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# The Limits to Transforming the Environment and the Limits to Sociological Knowledge

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**Abstract:** This paper argues that the social sciences are fragmented in addressing the environmental challenge of increasing resource depletion. To address this problem, the paper puts forward a framework which encompasses several disciplinary approaches, and above all a long-term historical perspective and a realist sociology of science and technology which, in combination, provide a means of understanding the disruptive changes in the transformation of the environment. The paper then focuses on energy and gives an overview of the various social forces that can potentially counteract the future tensions arising from the foreseeable depletion of energy sources. It argues that only some of these countervailing forces—namely state intervention and technological innovation—provide viable potential solutions to these tensions. However, these solutions themselves face severe constraints. The paper concludes by arguing that a realistic assessment of constraints is the most useful, though limited, service that social science can contribute to our understanding of the relation between social and environmental transformation.

**Keywords:** sociology; science and technology; environment; energy

## 1. Introduction

The social sciences are currently ill-equipped to tackle the environmental challenges confronting society. This is partly because there is a variety of disciplinary and theoretical approaches to the environment which cover different aspects of the topic but provide little by way of a coherent understanding. In other words, these approaches miss the forest for the trees; the forest being that the

human transformation of nature is facing limits. These limits arise from the combination of a foreseeable growth in the use of key resources and the equally foreseeable social tensions to which this will give rise. However, these tensions cannot be identified without a coherent picture which shows how social and environmental changes interact.

The paper will argue that there are bound to be major constraints on how society can respond to the increasing challenges presented by the environment. In this way, although we can foresee rates of economic growth and the speed of resource depletion and the social problems arising from this depletion, we can also foresee that there will be limited possibilities for counteracting them. The social sciences can therefore at best point to the limited room for maneuver that societies face. Still, this understanding of the potential tensions arising from a functional coupling between a consumer culture and its likely future social and environmental consequences can be an important first step. Such an all-encompassing analysis will be sketchy since it covers a lot of ground; the only justification can be the pay-off of the lessons that can be learned from it.

The paper synthesizes a number of areas in relation to environmental challenges which are currently isolated from each other. It will treat each of these in turn. It will begin with a discussion of why the various disciplinary approaches provide quite different and non-overlapping perspectives on social and environmental transformations. Next, it will present a long-term historical view which puts recent environmental ruptures into context. However, these need to be combined with a realist account of the increasing power over nature, which is developed here in relation to Weber's notion of an iron cage and expanded to include an exoskeleton. Then the paper will outline the tensions arising from the depletion of environmental resources, and ways to counteract this. The responses to these tensions include growing scientific expertise, shifting public understanding and media representations, and the possibility for civil society to influence the state—which is still the main institution through which a regulatory and socio-technical response can be orchestrated. Yet the state, it is argued, will also have a limited capacity to address environmental issues, as will the various scientific and technological options that are being put forward. The essay concludes by arguing that the social sciences can play an important, albeit limited, role, in pointing to the increasing constraints upon social and environmental changes, and the limited possibilities for counteracting them.

## 2. Disciplinary Fragmentation and Lack of Realism

The disciplinary fragmentation in understanding the relation between the environment and social change can be explained by reference to the fact that a number of topics, though interrelated in practice, are contained within silos of knowledge that have not engaged with one another [1]. So far, the environment has mainly entered social thought via five routes: one is in theories of society as a whole, such as the "risk society", where environmental threats influence people's perceptions of society generally. The second is via research on new social movements, and especially "green" or "environmental" movements, which exert pressures on states for environmental regulation. Third, the environment is the subject matter of the sociology of science and technology, which has mainly been concerned with scientific expertise and the public understanding of environmental issues (reviewed in [2-4], where further references can be found). A fourth recent area of research, notable for being completely separate from the other three, is the work of environmental historians. As we shall see, they

add a crucial aspect missing in the other approaches, which is to chart the massive transformation of nature that has taken place since industrialization, including its acceleration in the last few decades. Historians, however, are ill-equipped to provide an outlook on the challenges that may be faced in the future. Finally, fifth, there are the related areas of research which address how behavior in relation to the environment (in this case, energy uses) can be changed. Again, as we shall see, what is lacking in this research is the broader context of how these micro-level changes can potentially make a difference within longer-term and more macro- patterns of energy uses and its impact on the environment.

The area of the social sciences that might at first seem best placed to address these limits and challenges is the sociology of science and technology. This subdiscipline, however, has focused on local practices rather than tackling global issues. An even greater problem and reason why the sociology of science and technology has—surprisingly—not addressed this large-scale transformation of the environment, is the lack of "realism" in this subdiscipline: since nature or the physical world have not been treated as separable from the rest of the social world, the advance of scientific knowledge and progressive mastery of environment by technology are excluded from the analysis. (It should be mentioned immediately that "nature" and the "physical world" will be used interchangeably here; the latter includes nature beyond the earth. For the idea that the physical or natural worlds are separate from, but transformed by, scientific knowledge and technological manipulation, see Schroeder ([5], pp. 8-13), who also argues that the historical discontinuities in this manipulation can be charted. This idea will be discussed further in Section 4 below). This makes it difficult to explain the transformation of nature and its (separate or deterministic) consequences for social change. The argument in this essay will be that this lack of realism is misleading, and that only a long-term historical perspective which acknowledges the radical discontinuities in the mastery of the environment—which entails theorizing technological determinism—can provide a realistic assessment of the relation between the environment and social change. This argument entails that only a synthetic analysis of environmental and social change, without the subdivisions imposed by specialist areas or disciplines, can reveal the connections between the impending limits to transforming the environment and the social processes that are pushing up against these limits, especially unsustainable lifestyles of consumption. These limits include constraints on the possibilities for control or steering, via knowledge and social mechanisms, of society's potentially destabilizing use of natural resources.

## 3. Accelerated Transformations and an Uncontrolled Experiment

Before discussing these theories or gauging the relation between the environment and social change in the face of the future, it is essential to take stock of the radical social and environmental discontinuities with the past. Environmental and economic historians agree that the industrial revolution in the 19th century—or its two industrial revolutions—brought with them unprecedented levels of economic growth and resource exploitation. Sometime during the 19th century, in parts of Europe and the United States and for the first time in history, continuous economic growth and the associated belief in constant improvements in ways of life, came to be taken for granted—a belief that was subsequently borne out in practice.

This idea has become more deeply entrenched in the 20th century. As McNeill puts it, "economic growth became the indispensable ideology of the state nearly everywhere", and "the overarching

priority of economic growth was easily the most important idea of the twentieth century" ([6], pp. 335, 336). Economic growth has led to the accelerated transformation of the environment, and this acceleration is also historically very recent. By Christian's reckoning, "in the past 250 years…global industrial output has increased almost by 100 times" ([7], p. 406). Or again, "growth in just the three years from 1995 to 1998 is estimated to have been greater than total growth in the 10,000 years before 1900" ([7], p. 446), Whether we see these as one or more discontinuities or ruptures, the industrial revolution constituted a new departure and the idea of high-level growth has become well-entrenched as a result.

It is important to note immediately that it is not economically unsustainable activity per se that makes the 20th century unique in the exploitation of non-renewable resources; such unsustainable practices have taken place regionally for much longer. What is new is that this activity takes place on a territorially extensive or worldwide scale—and at an accelerating pace ([8], p. 250). Put even more succinctly, it is "not human behaviour as such" but its "aggregation" (or massification) that is environmentally destructive ([8], p. 18). A *mass* consumer society only emerged in the US in the early part of the 20th century ([5], pp. 64-66), and was subsequently exported to Europe [9] and across the globe [10]. Consumption has thus become a systemic part of the global economy: "The distinctive feature [of twentieth century consumer capitalism] has been the requirement that the mass of the population should consume commodities in ever-increasing amounts for the good of the entire system" ([7], p. 446). Note that this shift was partly a technological shift, partly a shift in the infrastructures of mass distribution, and partly a cultural shift in higher standards of living, including leisure activities such as travel. These have become widespread and routine as well requiring increasing amounts of energy.

Hence there has also very recently been a sea change in thinking about the *level* of economic activity. Christian notes that "whereas for most earlier epochs of human history scarcity had been the most fundamental problem faced by peoples and governments, now the main issue was"—or is—"to cope with abundance" ([7], p. 446). As we shall see in a moment, the problem with abundance is that it is not clear if the extension of the human footprint can continue in the same way indefinitely. But one counter-argument against the limits to this extension can already be noted: Christian says that "in principle, the recycling of resources or the sale of information and services rather than goods can generate profits as effectively as the exploitation of virgin resources" ([7], p. 480). Such a shift, according to Christian, could be enabled by governments "taxing unsustainable production methods" ([7], p. 480). This argument also raises the possibility that a slowing or reduction of the human footprint could also come about by means of technological innovation. Yet as we shall also see, it is not clear where the will to impose such taxes or to foster such innovation on the required scale could come from. Furthermore, looking ahead, it is possible to calculate the difference that this type of shift can make. For example, Pielke, Wigley and Green have argued that "only about 20% (+/− 10%) of global energy intensity decline can be expected from sectoral shifts in economic activity, such as from manufacturing to services. The rest must come from improved energy efficiencies in individual energy-using sectors, requiring either technology changes or new technologies" ([11], p. 532, citing an earlier study of theirs for the claim about sectoral shifts).

All this can be put differently: McNeill has called the recent intensification of the transformation of the environment "a giant uncontrolled experiment". "The human race", he says, "without intending

anything of the sort, has undertaken a giant uncontrolled experiment on the earth…Although there are a few kinds of environmental change that are new in the twentieth century…for the most part the ecological peculiarity of the twentieth century is a matter of scale and intensity….matters that for millennia were local concerns became global" ([6], p. 4). The question from a social science perspective is therefore to identify the consequences of this experiment, and how the potential limits (or disasters) arising from this experiment can be handled or mitigated. Still, in view of seeing these radical discontinuities from a longer-term perspective, it is important not to extrapolate the future from quite recent trends. First, future environmental changes will take a long time, as skeptics like Lomborg [12] have pointed out against the doomsayers. Second, it is not just the natural laws of the environment that play a role, but people are often capable of "counter-strategies" ([8], p. 8). However, these possibilities for counter-strategies must also be put into a sociologically and technologically realistic frame.

## 4. Technology, Social Change, and the Environment

Against this backdrop, how should the transformation of the environment be understood? The "experiment", as McNeill calls it, is an intensification of human mastery over the physical environment that extends our capabilities, but this mastery also imposes new constraints. To recognize these constraints and this extension of capabilities, we need to take into account both the constraining ("caging") and enabling (an "exoskeleton") sides of the relationship between technology and social change: one side is how the natural or physical world are transformed by science and technology, and the other how different parts of social life—social institutions and everyday practices—are transformed by science and technology. To understand how, we must define our terms: Modern science can be defined, following Hacking, as "the adventure of the interlocking of representing an intervening" ([13], p. 146), and, following on from this, technology as the "adventure of the interlocking of refining and manipulating" ([5], p. 9). What these definitions entail is a realist and pragmatist view of science and technology: by means of the advance (seen in purely neutral terms as forward movement) of scientific knowledge, we have been able to intervene more powerfully in the natural or physical world, and by means of technological artefacts we have been able to manipulate the natural environment more powerfully.

This intervention in—and manipulation of—the environment is limited by the extent to which the human-made environment has been transformed at any given point, and so also has a social side, whereby the world around us has become increasingly "rationalized", as Weber argued. The mastery of the world thus entails an increasing instrumentalization of the social world: Weber thought that rationalization led to disenchantment and to an "iron cage"; what he overlooked was that it also led to a more powerful "exoskeleton" with which we dominate the natural environment [5]. These ideas fit well with how environmental historians, as we have seen, speak of the extension or expansion of the human footprint in the environment.

These features of science and technology are distinctively "modern" (to take issue with Latour [14]). Only modern science, emerging since 1600 or so in Europe, is "high-consensus rapid-discovery science" (as Collins [15] calls it). Collins has also argued that "research technologies" played a crucial role in scientific advance whereby laboratory instruments, which could be endlessly modified,

provided physical demonstrations of phenomena and could reliably repeat experiments ([15], p. 163). This is an inversion of the "linear model" whereby science leads to more powerful technology: it is technology that drives science, rather than the other way around, though in the economic exploitation of both, or innovation, it becomes difficult to say that one precedes the other.

These laboratory instruments can, in turn, be exported from the lab so that ultimately they turn into consumer goods: "After modification at the hand of scientists, the equipment may become commercially viable when reintroduced into the lay world…Once this happens, the research process is legitimised to a high degree: not merely on the level of ideology (which may wax and wane), but in the taken-for-granted practices of everyday life" ([15], p. 165). The transformation of technologies into everyday consumer objects is the key to the link between economic growth and technological innovation: the mastery of the environment by means of ever more powerful technologies is primarily driven by rising standards of living, and especially the expansion of leisure. Here we can think, for example, of cars and other forms of travel for tourism, or of the increasing size of homes and their appliances, and many other artefacts for consumption—all of which, again, require more energy.

During the 20th century, science and technology have increasingly become harnessed to economic growth and consumption: the development of "large technological systems" [16] has to a large extent been driven by the need for social infrastructures (transportation, communication, energy) which support the increasing scale and scope of industrial production and of the service industries—and ultimately a consumer society. The transformation of the human-made environment is not, of course, purely driven by a consumer culture—much of the extension of the human footprint in the 20th and 21st centuries has taken place because it has been necessary to meet the needs of a growing global population with more powerful agricultural technologies and the technological infrastructures for basic human services. But the balance between transforming the environment to meet growing basic human needs as against raising the ever higher standards of living of the most affluent societies—establishing this balance would require a look into the future with a rear view mirror that is not necessary for the present purpose: both will continue to contribute to greater technological mastery over and transformation of the environment, and both contribute to the way that exploitation of the environment is rebounding on society. This rebounding and the limits of the human transformation of the environment can be seen most clearly in energy uses, on which this essay can focus from now on [17]. Note, however, that the argument potentially has much wider implications, and the essay will return to how energy uses are only one part of "limits" in the conclusion.

## 5. Energy Infrastructures and Developmental Paths

Energy resources provide the power for continued economic growth and rising living standards. But from the perspective of the sociology of technology, these power sources must be conceived of as "large technological systems" [16], or as an infrastructure of society. The systems, moreover, tend to gain a momentum of their own [18]. Energy, as Radkau notes, only became a "system" with centralized electricity supplies and the supply of petrol for cars [8]. With this, energy became an infrastructure in the sense that it became an essential support system for the whole of society (recalling the "massification" discussed earlier). Energy needs are still rising on a global level, but energy has also become more effectively produced and used as well as cheaper (perhaps until very recently) over

the course of the last two centuries ([19], p. 17). Thus, "in the world as a whole, energy intensity [ratio of energy use to GDP] peaked around 1925 and by 1990 had fallen by nearly half. This meant far less pollution (and resource use) than would otherwise have been the case in the twentieth century. But this happy trend was masked by the strong overall expansion of the scale of industry" ([6], p. 316). Hence we must focus not just on the technological system, but on the energy use it supports—which is the key resource which underpins economic growth and consumption.

To ascertain the potential limits of these infrastructures, we must look at "demand" and "supply" simultaneously, both their past trajectory [20] and how they will relate to each other in the future: Maddison estimates that fossil fuels as a percentage of total energy consumption will only drop from 80.4% in 2003 to 76.9% in 2030 ([21], p. 334, Table 7.13). His forecast is based on projections that global GDP will more than double for the period 2003 to 2030 (using purchasing power parity converters), and that world energy demand will increase by approximately a third during this period. Thus Maddison concludes, for example, that "proven reserves of fossil fuels are in any case likely to be inadequate to sustain the growth potential of the world economy to the end of the current century"([21], p. 366). Even without taking into account the issue of climate change, there is widespread agreement among expert groups such as the Intergovernmental Panel on Climate Change (http://www.ipcc.ch/), the Stern Review of the Economics of Climate Change [22], and others [23] that some urgent remedial actions are needed to meet future energy needs and avert serious economic and environmental costs.

A key consideration here is the difference that overall higher incomes will make in the future, since these could either mean that people will be able to pay more for fossil fuels (for example) if they are priced higher to reflect the environmental damage they cause (which could also lead to a shift to non-fossil fuel sources), as against a scenario without these higher prices and which nevertheless still entails higher incomes and thus higher levels of consumption and therefore energy use. These two possibilities anticipate an argument that will become relevant later: If there continue to be higher incomes, then economists would argue that higher energy costs (for whatever reason) can be shifted onto consumers. But such a shift that would either move energy supply from one source to another, or it would need to incorporate future costs of depleting resources that cannot be brought about by unaided markets alone: both would require government action to force people to pay more. Put differently, there is no market-based solution to rising energy needs and their potential limits. (Indeed, arguments are being made that economics needs to be rethought as a discipline to take the depletion of natural resources into account [24], but this change is not yet widely accepted among economists.) Instead, solutions will rely on government and thus on what governments are empowered to do by civil society (or not, in the case of governments that are less accountable to civil society). Hence we must now turn to the different constraints and possibilities for government action.

To do this, we can examine various socio-political paths and how they have fostered the development of technological and environmental infrastructures; for there is no single socio-political path but several—perhaps with different limits. Thus Pomeranz characterizes what he calls the "liberal developmentalist project" of the last two centuries as "the idea that useful knowledge creates power that can be mobilized to transform nature in pursuit of material benefit for people. 'Material benefit' is measured largely by levels of individual consumption, and to a lesser extent by the political status and security of a national state in which people are presumed to have a stake" ([25], p. 119). In fact,

however, this idea is not "liberal" so much as Western or modern, and rests on the notion of constant and open-ended material progress that we have already encountered. In any event, Pomeranz wants to argue that although the liberal developmentalist project has been partly adopted in China over the past century, and particularly in the recent reform years, there is also a longer-term imperial and state-centred developmental project that placed greater emphasis on overall economic well-being: under the Qing and Ming, he says, "the market and economic production were not ends in themselves: they helped facilitate the Confucian good life for as many people as possible" ([25], p. 121-122). This project, he argues, remains partly in place, even in recent years of rapid economic growth ([25], p. 119).

China, of course, may only be one example of a different developmental path, albeit one that has recently partly embraced the "liberal developmentalist project". But China deserves highlighting first, because it is an example of where the government may be constrained in different ways in meeting rising energy needs and counteracting environmental constraints, and second, inasmuch as it faces environmental problems related to energy needs on a scale that is otherwise only matched by the United States. Further, China is a clear case where, in relation to energy in particular, the current course of economic growth is unsustainable and radical changes to energy needs and supplies will be necessary in the coming decades ([26], pp. 487-504).

## 6. Counteracting Limits

Against the backdrop that it can be foreseen that societies will come up against energy-related resource limits, how are these likely to be addressed or counteracted? If we think of the most plausible candidates here, they can be put into four main categories: (1) changing consumer behaviour and in patterns of economic growth, (2) changes brought about by social movements and via the influence of expert views and how they influence public attitudes, (3) regulation and intervention by the state which can be placed in the context of the various socio-political development paths that have just been discussed, and (4) technological innovation. Of these, I will argue, only the last two have a realistic prospect of making a difference, and even these two face severe barriers. Thus I will conclude that change is most likely to come from—or better imposed by—the cage/exoskeleton of the physical environment itself insofar as there are limits to transforming it. But before we come to this conclusion, let us examine each of the four counteracting forces in turn.

1. Changing consumer behaviour and reduced economic growth: Social science surveys have claimed to detect "post-materialist values" in recent decades in advanced societies [27], but if so, it is difficult to reconcile these with the continuing emphasis on economic growth and rising standards of living. Moreover, it is not clear how the economic behaviour of consumers is changing in response to environmental concerns since, as Yearley notes ([4], p. 315), "many environmental issues—even if real—are plainly remote from everyday experience so that their reality is not apparent to everyday experience" (Hulme calls them "distant and intangible" ([2], p. 196) rather than "remote"). To give just one example: although the social sciences have extensively studied people's choices in relation to residential energy, it is unclear how these choices at the individual level, even if they could be changed successfully, would add up to larger changes that can have a significant impact. As Wilson and Dowlatabadi argue, decision-making about residential energy use from a broader perspective is

severely constrained, and from this social science perspective, the aim of "interventions should facilitate interactions between households, utilities, and all the other institutions that play some role in structuring everyday life and routine…Rather than prescribing individual behavior, the objective of these interactions should be to sketch out future sociotechnical conditions necessary for reducing demand or to influence expectations and norms" ([28], p. 189). It remains to be seen if a noticeable change in rates of growth as a result of environmental factors more generally can be detected—but for the moment, the inexorable drive for rising living standards shows no sign of abating. (In terms of research, Wilson and Dowlatabadi argue that "the main integrative challenge is to resolve this assumption of individual agency (in economics, technology diffusion, and social psychology) with sociological findings on the structuring of behaviour by sociotechnical systems" ([28], p. 191). The latter, of course, is the main aim of this paper).

If on the other hand, we think of economics not as consumer behaviour but as markets, then one key problem, as we have already seen, is that higher prices for energy are unlikely to come from markets themselves (even if they may come from scarcer energy sources driving prices up), but must rather be imposed by government regulation (of which more shortly). The problem here is that economic power is diffuse: it does not reside in any particular actors with bounded powers, but in many dispersed actors ([29], pp. 24-25). Further, the solution of economists, of putting a price on environmental problems themselves, is deeply problematic, as Yearley [4] points out, and it is unclear whether it can have a policy impact. For example, even when knowledge of costs to economic growth, including their origins in environmental damage, is available within the scientific community, it is difficult to see how this knowledge can be acted upon. Consider an example from McNeill, who quotes World Bank estimates from 1997 that "China's air pollution cost the country 8% of its GDP" ([6], p. 107). But the years since have also seen a considerable worsening of air pollution, presumably at equal or greater costs to the economy [30].

In short, knowledge or awareness of environmental damage and its economic costs does not necessarily lead to large-scale concerted policy change. This goes for developed and developing parts of the world as much as it does for less developed ones. Pomeranz points out that "unprecedented economic growth has created unprecedented economic inequality in the past two centuries. It has also created unprecedented environmental inequalities, with the world's poor far more exposed to unhealthy air and dangerous wastes than the rich, and far less likely to have clean water" ([19], p. 13, see also [31]). At the same time, Roberts and Parks say that there is "an enormous 'worldview gap'" ([32], p. 231) between the developed and the developing world, with only the former being able to push environmental problems into the future while the latter focus on current problems (though of course rich countries have much more power than poor). Here we can also recall Christian's argument (see above and [6], p. 480), that it may be possible to shift profit-making away from the use of virgin or non-renewable resources: again, it is hard to imagine how the balance between these non-resource intensive services and resource intensive ones requiring energy can be shifted, if we think only of the growing global demand for tourist travel and for automobiles.

2. Social Movements and Expert Ideas: To be sure, sensibilities about nature and about the mastery of nature have changed significantly and this shift has been charted even for the period before industrialization, at least in England ([33], pp. 330-333). But it is only recently, since the 1960s and 70s, that there has come to be a widespread awareness that the effects of the transformation of

nature are destructive. As Radkau notes, what is new about the environmental movement since the 1960s is not the romantic attachment to nature and the call for its preservation, which is much older, but rather the awareness that "in the long run the destruction of nature would threaten the physical existence of humankind" ([8], p. 270).

Yet changing sensibilities and ideologies need to be translated into action, and for this, they need organization and visibility. Political parties and social movements with an environmental agenda have made considerable strides, but their agendas in relation to lower-intensity economic growth and energy consumption have had a limited impact. As Keck and Sikkink note, although environmental transnational advocacy networks have often been successful in framing the debate, it is much more difficult to translate their agendas into action, unless this coincides with national interests and is not regarded as costly ([34], pp. 203-204). Parties and social movements are competing for attention in the media, their main avenue for influencing policy. Further, they are competing with other actors in the public sphere in which environmental issues are being debated and which, following Bauer and Gaskell [35], can be conceptualized as consisting of three arenas: policy regulation, public perceptions, and media coverage [36]. Within the triangle of these three arenas, environmental agendas are continually being pushed hither and tither by different actors, including actors with economic interests, social movements (including green parties and non-governmental organizations), and various expert groups.

The latter, of course, provide additional input into the public sphere, in the form of scientific expertise. Science has been quick to respond to environmental challenges. McNeill ([6], p. 340) suggests (based on the American National Science Foundation's estimations) that "global-change science programs…by 1998…amounted to the largest research program in world history". But scientific expertise, too, needs to be translated into action. One example can be used here to illustrate why it is particularly difficult to translate environmental issues into action: in a recent effort to prioritize different global challenges (the "Copenhagen Consensus"), social scientists (in this case, economists—though a youth forum panel which did not use cost-benefit but rather human benefit analysis did not differ significantly) ranked climate change much lower on the list of priorities than more tractable ones like communicable diseases and hunger and malnutrition—since the rewards for action seem to be so much higher and more immediate ([37], pp. 605-644; also discussed in [2], p. 266).

The relationship between scientific expertise and society is thus an indirect one: experts need to convince the public via media, and get the public on the side of their views. As Collins has pointed out, scientists need allies in society [38]. And even if epistemic communities [39] of experts can arrive at a consensus view that sways policymakers; again, these policymakers need to be enabled to take action in the form of policy and regulation. Yet, as we have just seen, policy takes place in a field which includes (according to Bauer and Gaskell) not just public perceptions and media coverage (itself constrained by balance, which can be biased, see Boykoff and Boykoff [40]), but also other actors who shape the agenda and include economic interests and NGOs. Thus surveys show that the public remains confused about who should act on climate change ([2], p. 318) and experts who have been in this field for a long time say that the preconditions for political action in this regard remain "weak" ([3], p. 72). In sum, scientific expertise and social movements may be able to shift perceptions,

but their combined efforts would need to be complemented by large-scale cultural change in relation to environmental transformation to enable policymaking that can translate this shift into action.

3. State Regulation and Intervention: Elucidating this counter-measure requires that we recognize that different types of states or regimes have different possibilities for action in the face of environmental challenges. One widely shared view [41] is that pluralist or democratic regimes are better able to cope with environmental problems than authoritarian or postcolonial ones. This is because their open political institutions are more responsive to the concerns and harms experienced by their citizens. Josephson's main examples here are the authoritarian regimes of Soviet Russia and pre-reform China, and he describes how these and other authoritarian states, by pushing through large-scale technological projects (or the "large technological systems" or "infrastructures" discussed earlier) and riding roughshod over the views of their publics, cause enormous environmental damage.

Yet those who argue as Josephson does overlook that these states also exercise greater control over environmental issues since they can ignore economic interests or public unwillingness to pay for the mitigation of environmental problems. As we have seen, Pomeranz for example argues that *post*-reform China exhibits at least some continuity with a much longer Chinese tradition whereby the government must be responsive for the care of environment and its beneficial use for the population [25]. It is also possible that scale is an important factor in the possibilities for political steering. In this vein Radkau suggests that environmental policies are easier in "small manageable countries" like Denmark and the Netherlands that are also able to achieve a "praxis-relevant consenus" ([8], p. 290). In any event, Pomeranz concurs with (and summarizes) McNeill's argument [6] that "thus far even fairly democratic polities have been much better at addressing environmental problems that are immediately and locally present (e.g., cleaning up the water that current citizens drink) than at addressing problems like global warming, which are diffuse and unfold more slowly" ([19], p. 13). This conclusion fits well with the point made earlier about the opposite situation whereby the distance and intangibility of environmental problems impacts on *not* being able to mobilize the public behind making changes.

The large-scale steering of environmental transformations in any case invariably involves the state—whether in authoritarian or democratic, or in small or large states. This is because states promote the largest technological projects. Even if multinational corporations sometimes also play a major part in these large technological projects, they do this only with state support. At the same time, states are also responsible for creating technological infrastructures that improve well-being and underpin economic growth, and so need to instigate large-scale projects in the first place which rely, to a greater or lesser extent, on public support. Finally, it can be added that large-scale transformations increasingly involve not just single states, but coordination among states as conflicts over resources which cross state boundaries move into the foreground. Yet global governance of climate change faces so many challenges that coordination is likely to be a process of long-term adaptation [42], aside from the North-South power imbalance and divergence of interests mentioned earlier [32].

4. Technological Innovation: we have already seen that dramatic solutions will be required for how energy needs are met. One solution could therefore be new technologies. However, all new technologies would necessarily take the form of "large technological systems", with all that this entails for creating infrastructures. So, for example, there could be new fuels for vehicles which might overcome the foreseeable constraints on fossil fuels and their harmful environmental consequences.

Yet the main obstacle to these are not so much the fuels or vehicles themselves, but the infrastructures to support them, which include the logistics of distributing fuels over extensive territories and the large-scale mechanisms for switching from one type of vehicle and its supporting institutions to another (and a key feature of infrastructures that is often overlooked is that they need to be maintained, as Edgerton [43] points out). Other new sources of energy which are less exhaustible—renewable energy like wind, solar, hydro and biofuels—have been shown to have limited possibilities for replacing non- renewable sources [44].

Similar considerations apply to the solutions to environmental harms that have become known as "geo-engineering", which also involve "large technological systems". These solutions, which would potentially allow much higher rates of energy consumption and mitigate the harms that are produced by this, would nevertheless require even larger "uncontrolled experiments" than hitherto which, even if they are aimed at "controlling" some of the effects of an intensified transformation of the natural environment, would introduce further "uncontrollabilities" of their own. In short, all technological options require large-scale and highly coordinated efforts which are supported by states, like all "large technological systems"—but perhaps more so since they either have high costs without certain benefits in the case of geoengineering, or they need to displace existing systems in the case of transport or energy—unlike earlier technological systems when they were initially created.

## 7. Implications and Conclusions

This essay has argued that limits that rebound on society can be seen in response to the recent and radical transformation of the environment. This rebounding is caused by the combination of increasing resource scarcity and expanding use—without at the same time having the capacity, technological, governmental, or otherwise, to cope with these combined trends. In any event, enhancing technological capacity would also lead to greater instability and further degradation of the environment. In short, there is a narrowing window of possibilities in the face of a constricting cage. Before going on to spell out implications, it is important to note that these constraints do no necessarily point to global resource wars, which is one prognosis. Wars are one possible outcome (though notoriously difficult to foresee), but the resource constraints that have been described are inescapable with more general consequences that can be foreseen.

The various limits that have been discussed should not be exaggerated: the transformation of the environment, or the extension of the human footprint, is still deepening and will continue to do so. Still, these limits will shape the direction of science and technology, the pace of economic growth (and with it the culture of consumption), as well as state efforts aimed at mitigating them. These limits are also bound to require an extension of technological infrastructures and how they support energy uses. It has been argued that when the various forces at play are seen in their entirety, it can be recognized that these limits or constraints are structural, caused by the relation between technological mastery and the physical world, and that social and political institutions will be forced to adapt to these constraints.

Put differently, these constraints follow from the argument about technological determinism that was made towards the outset of this paper. This technological determinism, combined with a realistic assessment of the countervailing forces which have been shown to have limited possibilities of success, leads to the conclusion that there are structural (technological and environmental) constraints

which will shape social responses. It can be foreseen that technological and environmental change, an extension of caging and of our exoskeleton, will be needed as responses, but will also produce new constraints of their own. The cage/exoskeleton concept thus:

- Foresees a condition in which technological mastery will need to seek a steady (or steadier) state and in which this mastery no longer causes environmental problems which rebound on society. The alternative is an unstable state in which the continuing expansion of the transformation of nature produces increasing tensions over growth.
- Suggests that continued instability is more likely because scientific and technological mastery, as we have seen, is two-edged. Even if further mastery therefore addresses the obstacles of implementation, it will also introduce further problems of "uncontrollability".
- Entails that the tensions that will arise, primarily over economic growth, will also produce issues beyond national boundaries. Hence these tensions will also be diffuse, so that conflict or dramatic policy changes are unlikely except when severe problems inevitably force responses and coordination.
- Any outcome is thus likely to produce instability and ultimately social conflict, and demand dramatic intervention by the state and by means of technology.

In short, the notions of cage and an exoskeleton allow us to recognize the shape of the bars of our cage or the limits of how far our exoskeleton can extend, given certain foreseeable technological, environmental, and social developments and constraints. The focus here has been on energy because that is the motor of economic growth, and thus a crucial technological and environmental determinant. Yet the argument should equally apply to any part of the transformation of the environment (for example, large-scale harmful pollution unrelated to energy, or growing needs for water, or climate change resulting from energy uses) that runs into the kinds of constraints that have been identified here. Thus one of the implications of this paper is that there should be continuous monitoring of how the various social forces and transformations of the environment are coupled in a single overall constraining feedback loop, which would also allow pinpointing the resulting tensions and ways to alleviate them. If this seems to be an overly ambitious idea, the counter-argument is that the scale, scope and complexity of the problem demands such ambitiousness.

The transformation of the environment is beginning to rebound on society in the sense that the increase in the mastery of nature evinces limits. These limits can be expected to change the direction of scientific knowledge and technological innovation, towards a focus on knowledge about these environmental constraints, the problems in overstepping them, and how to reign in economic development. Yet, as argued above, scientific knowledge, while it is intrinsically boundless, faces limits in this case of translating into policy and practice. Thus there is a further tension: only further scientific insight, including social scientific insight, and more effective technologies, can, in view of this rebounding, enable the envelope of human mastery to continue to be pushed—and simultaneously ensure continued sustainable growth. Yet as we have seen, the social sciences are ill-equipped to contribute to these insights because of their fragmented perspectives which overlook how long-term trends and large-scale transformations are combined with the limits of and tensions among the relevant social forces. And we have also seen that there are limits to this knowledge, quite apart from this fragmentation—not so much in terms of what we know or can foresee, but to putting this knowledge to

use in shaping shape practice. Social Science can therefore play a useful role by (realistically) pointing to its own, quite limited role in shaping practice, and at the same time also weighing the possibilities and constraints in other courses of action and inaction.

These limits and this rebounding thus expose a further tension between the imperative for continued economic growth which is essential to a culture of consumption and provides political legitimacy—and the constraints that this culture and this legitimation will face in the future. And while the evidence for rebounding is still weak as it is still mainly on the horizon, it follows from realistic forecasts about growth. How these limits to growth can be counteracted—and what the limits are to this counteraction—are thus also foreseeable questions. Social science therefore leads to the expectation ("prediction" is perhaps too strong) that only large-scale state-led dramatic intervention directly into the technology-environment relationship is likely to have the necessary impact required by foreseeable constraints [45]. Social science which, it has been argued here, needs in the case of transformation of the environment to provide an overall and integrative account of the problems in this transformation insofar as it can be foreseen, should thus also take the next step of theorizing how this dramatic intervention can come about.

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45. It will be evident that this theoretical frame is both functionalist but also based on conflict theory, a combination that is inescapable for the relation between technology and social change, as argued elsewhere ([5], esp. pp. 127-128).