now Lean Urbanism. Who better to advocate for urbanization as the key to mitigating climate change? This book, while vastly referenced and packed with information, is written in journalistic rather than academic style and thus accessible to a wider range of readers.

So, what does he suggest? To reduce the problem of urban heat islands Kelbaugh advocates four strategies: raising albedo through lighter-coloured roofs, pavements and walls; opening up tight street canyons to ventilating breezes and winds; reducing waste heat from tail-pipes, chimneys and air-conditioners; and providing cool micro-climates with more trees and other vegetation to cool the air, sequester carbon dioxide, and shade streets and buildings.

To reduce waste heat from tail-pipes, people are going to have to walk more, cycle more and use mass-transit more. This will require the development of new, closely packed housing near jobs and commercial centres. The built environment will be a network of small blocks with wide footpaths lined with trees and buildings, safe from crime and vehicular traffic. Gasoline-powered cars will have to be replaced by electric vehicles (EVs). Buildings will need to be less dependent on air-conditioners and central heating, and incorporate passive heating and cooling design strategies in addition to being energy-efficient.

If we are to keep within the Paris Accord, namely limit warming to no more than 2°C, then electricity-production will have to change with coal-fired coal power stations removed from the equation. There has to be a shift from fossil fuels to renewables; a distribution of micro-power plants within or on buildings (PV, wind, biomass, hydropower); hydrogen must be deployed for energy storage; smart grids built to save, store and buy-back energy, and vehicles powered with batteries and fuel cells.

Kelbaugh extols the virtues of higher densities (though many parents, who would prefer a backyard in which their children could play, might disagree). Cities are places of economic opportunity and productivity and some studies suggest doubling density raises productivity by 6 to 28 per cent. On the other hand, cities have generated outright negative externalities, including higher levels of crime and congestion, the spread of infectious diseases and being less resilient in crises. Yet, he argues, "cities have historically reduced these negatives through greater wealth, education and infrastructure, from sanitary infrastructure, to hospitals and universities to garbage collection and policing" (p.259).

Cities have allowed humans to flourish through the benign climate of the Holocene. As that favourable climate changes, he writes, "let's hope civilization does not abandon its many hard-won fruits" (p.259). Kelbaugh emphasises that we have little time to lose. "Our species has never faced a crisis as pervasive as climate change, and with so little time to address it" (p.288). Given the six warmest years on record have all occurred since 2010, and 17 of the 18 warmest years since 2001, it is clear we must act now to mitigate climate change.

According to the Global Footprint Network (2019), presently 1.75 Earths are needed to sustainably support the consumption of resources and to absorb the waste of 7.6 billion humans. The ever-enlarging footprints of those in the fast-growing developing world are now adding to the large footprints of those of us in the developed world, seriously and irreversibly affecting the climate system. Thus, Kelbaugh argues, "extreme population is as serious as extreme heat" (p.285) and, somewhat counterintuitively, urbanization is a way to reduce it.

So how do cities help solve overpopulation? The "population paradox of cities" (p.20) largely applies to developing countries, many of which are following a similar trend toward urbanization experienced in Europe during the 19th century. The paradox consists of a reduction in the birth rate of urban populations when it might be expected that wealthier urban residents could afford to have more children than their poorer rural cousins. However, a number of factors including easier access to contraception, improved education (especially female), the higher costs and complications of raising children in the city, and the fact that children are no longer required for their labour all influence the reduction in family size.

This often-dramatic drop in the birth rate when rural dwellers move to cities, however, may be offset by their larger environmental footprints consequent of their rising incomes. Nevertheless, it is critical that population growth is dampened in those developing countries that have become too populous for their resource base.

Kelbaugh cites Paul Hawken's book *Drawdown* which he claims, "offers the most complete menu of how not only to address and stop climate change but also to reverse it" (p.279). Significantly, if fully implemented, of the 80 solutions offered, the *urban* and *architectural* strategies can get over a third of the way to reversing climate change. Family planning and educating girls account for over a tenth. (Indeed, if Educating Girls and Family Planning were combined, they would be at the top of the list). Hawken, however, left out urban albedo, which the Intergovernmental Panel on Climate Change estimates would offset 44 gigatons of CO_2 emissions, earning 8^{th} place in the rankings.

So, what next? Kelbaugh argues for more research to fill significant gaps in knowledge about how to cool cities. Greater cooperation is needed between planners, urban designers, architects, engineers and climatologists. A research priority will be how to deal with the potential doubling of cities' physical footprints within 15 years. For the existing urban fabric, change is difficult though treating surfaces to increase albedo is possible. For new structures, the goal should be to ensure access to the sun for solar thermal and solar electric, and provide shade, wind protection and ventilation by breezes.

All cities need a coherent climate plan, Kelbaugh argues, one that address flooding and air quality, as well as surface and air temperatures. There must be a priority on mitigation strategies that simultaneously yield adaptive benefits. Fortunately, there are powerful new tools for planning and design professionals, such as "Urban Footprint", computer software produced by Calthorpe Analytics.

Kelbaugh notes that more carbon has been emitted since 1988 when James Hansen made his famous testimony to the US Congress, than in the entire history of civilization prior to that. We have no choice but to arrest and reverse this acceleration. A sustainable economy is needed, one that is something more than the sum of its carbon-neutral parts. The goal of a sustainable economy, Kelbaugh writes, "…is to provide a peaceful prosperity, without blind growth and escalating competition, as well as to outgrow novelty and consumption for their own sake. It strives to replace inequality with equity, attachment and greed with compassion and wisdom. It believes that …mindfulness can instil moderation and modesty; cooperation can beget community; and economic and social justice can improve – all of which mean that common cause can prevail over self-centred gain" (p.296).

References

Global Footprint Network, 2019. *Ecological Footprint.* [online] Available at: <https://www.footprintnetwork.org/our-work/ecological-footprint/> [Accessed 11 November 2019].

Editorial introduction
DAVID SAMWAYS

Disaster vulnerability by demographics?
ILAN KELMAN

Endangered species condoms: a social marketing tool for starting conversations about population
SARAH BAILLIE, KELLEY DENNINGS & STEPHANIE FELDSTEIN

Anticipating urbanization-led land cover change and its impact on local climate using time series model: a study on Dhaka city
RIPAN DEBNATH

Measuring net environmental impact from population growth and alternative energy
TRAVIS D. EDWARDS & LUIS GAUTIER

Book review: *The urban fix – resilient cities in the war against climate change, heat islands and overpopulation* by Doug Kelbaugh
JENNY GOLDIE

ISSN 2398-5496