NATURE CLIMATE CHANGE | **REVIEW**

Human drivers of national greenhouse-gas emissions

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Abstract

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Centuries of speculation about the causes of human stress on the environment is now being disciplined with empirical evidence, including analyses of differences in greenhouse-gas emissions across contemporary nation states. The cumulative results can provide useful guidance for both climate projections and for policy design. Growing human population and affluence clearly contribute to enhanced environmental stress. Evidence does not support the argument for amelioration of greenhouse-gas emissions at the highest levels of affluence. However, the role of other factors, such as urbanization, trade, culture and institutions remains ambiguous.

Introduction

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The recent recognition that humans are shaping climate change is a contemporary addition to a very long, historical recognition of how climate has shaped humans — especially the evolving patterns of social systems[1]. Indeed, it is plausible that key transitions in human evolutionary history have been driven in large part by climate change[2, 3]. Changes in climate will doubtless be a key force in the future evolution of social systems, including all aspects of social, economic and political life, while impinging on the health and well-being of the individuals who populate them[4].

Considerable progress has been made in developing a better understanding of how human actions lead to environmental change and in particular on what is most often called the anthropogenic drivers of climate change. By anthropogenic drivers we simply mean the range of human actions that cause climate change and the factors that shape those actions.

There are two major streams of research on anthropogenic drivers of climate change. One highly developed stream has focused primarily on land-use change and its impact on ecosystems. It is motivated not only by a concern with changes in albedo, but also with changes in the supply of ecosystem services, including carbon sequestration, and the emission of greenhouse gases from agriculture. This research stream is prominent in anthropology, geography and sociology, and most study designs focus on the household or local to regional landscape as the unit of analysis. As there have been several excellent recent reviews of this literature[5, 7], we will not repeat their findings in detail in the discussion that follows.

Examination of the drivers of greenhouse-gas emissions, the second research stream, has been conducted by scholars mostly from economics, political science and sociology. Many studies examine differences across nation states or other geopolitical units, such as cities, as it is typically at that level that institutions, policies and technological portfolios are organized. Furthermore, it is these units that define the boundaries of governance and collect the types of data needed for analyses. A growing number of studies are also looking at the household level, where the challenge is to find adequate data on energy consumption — the major source of emissions from households[8]. As greenhouse-gas emissions are the dominant driver of climate change and as studies of emissions at the national level have been less systematically reviewed than studies focused on land use, they are our focus here.

Consumption and population

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Candidate drivers have been discussed for decades, even centuries: population, affluence and consumption, choice of technologies, institutional arrangements and culture. The general arguments stretch back at least to the writings of Thomas Malthus in the eighteenth and nineteenth centuries, and can be sketched quickly. Growing human population puts stress on the environment. That stress is conditioned not only by population size and rate of increase, but also on the patterns of consumption of the population. And consumption, in turn, is primarily a function of affluence. Culture may have some mitigating impact through the composition of consumption, but over the course of the past several decades, many forms of consumption seem to converge upwards to a Western pattern as affluence increases[9, 10, 11]. Thus there are concerns with increases in consumption as average affluence increases in many nations, often accompanied by the emergence of an affluent middle class.

However, the stress on the environment produced by a population and its consumption also depends on the technology used to produce what is consumed. The critical point — elucidated nearly four decades ago in a debate between Barry Commoner, on one side, and Paul Ehrlich and John Holdren, on the other — is that population, affluence, technology and all other drivers act not alone or additively but in a multiplicative fashion[12, 13, 14] (Box 1). The projected increase in the human population to ten billion or more by the century's end unquestionably threatens the carrying capacity of the planet[15]. The size of the impact that will occur depends on both patterns of consumption and the technology used to supply it. It makes little sense to speak of the effects of population without simultaneously taking account of the effects of consumption and technology. Recent discussions have added nuances to arguments about population — the number of households may matter more than the number of people, shifts in age structure may change consumption patterns, urbanization may have either deleterious or beneficial effects on the environment.

Box 1: IPAT and the Kaya identity.

Full box

To either understand the historical pattern of climate forcing, which can largely be attributed to the affluent nations, or to project future emissions, where nations rapidly increasing in affluence will probably be major contributors, we must test these conceptual arguments against empirical evidence. However, it is only in the past decade or so that arguments about drivers have been disciplined with empirical analysis producing estimates of the respective effects of each.

Consumption. Ultimately, most releases of greenhouse gases are driven by consumption of goods and services by individuals, households and organizations, and the manufacturing, transport and waste disposal that underpins that consumption. Thus the rate of emission depends on the scale of consumption, its composition and the techniques used to produce and transport goods and services. For the next several decades, the human population of the planet as a whole and of most nations and regions will grow, and nearly all policies and projects anticipate and promote economic growth. Although it is nearly certain that the scale of human activities will increase, the key question is by how much? It is possible that the composition of consumption might shift from current patterns to more benign ones, as might the technologies supporting manufacturing, transport and waste disposal. Indeed, many policies seek to encourage such changes. So a central theme in research on drivers concerns the extent to which changes in composition and technique will compensate for increases in scale.

We note an important methodological limit of most current research. Most data on national greenhouse-gas emissions are based on the location of production processes even when consumption of the goods and services takes place in another country. In most data sets, the manufacture of a product in China or a question answered by a call centre in India will contribute to the estimated emissions of China and India, not to those of the country where the product is used or the question asked. Accounts for both consumption- and production-based emissions have been developed recently[16, 17]. Both approaches are needed for a full understanding. However, we acknowledge that many of the analyses of anthropogenic drivers so far rest on emissions estimates based on production data.

Population. Perhaps no driver has been subject to more heated or longer debate than population[18]. Many analysts uncritically assume that changes in the scale of the human population produce proportional changes in stress on the environment by dividing population size into aggregate measures of stress (for example, greenhouse-gas emissions) to yield per capita stress (for example, greenhouse-gas emissions per capita). However, it is plausible that there are economies or diseconomies of scale associated with larger populations. For example, larger populations may allow more effective use of mass transit systems and other infrastructure, reducing per capita impact at higher levels of population. On the other hand, larger populations may produce 'frictional' problems such as traffic congestion, resulting in increased impacts, such as carbon dioxide emissions.

At the national level, most studies looking at population and either greenhouse-gas emissions or the ecological footprint (a measure of overall stress on the environment in which the largest component is the estimated land area that would be needed to sequester carbon dioxide emissions) find a population elasticity between one and two — indicating that population changes have a directly proportionate or greater effect on environmental stress[14, 19]. In a careful assessment of the effects of national population levels on carbon dioxide emissions over the past 45 years, Jorgenson and Clark found elasticities from 1.27 to 1.86, indicating that increased population has an elastic (a greater than proportional) impact on carbon dioxide emissions[20]. They also noted that these effects were stable over the more than four decades covered by their data.

Thus despite lengthy and heated debates about the effects of population growth on the environment, the best empirical evidence suggests a consistent impact on greenhouse-gas emissions — one that is more than proportional — despite the substantial changes in economic activity, technology, social change and especially rates of population growth over the past four decades. Of course, the nation state may be too large a unit of analysis to reveal scale effects of population coming from either congestion effects or more efficient resource use. Lankao *et al.* examined transportation energy use in 84 major cities around the globe, and found, consistent with cross-national results, a population elasticity of 1.4, indicating some diseconomies of scale with a larger population[21, 22].

Although the size of a population may not be the only demographic driver of greenhouse-gas emissions, only a few disaggregated components of size have been investigated, none extensively.

Number of households. Several studies have found that the number of households may be a more important factor than the number of people[23, 24, 25, 26, 27]. The importance of households for greenhouse-gas emissions is evident, as a large proportion of household energy consumption is used to heat, cool and light dwellings and power the appliances in them, and such uses may be insensitive to the number of occupants. In China, growth in the number of households is accompanied by an increase in the number of appliances per household[28]. Transportation is probably quite sensitive to the number of households when their growth is in the urban periphery where low-density suburban landscapes prevail. This results in more passenger vehicles and more commuting adding to petrol consumption and greenhouse-gas emissions.

Age structure. The age structure of a population changes as rates of population growth change; for example, slow-growing populations have a smaller fraction of children and a larger fraction of elderly. It has been proposed that age structure, in particular the fraction of the population in the ages generally considered economically active (typically 15–65) may contribute inordinately to greenhouse-gas emissions. However, the empirical results are mixed, with some studies finding the proposed effects and others not[19, 22, 29, 30]. In part, this may be because it has not been adequately conceptualized how age structure might affect greenhouse-gas emissions. The middle age group may demand more resources and contribute more to emissions from production processes, a topic that could be investigated at the individual and household level.

Rate of growth. Although human population size is most often invoked as a driver of virtually all stresses on the environment, rapid population growth may make it difficult to provide environmentally benign infrastructure and strain the institutions required to manage the environment[31, 32]. Although this conjecture has not been directly tested, several recent studies indicated that the effects of population growth are greatest in the least-developed nations where population growth is also most rapid[26, 33, 34]. Further research will be needed to elucidate the effects of the size of the population, the rate of its growth and differences between the more and less affluent nations in the effects of both population size and rate of growth.

Consumption and affluence

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The scale of consumption, its composition and how the consumption is produced all shift as societies become more affluent. The increase in scale — consumption per person — *ipso facto* tends to increase emissions. Certain changes in the composition of consumption, such as an increase in animal products in the diet, also tend to increase the release of greenhouse gases and other environmental stresses. But a variety of changes that accompany increased affluence might moderate the consumption effects of scale from shifts in the composition of consumption. For example, increased use of electricity generated by renewable sources that do not emit greenhouse gases might partially or wholly compensate for the tendency towards increased emissions that comes with increased affluence, although York found that each unit increase in non-fossil-fuel energy displaces less than one-quarter of a unit of fossil-fuel-based energy[35]. With affluence may come policies that seek to cause less damage to the environment — policies that encourage shifts in composition and technique even while scale increases. These shifts may or may not countervail entirely the tendency of increased affluence to increased consumption and greenhouse-gas emissions.

Weighing these countervailing forces, some scholars have argued that increasing affluence will inevitably increase environmental stress[36, 37]. Others disagree, offering the hypothesis that structural and political changes accompanying affluence will more than compensate for increased consumption. Thus affluence, after a threshold is reached, leads to declining stress on the environment. This hypothesis is labelled the environmental Kuznets curve (after a similar argument about changes in income distribution with economic growth offered by Nobelist Simon Kuznets[38]) or ecological modernization[39, 40, 41, 42].

The declining-impact hypothesis has been the subject of far more empirical testing than any other hypothesis about drivers. There is some evidence supporting the hypothesis for impacts of emissions of some air and water toxins on human and ecosystem health at the local level[43, 44]. However, evidence shows that greenhouse-gas emissions and other systemic impacts, which are not geographically circumscribed, do not follow the inverted-U pattern. In sum, the majority of empirical literature shows no support for this hypothesis[45, 46, 47, 48, 49].

Urbanization and trade

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The concentration of people in cities and the volume of trade have both increased substantially in recent decades. This trend is expected to continue, so a careful assessment of the resulting stress on the environment is clearly warranted.

Urbanization. For the first time in human history, more than half of the human population lives in cities[50]. It is expected that global urban population will rise to nearly five billion by 2030. Like population, arguments can be made for both economies of scale that come from urbanization and for frictional effects that would lead to diseconomies of scale. Several studies found that urbanization tends to increase energy consumption and greenhouse-gas emissions[19, 22, 29, 33, 51, 52, 53, 54]. However, there may be countervailing effects, with suburban growth increasing emissions and core urban growth reducing emissions[30, 55]. Zhou *et al*. found that in China, the share of total energy consumption used in urban areas has remained constant even as total demand increases, suggesting that economic growth is more important than urbanization in driving increased energy use[28]. Their results are consistent with the argument that cities generate substantial demand for goods and services that can induce emissions in distant places — a process that has been called 'the metabolic rift'[56, 57].

Trade. Intense debates have raged over the environmental effects of international trade, and in particular, liberalized trade of the sort encouraged by the World Trade Organization. Some argue that trade produces a 'race to the bottom', where underdeveloped countries with lax environmental regulations become 'pollution havens' for transnational corporations. Others point to the practice of transnationals to transfer domestically developed advanced technology and environmentally benign attitudes and culture to their overseas operations as a cost-effective strategy. In a series of studies, Cole found, in general, that openness to trade reduces emissions and energy use in the more affluent countries while increasing emissions and energy use in the less affluent[58, 59, 60]. In contrast, Jorgenson found that foreign direct investment tends to increase greenhouse-gas emissions in less-developed countries[51, 52, 61]. So it appears that the effects of trade on greenhouse-gas emissions is nuanced, with emissions increasing in the less-developed nations perhaps as energy-intensive and highly polluting activities move there from developed nations.

Institutions and culture

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A nation's institutions and culture also probably influence the composition of consumption and the technologies used to support it. However, these factors have been less systematically investigated than population, affluence and political economy.

Institutions. The global atmosphere is an all-encompassing commons. The extensive literature on the commons demonstrates the importance of institutional forms in shaping environmentally significant behaviour, although the empirical studies in this tradition are overwhelmingly at the local level[62, 63, 64, 65, 66]. A parallel literature has examined international environmental agreements, but work estimating the effects of such agreements on environmental performance is still in early stages[67]. At the national level it has been proposed that democratic institutions of governance will lead to greater protection of the environment, such as effective climate policies, because of the influence of citizen preferences and environmental movements. In authoritarian regimes there seems to be little incentive for elites to provide collective goods such as environmental protection, whereas in democracies governments show more interest in the provision of such goods. Empirical studies found that democratic nations are more likely to participate in climate treaties and related agreements, but systematic investigation found that forms of governance are generally not significant predictors of greenhouse-gas emissions, net of other factors[22, 52, 68, 69, 70]. This lack of observed effects is partly due to disagreement over the accuracy of measures that compare forms of governance across nations[71, 72]. It is also partly due to the lack of a conceptual framework for testing hypotheses and accumulating the results, one of the particular strengths of smaller-scale studies of commons governance. Developing a conceptual framework that would link the commons literature to the study of nation-state-level governance, although challenging, could inform our understanding across these scales, clearly a key to understanding coupled human and natural systems[73].

Values, beliefs, norms, trust and world-views. It is commonplace to expect human values, beliefs, norms, trust and world-views to be key drivers of environmental change, and an immense literature examines their role in shaping the environmental behaviour of individuals[74, 75, 76, 77, 78, 79]. Of course, although some of our decisions reflect a formal weighing of values, beliefs and trust, many others are made without much reflection, but on the basis of normative expectations, emotions, interpretations of symbols and snap judgements[80, 81, 82]. Much is known about the social psychology of individual decision-making, and there is a substantial literature on cross-national differences in environmental concern[83, 84]. Yet, the widely held expectation that such factors influence cross-national differences in environmental stress, and in particular, emissions of greenhouse gases, remains undisciplined by a supporting body of research. We lack the consistent measurement of theoretically relevant values, norms, beliefs, levels of trust and attitudes across a large sample of countries over time that would allow us to disentangle the effects of these cultural influences net of population and other demographic factors, affluence, structure of the economy and institutional arrangements. The handful of studies that have explored existing data have found weak links, but are compromised because of their reliance on data sets never intended for the purpose for which they were used — country coverage is limited and key measures from the social psychological literature are omitted[84, 85, 86].

Other conjectures

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Other factors have been suggested as potential drivers of greenhouse-gas emissions. Ethics of care arguments and the general observation that in most studies women tend to express more concern about environmental issues, such as climate change, than do men imply that women's political empowerment might lead to amelioration of greenhouse-gas emissions[87, 88]. High levels of militarization have been proposed as antithetical to environmental protection and there is some evidence to support this argument[29]. Some have argued that major world religions differ with regard to the concern for the environment, and thus the religious composition of a nation might influence environmental stress[68, 89]. It is plausible that nations with strong environmental movements might adopt both public policies and private practices that reduce emissions, but again, this link has not been extensively explored[68]. In sum, although a diversity of factors related to culture and social structure have been proposed to be important drivers in a nation's level of greenhouse gases, these hypotheses have been under-researched compared with demographic, economic and trade drivers.

Next steps

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Looking across the social science literature on drivers of greenhouse-gas emissions, several themes emerge. First, the literature is blinkered across disciplines, with economists ignoring the work of sociologists, sociologists rarely citing political scientists, and so on. As the community examining drivers of greenhouse-gas emissions in any one discipline is relatively small, much could be gained by a more cross-disciplinary dialogue. Second, although some aspects of the reviewed literature are reasonably robust, with multiple studies converging on the same conclusion, there is little evidence that this literature has had any influence on, among other things, the development of emissions scenarios — a key tool of major climate assessments, such as the Intergovernmental Panel on Climate Change. Mapping plausible futures would be enhanced if the emissions calculations were based on disciplined empirical estimates of driver weights rather than the *a priori* assumptions of proportionality in the Kaya identity used by the Intergovernmental Panel on Climate Change (Box 1). Morgan and Keith noted the value of decompositions such as Kaya as a component of developing more realistic assessments of the probabilities associated with climate scenarios[90]. Incorporating a variety of elasticity weights — available in the social science literature — to drivers in such decompositions would be useful to that exercise, by enabling more refined sensitivity analyses. Finally, cross-national examination of the social driving forces of climate change is a very useful test bed for furthering our understanding of coupled human and natural systems[91, 92]. Although much has been and will be learned from local and regional studies, the broader international comparative perspective is a needed complement to that literature. Unfortunately, the research we summarize remains a 'cottage industry' with very little funding and few mechanisms in place to build the international and interdisciplinary community needed to discipline ungrounded conjectures with careful empirical analysis.

The substantive conclusions that one draws from the comparative literature on greenhouse-gas emissions is sobering. The population and economic growth that can be anticipated in coming decades will tend to push emissions substantially upward — a scale effect. We do not know whether shifts in the efficiency of production or in the composition of consumption will accelerate or counteract the scale effect. However, most policy proposals for limiting the magnitude of climate change address only mechanisms for changing composition and technique, taking increasing scale as given[93, 94]. Yet to be empirically demonstrated is that technological and composition shifts can consistently produce such a countervailing effect that neutralizes scale effects. Indeed, much of the resistance to climate change mitigation policy points to the presumed large-scale changes in technology and forms of consumption that will be required to stabilize atmospheric concentrations of greenhouse gases. These changes will need to be huge because they must counter substantial increases in scale coming from population growth and especially increasing affluence. Concern with the magnitude of population and economic growth has led to renewed calls to slow population growth as well as to questions about the relationship between affluence and societal health and well-being. However, in a time of global recession with intensified demands for economic growth, and with waxing concern about how elderly populations can be supported in low-fertility nations that have a high dependency ratio, such reconceptualizations of basic societal goals face a struggle. Nonetheless, it is clear that reducing emissions of greenhouse gases in the face of scale growth will not occur in the context of the institutional, political and cultural forces that have prevailed so far.

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