Journal of Energy Research and Reviews

1(3): 1-14, 2018; Article no.JENRR.42489

Flaws in the Scientific Method and Their Relevance for Energy Research: A Cautionary Tale

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Authors' contributions

The work was carried out in collaboration between both authors. Author TJB is a sociologist and brings the perspective of observation and analysis of social phenomena—in this case, of science as it engages and is impacted by society. Author TWB brings the Philosophical approach to considering science as a social phenomenon. The authors' home disciplines converge around a phenomenological approach to examining science, both as a world view and as a social enterprise, and both authors bring that perspective. The paper emerged largely from the discourse around the dialectical relationship between the authors' analyses. Both authors were deeply involved in the writing and reworking of the manuscript, and both authors read and approved the final product.

Article Information

DOI: 10.9734/JENRR/2018/v1i39814
Editor(s):
(1) Salisu Muhammad Lawan, Department of Electrical and Electronics Engineering, Kano University of Science and Technology (KUST) Wudil, Nigeria.
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Complete Peer review History: http://prh.sdiarticle3.com/review-history/25609

Policy Article

Received 26th April 2018
Accepted 9th July 2018
Published 19th July 2018

ABSTRACT

The *Aim of the Paper* is to explore how scientific methods, while strong in principle, can have serious flaws in practice. In focusing on circumscribed aspects of an overall system, science is able to bring a greater level of control over what is under its gaze. Yet imposing order on some aspect of a system increases entropy in other parts of that system. Because of the combination of what is at stake and the secrecy of many of its aspects, this is of particular concern with Energy Research.
Using *Methods* that flow from the interface of the disciplines of Sociology and Philosophy, the paper considers the most pressing problems and suggests ways of addressing them. The Sociological

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perspective involves observation and analysis of science as it engages and is impacted by society. The philosophical approach is brought into play in the interest of considering science as a social phenomenon. The disciplines converge around a phenomenological approach to examining science, both as a world view and as a social enterprise. In the process, the article raises implicit ethical questions.

Results of the analysis offer a series of challenges and invitations to the scientific community, encouraging scientists to lead the way in reexamining their methods and how they relate to and impact both society and ecology. Typically, the most profoundly affected parts are those most closely connected with the elements under study and manipulation, and yet defined out of the system. Scientific paradigms would be more viable if a metavariable were incorporated into them—one informed by where the processes in question stand within the scope of history and the trajectory of life. The article also underscores the fact that science itself is a social enterprise and, as such, bears questioning by the society of which it is part. With appreciation and respect for what discoveries science has made thus far, the paper makes the case that it is time to examine the inertia of scientific methods as they have come to be honed by practice over the last several centuries.

Keywords: Scientism; technology; scientific method; post-normal science; externalities.

1. INTRODUCTION

At least since the dawn of recorded history, human civilization has been influenced by, and in turn has impacted, the natural environment. Yet in the current century, humankind faces problems of heretofore unseen magnitudes. What is timeless and what is new? There currently are more people on the planet than ever in history, and by all indications and barring some catastrophe, there will be significantly more people before there are fewer. Science and technology continue to advance, and in fact, much of the social and even cultural change, particularly since the advent of the Industrial Revolution, has been intertwined with such advances [1]. This has been particularly true in terms of the exploration, development and usage of inanimate energy sources in general and fossil fuels in particular [2,3,4,5].

In the sense that much of what is known and experiencedin the contemporary world have arisen from technological innovation, there are phenomena that can be truly said to be "new." What can be made of them? Certainly, they have components of the old, known world, and to some extent these older tools can provide an *entre* into thinking about them. Yet there are limits to this approach as well, that invite some reworking in light of current trajectories of social and technological developments.

2. THE RISE OF SCIENCE AS A WAY OF ORGANIZING THOUGHT

When Isaac Newton published the *Principia* in the late 17th Century, he could not have foreseen what sorts of social changes would come about in its wake. Within the time since then, people in many societies have gone from a largely unquestioned faith in religious authority to a faith in science that in many ways is just as strong, if not more ubiquitous. This sometimes mythical belief in science and its practitioners goes by a variety of names, but perhaps the most apt is *scientism*.

The goal in this paper is not to step into the tired religion vs. science debates. It is, rather, to point out some of the limits of science as it has come to be practiced and as it inhabits the popular imagination in our time. Questions that grapple with the complexities of religion in a modern/postmodern age, and what spirituality may mean as societies hurtle into the future, while not unimportant, are outside the purview of this paper. For now, consider what scientism itself has wrought.

3. A BRIEF PROLEGOMENON

The paper offers a critique of contemporary science, but a preliminary clarification is necessary for two reasons. First, at present science is and has been suffering for some time from extreme versions of what is popularly called "anti-science." For instance, this has been going on for over a hundred years in the guise of religious objections to evolution. More recently the disturbance lies in the blatant rejection of science in reaction to scientific claims regarding climate change. In addition, the current dismissals of scientific claims in political discourse, many of which have come to a head particularly since the advent of the denial of basic scientific findings in the United States, only further aggravate anti-scientific attitudes of the day [6,7].

Second, the scientific community has understandably found itself on the defensive. As a result, any criticisms of science, sometimes including internal critiques among scientists, have become increasingly suspect. The presentation being made today could be mistaken for another assault on science; yet it is nothing of the sort. Indeed, science has more than proven itself by its remarkable beneficial consequences for society and the people in it. Even so called "anti-scientists" unwittingly benefit from science to the point of dependency on science. The current and growing body of knowledge of humanity, its society, and indeed the world itself is more than sufficient to make this case. This article operates within the realm of the social sciences, albeit while also relying on interdisciplinary sources and perspectives.

Inherent limits of humanity in all of its manifestations place constraints on what can be achieved. Thus, every human effort, whether scientific or other, tends to overstate its case and to press various perspectives beyond their legitimate bounds. Scientists are no more or less tempted by this tendency than other human endeavors. Science, in the end, is a heuristic process geared toward greater knowledge and understanding.

The present article challenges this overreaching in science with, for want of a better term, the need for *humility* to balance the devotion to science. The work of science needs this, not only when offering specific scientific claims, but also regarding the limits of science in relation to other approaches to understanding the world and humanity's relation to it.

4. NOTES ON METHODOLOGY

The method employed in this article balances two perspectives: one of Sociology and the other of Philosophy. From the sociological perspective Max Weber's *Methodology of the Social Sciences* [8] provides guidance. Guided by his vision of *Verstehen*, that is, coming to an understanding underlying the subject that goes beyond collecting and "number crunching" quantitative data. This aspect of the method may best be characterized as hermeneutical.

From the perspective of Philosophy this article is informed by Phenomenology. That is, the article concentrates on a comprehensive approach to scientific method as it has emerged since Occam and Bacon. This method juxtaposes with a sociological hermeneutic. From the dialectic of these two methods emerges a critical view of scientific method. Out of this framework emerges a Sociology of Science. It offers a sustained critique of science, particularly as a social enterprise.

5. SCIENCE AND TECHNOLOGY IN THE 21ST CENTURY—NOVELTY AND REPLICABILITY

The scientific method stands or falls on the basis of replicability which, of course, is a function of the philosophy that events repeat themselves. Even bracketing the sorts of concerns raised by Husserl [9] and other phenomenologists about whether *anything* ever repeats--and stipulating that there are indeed many repeating phenomena which can be enumerated, from voting behavior in presidential elections, to increases in earthquakes and the prevalence of a variety of maladies around fracking sites and numbers of deaths per live birth—one is still left with a number of quite *bona fide* concerns from a methodological perspective.

There are pressing questions about social phenomena, particularly in terms of technology, but probably also of population, for example, which are novel in ways that are crucial to consider. Much of what they present falls outside the range of what has been tested enough to be considered "reliable" and so on some level, scientific rigor would advise against speaking with any sort of authority outside of the scope of knowledge.

Ready or not, the world and its problems present themselves daily; and society looks to science and its offspring, technology and engineering, to be at the forefront of engaging those problems. Yet with many of the problems being truly new, at least in order of magnitude, then a significant aspect of the faith in science could more accurately be characterized as mythological, or perhaps scientistic, in contradistinction to scientific.

One reaction to true novelty (albeit novelty largely fostered by science and technology of an earlier time, variably in terms of weeks, months or centuries) is for science to move forward doggedly, to measure what it can anyway, and to extrapolate. This may be preferable to the alternative of inaction and helplessness. At least in theory though, a *tertium quid* may be the next phase in the scientific method. In such a scenario, for example, science may rethink its norms about Type I and Type II errors and the epistemological positions about Truth and Falsity underpinning them.

Given the overwhelming complexity of many problems such as global warming or the AIDS epidemic in many parts of the planet, coupled with the tendency for such problems to change more quickly than even the most astute science can track them, some rethinking of the method itself is called for. It may be in order to acknowledge that, even if Truth is knowable through the scientific method, there still likely are at least some problems for which there is neither sufficient time nor resource relative *to* the potentially catastrophic consequences of waiting until "all" the evidence is in.

For some problems, particularly the complex variety that involve potential interactions which have not been tested and could not reasonably be expected to be tested in time to intervene to avoid a catastrophe—a different principle than finding the Truth or Falsity of "all" the variables may be essential. An engagement of questions about the potential or likely consequences of an array of actions, as well as inaction, is called for. To do that, analysts would need to take into account the traditional Type I and Type II *alpha* and *beta* levels, but also to take a crucial step beyond them.
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Prescinding from the question of ultimate knowability, if it is correct to say that much of the natural world is unknown, then a type of precautionary principle is needed to fill the void of the unknown areas. Of course, many problems to which it would apply are themselves a function of a scientific enterprise that was able to create technologies more quickly and efficiently than it could know the consequences of what it has created.

Decision scientists have developed an elaborate set of measures and statistics to deal with situations where phenomena are perhaps on the edge of perception, where the perceiver is not sure whether it is truly present or not. These techniques have been used to good effect with, for example, air traffic controllers who are in situations where certain kinds of mistakes (e.g. not perceiving two planes on a collision course) have more serious consequences (a plane crash) than others (e.g. having a plane make an extra loop before landing, even though that action may be extraneous and annoying).

Arguments for the refusal to acknowledge the relationship between the profligate consumption of fossil fuel energy sources, and anthropogenic global warming and its consequences, though recalcitrant and very likely wrongheaded, often tend to be couched in a rhetoric of scientism. Despite the preponderance of evidence showing ominous signs that there in fact *is* significant anthropogenic global warming, particularly with the intense extraction and consumption of fossil fuels as energy sources, it is also the case that *some* studies can be adduced that would seem not to support that conclusion. And yet to make such an argument betrays an incomplete sense of "science" at best, and perhaps a willful ignorance based on self interest (e.g. a politician who receives contributions from oil companies while at the same time favoring such companies and not supporting research into alternatives while dismissing them as not "cost effective").

In some situations, narrow self interest skews perceptions of Truth. In others, intellectual laziness, anti-intellectualism, or busyness with other aspects of an overwhelming (post)modern condition may lead to over-reliance on easily accessed non-scientific sources (e.g. talk radio hosts or the chatter on an internet blog site) as a stand-in for a person's sense of "science." Positions then harden around communities of discourse, where Truth in the mind of a public person becomes a function of a number of social phenomena. Positions around issues such as global warming become something of a shibboleth for these communities rather than a problem for good-will public engagement [6,7].

So debates about whether or not global warming even exists ensue and inaction continues. A more fruitful way to conceptualize and communicate about such an issue would necessarily engage the consequences of being wrong. It is not a question that even makes sense to debate as one would, say, argue about who the best sports team is. The consequences of a wrong position need to be weighed, at least for the time being, with incomplete information. As the pioneering work of Rachel Carson [10] and others linking environmental degradation with certain types of cancer and birth defects [11,12], it can be catastrophic in the long run to make the default burden of proof lie with those inclined to err on the side of caution, rather than with those having a material or ego interest in ignoring such caution while enjoying a legalistic advantage.

The scientific method has worked remarkably in a number of ways, and yet has not changed much at all since Bacon and Occam, particularly in terms of its propensity to isolate phenomena from ecological systems in which they are embedded. To be sure, paradigms have come and gone. But we are talking about something different—a metamethodological paradigm as it were [13,14].

Following Kuhn [15], perhaps it is time to take an account of what works and what does not work about the scientific method. In the face of this new set of circumstances where, *inter alia*, the consequences of being wrong would be catastrophic, it is time for reworking some aspects of the method. Science, and particularly the society of which it is part, fail to do so at their peril.

This is not to suggest a wholesale dumping of the scientific method in favor of a return, for example, to magical thinking. And yet science has given rise to its own brand of scientistic magical thinking. As Karl Popper [16] has noted, scientific paradigms can themselves be seen in mythical terms.

The responsible interpretation of a regression statistic, for example, would preclude making an extrapolation beyond the range the data collected. And yet much of scientistic thinking does that regularly, with the extensions tending to be of a certain sort—such as how much of a process can be controlled and what might be the logistics of technological transfer.

The extensions of assumptions beyond empirical ranges almost invariably fall short of engaging an overall ecology. An imbalance has occurred from the overuse of some aspects of science relative to others. It has come to a point where science and technology, and perhaps even the considerable aspects of civilization stemming from them, are laden with patterns of convergent/analytic thought that are no longer held in balance by a vibrancy of holistic/synthetic thought [17].

Paradigms of science and human ecology would do well to incorporate explicitly into their thinking a metavariable—one informed by where the process stands within the scope of history and the trajectory of life [13]. Yet we hesitate to characterize it as a variable, because the very word leads to an almost reflexive tendency to routinize and quantify it. It is more important, crucial really, that science (and the associated technology) incorporate the idea into its thinking—to embrace a new level of complexity in fact—rather than necessarily adding another quantitative variable [18].

6. EXTERNALITIES OF TECHNOLOGY AND THE SCIENTIFIC METHOD

In its focus on some circumscribed aspect of an overall system, science and the technology stemming from it, is able to bring a greater level of control over what is under its microscope. Yet imposing order on some aspect of a system often imposes entropy on other parts of the system [19]. Typically, the most profoundly affected parts are those most closely connected ecologically with the part under study and manipulation, and yet *defined* out of the system for purposes of scientific investigation.

In an analogous vein, a fundamental flaw in econometrics lies in the conceit that its models have included the important parts of the whole and, parsimoniously perhaps, ignored the others—the “externalities” as they have come to be known euphemistically. And yet, as serious a set of problems as ignoring externalities are in econometrics, at least a competent econometrician tends to acknowledge that externalities exist and, at least in theory, potentially render a model underspecified.

The scientific method is in some ways analogous to, and in other ways quite distinct from, the economic method (as practiced in orthodox economics departments throughout much of the world, and particularly in the United States) [20]. Science tends to focus on circumscribed aspects of reality and in so doing largely to ignore others.

7. PERVERSE CONSEQUENCES OF TECHNOLOGY IN AN AGE OF GLOBALIZATION

The serious ecological consequences of this artifact--not so much of the scientific method itself, as of the *de facto* way the method has come to be used--are experienced later, when the science is cast into technology [21]. This is due to several factors. In ignoring related but externalized aspects of the ecological system of which the process under scrutiny is part, there is an increase in entropy in the overall system proportional to the negentropy (or degree of technological innovation) in that circumscribed part [22,23,24].

This creates imbalances in the system. In some smaller cases particularly, the fallout may still be something the natural ecosystem can process. Yet much of technology tends to be organized around routinized large scales of production and consumption, and so small systemic eccentricities, or imbalances, tend to be magnified [25]. This combination of entropy in parts of the system, multiplied by large scale production, leads to potentially catastrophic consequences. This then is the crux of why "technology" is such a potential problem in the contemporary era of global scales of production and consumption [26].

8. AS SOCIETY MOVES INTO THE 21ST CENTURY

"*And so we beat on, boats against the current, borne back ceaselessly into the past*."

F. Scott Fitzgerald, from *The Great Gatsby*

One of the central problems of science of the current century will be to attempt to neutralize the imbalances it has created, particularly since the Industrial Revolution [27]. The tendency to hyper focus on some aspect at the expense of other processes with which it may be connected, has created heretofore unknown magnitudes of imbalances [1].

The hubris of science lies, *inter alia*, in its promulgation of the myth that analytical thinking about circumscribed aspects of a system, isolated from their ecological embeddedness in larger processes, can go on indefinitely—and marks "progress" some how. This emphatically is *not* a call to end scientific analysis, but rather to leaven that analysis with a serious engagement of questions of scope and situatedness.

There are some ironic and ominous parallels between the convergent analysis of the techno-scientific enterprise, and the rise of anti-intellectualism in the public sphere. These, in combination with increasingly greater concentrations of resources in fewer hands, give rise to a perverse dialectic.

With large-scale technologies, we have the advent of the technocrats with narrow expertise not counterbalanced with the broader view that might give rise to wisdom—a class of techno-elites developing for mass and niche markets to feed the treadmill of production and consumption. That this leads to ever greater concentrations of wealth of the financial classes is but part of the picture. It redounds in ever more extensive avenues of hyper-individualism and of the narcissistic absorption stemming from it. This extracts a cost in terms of mass disengagement from civil society, social responsibility, and a disconnectedness from the natural environment.

9. CONSTRAINTS ON FUTURE ACTION

As a general rule, prior actions of ourselves and others constrain current and future options. This is true fora number of time frames and levels of activity.

Increasingly, there is the ability with technological advance to make deeper and broader incursions into the earth. Take for example, the consequences of the dual enterprises of intensive coal mining and extensive strip mining. According to recent interviews aired on National Public Radio, on the perceptions of people living in the vicinity of strip-mined mountains in West Virginia, much of their local ecology has gone from "Almost Heaven" to "Hell on Earth" often in less than a decade.

There are longer term consequences for skewing the emphasis toward fossil fuels for decades after the peak of their utility [28], thereby effectively prolepting serious consideration of alternative energy research [29]. This is worth giving careful consideration, because there are lessons from the past to be learned [6,1].

Meanwhile, the scientific imagination is caught in a process of fractionation that appears to have taken attention away from many of the pressing problems caused by a scientistic culture. There is now somewhat of a disconnect between the synthetic thinking of theoreticians such as Nobel Prize winners, Ilya Prigogine [19] and David Bohm [30], and the more linear analytical thinking that drives much of technology. While the first may have found a place in the popular imagination, the latter is firmly ensconced in the technology that has become married to global capitalism. Each of these has its own implied metanarrative.

Another dialectic that appears to have captured the popular imagination is that between particular evolutionary accounts [31] and particular religious accounts (typically a circumscribed variant of creationism or intelligent design).This rear-guard action of scientism tends to flatten and stunt thinking about problems associated with default ways of doing science and its technological offspring. It defines the primary dialectic in a direction that abrogates responsibility from engaging the problems caused by hyper focus on certain scientific problems—typically those with potential for “technology transfer” and the concomitant monetary payoff.

Thomas Kuhn [15] discusses many of these processes in depth in his landmark work, *The Structure of Scientific Revolutions*. As Kuhn describes it, “normal science” tends to maximize continuity; in contrast, “revolutionary science” is characterized by discontinuity, where there is a change in fundamental thinking, or a “paradigm shift.” Normal science is characterized by second order change, while crisis or “revolutionary” science typically involves first order change. Even revolutionary science often stops short of zero order change, however.

10. CONSIDERING THE PHENOMENON OF CHANGE ITSELF

Seen in this light, what would involve zero order change? Certainly there was a discontinuity between, for example, the medieval consciousness and the modern consciousness. Now in late modernity, we find analogous discontinuities. A zero order change would be as profound as the transformation from hunting and gathering to horticulture and farming, or from agrarian to industrial society—or more precisely, a change in the consciousness that envisioned and drove them.

Some have argued that society is in the midst of another axial age right now. Yet this axial age may be largely a function of the Pandora's box opened with modernity in general, and with the uses and types of energy in particular and its unique brands of science and technology [32]. The scientific method, while leading to great advances, also led away from the natural ecology of which we are part [14].

With modernity of course comes the rise of science and its stepchild technology [33,1]. Scientism, or faith in science’s methods and its practitioners, in fact is one of the central ideas that emerges as societies modernize. This is not to say that people do not practice religion in modern and post-modern societies. There is, of course, much more one could say about that later but suffice it to say here that even religious people as well as atheists, tend to take their child with strep throat to a physician for antibiotics.

Contrast the modern age crisis with the bubonic plague. During that plague, which is estimated to have killed about a third of the European population and a quarter of Asia, history does not record even a single instance of someone suggesting that more research be done, that science or technology would in fact have anything to do with addressing the plague.

Indeed the decennial passion play in Oberammergau Germany dates back to the time of one of the subsequent plagues, when the townspeople pledged to God that, if they were spared, they would produce the Passion Play every ten years in perpetuity. God, or at least the plague, did spare them--and they have been true to their word.

Contrast the people of Medieval Oberammergau with those of more modern ilk. One way to think about the difference is in terms of what some historians characterize as the transition from *mythos* based thought to *logos* based thought, or pre-Newtonian to post-Newtonian thought. Before Newton and Copernicus and Galileo, there was more room for things like magic and miracles. To be sure, some people still think in terms of magic, but we would venture to say magical thinking is not a central organizing principle of modern thought. Scientism serves as such an organizing principle in modern times.

This does not imply that people with faith in science have necessarily studied science. They might have taken, for example, high school biology or chemistry or physics and perhaps some astronomy and botany or zoology in college. A curious modern phenomenon is the advent of people who have little or no faith in a God, and yet who still make a breathtaking leap of faith that the enterprise of science and technology redounds to the common good.

And yet, many if not most people remain alienated from science on some level. Complex societies rely on the expert, and as science becomes more rarefied, the truer this becomes.

Many individual scientists rely on the largess of foundations, governments and other large entities with concentrations of capital. This is particularly true for fields in which the tools themselves are prohibitively expensive. Consider, for example, that particle accelerators in high energy research can cost in the billions of dollars.

The science and technologies that are supported are those seen as useful on some level, which increasingly is conflated with commercial application and the potential to make large profits. Thus, it is able to attract capital, which in turn is able to skew the legal system in its favor and to cast doubt on alternative theories and world-views [34]. Considering the strong and long-standing connections between well-funded interests and the legal system [35], it perhaps is not surprising the situation has come to this.

There is no particular need to mystify this process. Put in prosaic terms, the tragedy of the commons [36] can occur with science as readily as it can anywhere else. Individual scientists and people in the agencies that fund and direct them may all see their own individual actions as justified and leading to the common good, yet the outcomes of this uncoordinated, de-contextualized activity, stands to have serious dysfunctions. With the power of science to focus, and the ability of technology to make deep and wide-ranging incursions, the ante goes up considerably with every breakthrough.

Technological discovery historically has given people an advantage in war. For example, the advantage of the longbow over a standard bow, certainly afforded the archer an ability to shoot farther than the opponent. But now, our weapons can reach across the globe and beyond. Intensive technologies have become so focused that even someone with fairly limited knowledge about the overall process can still wreak tremendous damage [4].

The scientific method was developed over time. While pockets of science have become much more precise and more advanced over the last several hundred years, the scientific method itself has changed hardly at all [37,38]. This is not to argue for the abolition of science. That would be ludicrous. It is a call for recognition and respect of what it can do.

11. EMERGENCE AND SCALE

The scientific method almost always necessarily isolates phenomena from their surroundings, and that in and of itself is not necessarily a problem. Yet particularly when one combines that practice with economies of scale that have become the standard in modern societies, the potential hazards and risks go to unprecedented levels.

Seen in this light, the *telos* of science is not knowledge, but technology, with engineering as the midwife. And the types of technology that are promulgated tend to be those that survive and thrive in the economic Darwinism of the market.

In any system, there are levels of emergence. Human beings can be thought of as physical, chemical, biological, psychological, social or cultural entities, for example. Each of these emergent levels, not necessarily reducible to others, tend to have a discipline to go with them (e.g. physics, chemistry, biology, sociology, anthropology, etc.), and the knowledge of each of those disciplines is largely lost on the others.

Intellectuals from a wide array of disciplines have observed and written on this principle of emergence—Simmel [39] from Sociology and Whitehead [40] from Philosophy, for example. One of Whitehead's principal concepts in *Process and Reality* is to show that, when there is a sufficient change in *degree* for a thing or process, it becomes a change in *kind*. Given such changes, the new "kind" can no longer be explained in terms of the kind that preceded it.

As anything gets bigger it tends to change not only in size but in structure and character. In human institutions there are tipping points where changes in quantity become changes in kind. There is a case to be made that we have indeed gone so far beyond tipping points in some areas that we are on the verge now of entirely new tipping points—ones in which, because of the economies of scale and globalization that have come to serve as the backdrop, the stakes are higher than ever before [1,5].

Many social problems are a function of overreaction to problems of the past. Meanwhile, technologies in the world have moved on to another set of issues. Overall, collective knowledge and the systems it spawns become more complex, but thinking and ways of seeing the world, even among the most deeply focused in a particular circumscribed set of experiments and studies, do not necessarily reflect this.

In pointing out some of the weaknesses in science as it tends to be practiced, we do not advocate for a Luddite position. Rather, we would like to see the enterprise of science move in the direction of fulfilling its original vision of increasing knowledge about the natural world. Yet when that knowledge is disembodied—disconnected or alienated from the natural world of which it is an integral part--the potential for mischief and harm become high.

By almost all accounts, science since the Industrial Revolution has been a success. And yet it is time for science, if not to give an account of itself, at least to *take* an account of itself, in view of the consequences of its massive *success*, particularly in the industrial and "post-industrial" eras.

It bears noting again here that with industrialization, if not since the time of Newton, there has been a rise of science as a way of organizing thought. This, we believe, is central to the modernity project itself, at least from one foundational perspective. Scientism is the elevation of the scientific orientation to privileged status. That is, when science holds that nothing can be known beyond what the scientific method allows, we have scientism. It becomes a system of self-drawn boundaries around what *can* be known. The rest is simply "unknown" and often "unknowable" by implication. In extreme cases scientism even claims that, in principle, everything worth knowing can be known through scientific processes.

12. SCIENCE, ENVIRONMENT, AND THE AMERICAN PRESIDENCY

To show the relevance of this analysis, an instance of interface between science and public life seems pertinent. The way politics, especially at the presidential level, has responded to the impact of science specifically bears noting. To be sure, an in-depth analysis is beyond the scope of this article, but a brief statement is in order.

Science was more or less on its own with respect to American political life, until WWII, when military armaments required the enlisting of scientific knowledge. Nowhere is this more dramatic than with the development and use of the Atomic Bomb. President Truman was charged with the deciding whether, when, and how it would be deployed. After its successful use at Hiroshima and Nagasaki, an entirely new era was born, one in which the use of science and its methods had an increasingly closer interrelation with government. This was particularly true of how science was to be put to use in the socio-political arena. Assessments and decisions required of American presidents were at the center of motivating this process.

Over the years between Truman and succeeding presidents to the present this process was worked on. An early example was the formation of the Atomic Energy Commission, and the interface between science and presidential decision-making only increased through numerous permutations. Beyond the matter of nuclear weapons and nuclear energy, this concern expanded to include Space Exploration and numerous other fields requiring the expertise of science. Finally, at present it is safe to say that the mutual engagement of presidential politics and science and its methods is now *necessary*.

Not long afterward, the Environmental Protection Agency (EPA) was established in the United States to deal with the rapidly worsening environmental issues there. It was envisioned to watch for and to help address these environmental problems, many of which were new and not yet fully understood, but which posed huge potential risks to natural ecosystems and the life dependent upon them. In fact, part of the legacy of Rachel Carson [10] was a series of events leading to the establishment of the Environmental Protection Agency. The fruit of bipartisan efforts by Democrats and Republicans, it was begun under the administration of the Republican President, Richard Nixon [41,34]. The original vision of the EPA was to be an apolitical sentry, and advocate for the well-being of the planet and the people on it. Yet in subsequent years, in some succeeding administrations, the EPA did indeed fall under the heavy hand of political networks.

The EPA was weakened considerably during the Reagan presidency, again in the George W. Bush administration, and most recently under the Trump administration. As with any system under the influence of concentrated special interests, all sorts of abuses of the original intent can take place, and it can be difficult to track, sometimes coming to light only much later. This is not to imply uniform good faith in the other administrations; but during each of those regimes, the EPA's function became hyper-politicized to the point of its very legitimacy being questioned, typically by politicians with network ties to polluting industries [29,34]. In each case, this has placed huge challenges on the natural environment. As a case in point, the most recent EPA Administrator, Scott Pruitt, by his own admission knows very little of the science that would explain anthropogenic global environmental change. Rather, Pruitt had spent the better part of his career suing the EPA and trying to dismantle many of the safeguards which earlier members of EPA had so painstakingly put in place over years in response to the best science of the day.

More broadly, it is particularly telling that in many of the debates at all levels of governance in the United States, from the national Presidential and Vice-Presidential, to the state congressional contests, environmental issues were scarcely mentioned. It is as if environmental issues have been ceded to the Democrats, many of whom ignore them or view them as less important than their higher priorities, even as many on the Republican side treat the environment and those who would advocate for it with outright contempt [6,7].

The point of this section is to demonstrate how what may on the surface be thought of as "science" can so profoundly fall under the sway of the political system. It involves the President and the executive branch, to be sure, and the illustrations just given begin to show how easily the judiciary can become entwined. Over the course of little more than a half century, science has gone from giving advice to (at least in theory) well-meaning public administrators, to running the risk of being co-opted by over-reaching politicians who themselves are caught up in a political process that does not have fair and unbiased scientific knowledge as a priority. As elected officials are so beholden to campaign "contributions" to get elected and re-elected, the possibilities of co-optation of the legislative branch are nearly endless as well [6,7,29,34].

This excursus into the political realm was simply meant to illustrate how easily science can be, and is, co-opted on a regular basis, particularly by the potent combination of money and politics.

13. THEORETICAL PROPOSITIONS

The propositions that follow emerge from the foregoing discussion. They summarize and focus on the most problemmatic aspects of the scientific enterprise:

1. A serious weakness of scientism lies in its particular brand of *reductionism*, or a misuse of parsimony. That is, science tends to artificially reduce explanation to what the state of measurement and research allows. It denies, or at least collapses, crucial levels of emergence and particularly any level that cannot be measured by current scientific means.
2. A perverse complement of over-reduction is *extrapolation* beyond the scope of what empirical evidence can support. This is standard procedure in much of science, particularly in the social sciences. In common parlance we call this "over-generalization." It might be helpful to reflect on how reductionism and extrapolation are related in scientific method.
3. The possibility of genuine *novelty* in the science-technology matrix is important to consider. When technology produces consequences of (a) sufficient *magnitude* and (b) sufficient *speed of change*, the whole enterprise undergoes a meta-change—that is, novelty. In brief, technology turns back upon itself by virtue of having created consequences that it can no longer control or eliminate. An exemplar for this may be the contemporary phenomenon of anthropogenic global environmental change, largely attributable to cumulative effects of energy-related decisions. This is particularly true of the continued emphasis on fossil fuels, despite overwhelming evidence of risk and harm.
4. Much of the faith in science stems from its *replicability*. The larger (more comprehensive) our explanations are and the more comprehensive the ecological system of which they are part, the less replicable they become. There is a point at which replicability becomes impossible. This is a particular concern with novel situations and aspects of the natural ecology and human societies that do not lend themselves to experimentation.
5. Much of science in the contemporary era has morphed into technology, particularly of the commercial variety. When technology reaches the apogee of no longer being able to comprehend the *consequences* of its productions, it has lost its primacy as a way of solving related

problems. As Garret Hardin [36] insists in "The Tragedy of the Commons," *there are problems for which there is no technological solution*. A corollary to this that many of those problems were caused in no small part by technological developments outrunning the culture's ability to integrate them fully [33].

6. There is a fundamental *disconnect* between the rigorous methods of science and the popular imagination. Particularly in late modernity, science has come to be largely taken-for-granted among the common folk but also is so profoundly mystifying to the public, that it creates an ever-widening socio-cultural cleavage [33]. This is a recipe for social disaster, particularly when considered alongside the largely unmanageable crises of global environmental change [1]. People are lulled into cultural disengagement, biding their time and attention with vapid entertainment, consumption, and celebrity [41].
7. A crucial cultural project would involve wresting science from its own incipient *scientism* long enough to *test its method* against what we need to know and what we can actually claim with any degree of assurance. Yet the scientistic mind has so galvanized its methodology that the very notion of "revising," let alone "transforming," it is unthinkable. One place to begin might be the reflective task of addressing questions of the consequences of being wrong. There is some effort at doing this, but it often is received as unnecessarily alarmist, especially among the "madding crowd" who stroll contentedly into the future. If this task of reforming scientific method is to be undertaken, who will do this? Further, how might such an enormous task begin?
8. As a number of theorists of science from Karl Popper [16] to William Irwin Thompson [42] and David Bohm [30] to Richard Harvey Brown [41] have pointed out, science has its own *myths*. To even suggest that science has become, under some expansive conditions *mythological,* tends to meet with the most strenuous of objections from many people involved in the day to day business of science.
9. A way of construing modernity itself is as *complexification* of society and its institutions, as well as the ways of thinking, storing and communicating knowledge. The current state calls for a new level of complexification in science as well. Put another way, it may be time to revise scientific method itself to account for that which is so often left out of account in scientific work.
10. In a related vein, it is crucial for scientific practice to take serious account of its *externalities*. This concept is most closely associated with economics and what it "leaves out" of its measures. But it does bear noting that scientific practice affects not only what it studies, but what it willfully ignores.
11. This is particularly problematic in energy research for two major reasons. There are significant externalities in energy usage in general, and in fossil fuels in particular. To wit, the types of energy with the most severe externalities typically are tied to vested interests with the power and resources, not only to skew civil discourse and the political process flowing from it, but to a large degree, to define what important scientific questions are in the first place.
12. There are, of course, important value questions as well. Science cannot by its very nature address, let along redress, values. As such, it misses crucial parts of the array of the human and planetary condition. Particularly as science becomes more formalized and rational (in the sense articulated by the sociologist, Max Weber [43,8], much of the value becomes collapsed into measurable outcomes such as funding dollars accrued, number of publications and numbers of times they are cited, etc.; or framed in terms of money-driven "technology transfer."
13. Science has accrued a significant *institutional inertia*. As such, it may inadvertently be moving to an accumulation of problems where quantitative change reaches a tipping point into a new qualitative realm. It is amazing how long our system has survived while doing this. By keeping projects sufficiently manageable, it is possible to defer indefinitely the larger implications of the vast array that comprise the overall scientific/technological enterprise.
14. This, again, calls for the reorientation of science around the massive reach of what is at stake, tempered by the concrete situation in which the earth and its people are inextricably linked. In a related vein,

this calls for a convergence of consciousness across level of thinking, perhaps with a more adequate sense of *communitas* and a spirit of cooperation stemming from it, with a genuine sharing of perspectives in the interest of actual resolution of dilemmas.

15. *Broader modes of* thought are exactly what have been lost in the sea of specializations and relative isolation of endless scientific "projects." This calls for nothing short of a "revolution" in thinking and especially in what counts as science now and in the future. Society is rapidly coming to the end of what isolated, monadic ways of doing science can achieve. Survival requires some alternative avenue—one more ecologically embedded.
16. Science is a social enterprise and, as such, can come under the sway of social institutions. At times it can and has acted independently, yet with the increasingly powerful juggernaut of money and politics in late modern society, there is an increasing vulnerability to co-optation. This calls for a re-commitment to working in good faith and vigilance.

14. CONCLUSIONS

Further, science is a human enterprise that profoundly affects both society and its environment. As with any such endeavor, it is more than legitimate to examine science for its adequacy, particularly in view of the reach of its burgeoning influence. When considering the far-reaching externalities, these problems are particularly acute in areas of energy research.

Because science has such profound impacts on society and ecology, it must examine its own methods in light of certain side effects and unintended consequences of its practice. This article does not opposes or reject science. On the contrary, throughout the text it is assumed that science retains its central place in modernity by continuing to make phenomenal contributions to society and humanity.

This shows that society currently struggles with where the most definitive source of guidance for modern life is to reside. History appears to be on the side of science and technology, but if this is the case, science, being a social enterprise, must participate in the quality of the social future of humankind. This calls for science to engage in a self-examination of its methods in view of their current and growing impact on social life and the environment.

This account begins with a critical view of two counter-productive trends. The most salient is the current trend toward reifying science into *scientism* and treating it as sacrosanct, thus suffering from over-reach into mythic proportions. At the same time, a counter-trend of anti-scientific bias from one quarter or another rears its head.

The body of the article takes up a wide-ranging series of issues related to science and its methodology as they bear on social life. The underlying motivation for discussing these is to challenge the presumption that scientific method, as it has been practiced since William of Occam and Francis Bacon, continues to be sufficient for today. Revisions in method are now necessary in light of the remarkable impact of science on the ecology of the planet and on human life and society.

The last part of the article offers a list of salient items in seeing the project of science's self-revision realized. These converge toward the urgency for scientific humility to play a decisive role moving forward, in order to contribute to the quality of the natural environment and of social life for the future.

Science itself is a social enterprise and, as such, bears questioning by the society of which it is part. With appreciation and respect for what discoveries science has made thus far, it is time to examine the inertia of the scientific method as it has come to be honed by practice over the last several centuries, and to judiciously make course-corrections as society moves forward in the 21st Century and beyond.

ACKNOWLEDGEMENTS

The paper benefitted greatly from the careful reading and detailed assessments of five anonymous reviewers and the Editor of the *Journal of Energy Research and Reviews*. In addition, the authors gratefully acknowledge Douglas Gaffin, Peyman Hekmatpour, and Stephen Weldon, who made helpful comments on an earlier draft.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://prh.sdiarticle3.com/review-history/25609