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Article

Review of Potential Characterization Techniques in Approaching Energy and Sustainability

David J. LePoire

Environmental Science Division, Argonne National Laboratory, 9700 S Cass Ave, Argonne, IL 60439, USA; E-Mail: dlepoire@anl.gov; Tel.: +1-630-252-5566; Fax: +1-630-252-4624

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Abstract: Societal prosperity is linked to sustainable energy and a healthy environment. However, tough global challenges include increased demand for fossil fuels, while approaching peak oil production and uncertainty in the environmental impacts of energy generation. Recently, energy use was identified as a major component of economic productivity, along with capital and labor. Other environmental resources and impacts may be nearing environmental thresholds, as indicated by nine planetary environmental boundaries, many of which are linked to energy production and use. Foresight techniques could be applied to guide future actions which include emphasis on (1) energy efficiency to bridge the transition to a renewable energy economy; (2) continued research, development, and assessment of new technologies; (3) improved understanding of environment impacts including natural capital use and degradation; (4) exploration of GDP alternative measures that include both economic production and environmental impacts; and (5) international cooperation and awareness of longer-term opportunities and their associated potential scenarios. Examples from the U.S. and the international community illustrate challenges and potential.

Keywords: energy efficiency; integrated economic indices; research and development; environmental impacts; foresight techniques

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1. Introduction: The Importance of Energy

Energy in the 20th century enabled rapid growth, accelerated technology development, and freedom from many menial tasks. However, the competition for energy contributed to global conflicts, environmental impacts, and large uncertainty in energy prices leading to instabilities. What will energy enable in this century? One perspective is that competition will increase, environmental impacts will be more hazardous, and markets might be more volatile. Hopefully, this scenario will not be realized. Yet, much work needs to be done to ensure the path to sustainable energy use. Ideas from others that might help guide along this path are collected in this paper and placed in a simple framework.

This simple framework is based on the sustainability characteristics of efficiency, robustness, and resilience which are similar to those of sustainable ecosystems [1]. This introduction briefly discusses these issues as integrated economic and environmental efficiency, maintaining an environment which is effective and resilient, and incorporating techniques into decisions to maintain a robust system that does not collapse as many smaller historical societies have done. The paper then proceeds with a discussion of the need of an energy bridge while information is gathered through research and development about the potential sustainable technologies and approaches. The remaining parts of the paper addresses potential tools for each of the sustainability characteristics: (1) technology development to deliver cost-effective energy with reduced environmental impact; (2) understanding and decision tools to support environmental assessments; and (3) exploration of new indices that include both economic and environmental aspects which would help guide the system to a more sustainable state.

Energy is important to sustain lifestyles, organization, and safety. Energy does not determine what we do; it does, however, determine what we can do. What happens when electricity is not available is seen when major power outages occur. In those situations, fundamental services such as food storage, store operations, safety systems, and transportation can quickly deteriorate. While inexpensive energy has been available for decades, significant trends in energy use, energy production, and energy infrastructure indicate major potential future challenges. These challenges include a larger global population leading more energy-intensive lifestyles, diminishing non-renewable fossil fuels, uncertainty regarding the environmental impacts of energy generation, and aging of energy infrastructures. Many countries and regions have prioritized goals to address these challenges by developing inexpensive, reliable, sustainable energy independence with minimal environmental impacts. However, challenges are made more difficult by the scope and interdependence of the issues.

The developed world's lifestyle has significantly changed through the application of new technology and fossil fuel energy sources over the past 150 years. This technology has led to rapid changes in the way we work, move, communicate, heal, and relax. For example, the change in work settings has led to a large increase in economic productivity through the application of relatively inexpensive energy, along with automation and computer networks. This rapid rise in economic productivity is being replicated throughout the world at the same time that the population is increasing. Higher population, along with a higher quality of living is increasing the pressure on limited natural resources [2,3]. For example, while the demand for energy has been increasing, the amount of fossil fuels seems limited, with about half of the energy already extracted. Its future scarcity will tend to drive prices higher. Fortunately, sufficient fossil fuels have been stored for millions of years and have enabled previous significant advances in science and technology, in addition to searches for new renewable energy sources.

Robert Ayres [4] recently defined sustainability economics as an extension of environmental economics along with the issues of maintaining development while reducing environmental impacts with an emphasis on the linked problems of energy, global climate change, and fossil fuels. He outlines progress towards sustainability through three phases of eco-efficiency. The first phase uses treatment of the pollutants, e.g., reducing emissions from automobiles. These emission reductions regulations reach a marginal benefit compared to other techniques such as increasing the efficiency of making products, e.g., more efficient car production with new and less materials. This phase reaches a limit when the efficiency of the service delivery becomes more productive, e.g., how best to provide the services that a car currently is needed.

Energy use and production also impact the environment. These impacts include particulates and hazardous materials from production and burning, resource and land usage, and water demands to convert heat to useful electricity. The importance of properly managing environmental impacts from energy usage is not new. Historically, progress is made by increasing energy usage with a respect for environmental issues [5]. These issues have included pressure on land resources, soil renewal, sanitary maintenance, deforestation, soot, and acid rain. In addition to the direct environmental impacts, the uneven fossil fuel distribution has led to conflicts and instabilities in both resource-rich and poor regions.

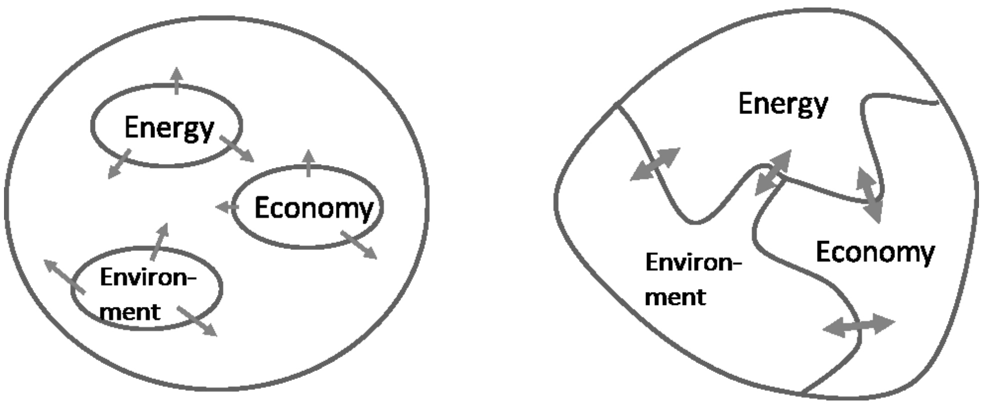
By definition, civilization must return to a sustainable energy economy that works within the environment. This eventual sustainable energy solution will have the advantage of the knowledge gained over the past 200 years to more effectively extract renewable energy from the sun or nuclear resources. Essentially, this transition from one energy sustainable civilization to another, with the intervening few hundreds of years of fossil fuels is a major experiment. Humans have never gone so far from an equilibrium situation. While life itself is far from equilibrium, the current case is doubly so—using energy at a rapid rate and getting that energy from an unsustainable source. Several historical societies have faced similar, although smaller-scale issues. The tie among economic production, energy, and the environment seems to have contributed to breakdowns in many civilizations before, including the Easter Island society, Mesopotamia, the Maya, and the Roman Empire.

In these cases, the energy sources were animal- and human-based and were dependent on the agricultural productivity in increasingly urban conditions. When these civilizations failed, there were others to take their place, find alternative solutions, and move on. In our current situation, we have moved to a more leveraged position with the use of non-renewable fuels, pushed the limits of the global environment, and become dependent on a high-technology lifestyle. Researchers such as Joseph Tainter, Homer-Dixon, and Diamond describe civilizations that might have collapsed with a large influencing factor being the neglect of overall resource use and negative marginal use of resources leading to environmental degradation [5–10].

The path to energy sustainability requires improvements in many areas such as (1) identifying renewable energy sources that technology is able to economically convert to useful energy without much environmental impact; and (2) reducing the amount of energy needed through improved efficiency in both conversion, e.g., to electricity, and use. Many ideas have been proposed but much work remains to research and develop the technology for a wide-scale deployment. Complicating issues arise through (1) increased energy demand due to simultaneous population growth and global development; (2) the long lead times and capital investments necessary for research, development, deployment; and (3) the coupled nonlinear nature of energy, the economy, and the environment as depicted in Figure 1. This figures shows on the left a conceptual early growth system where energy, environmental, and economic issues can be treated somewhat independently. As they grow to approach natural limits, the components can no longer be treated independently, and a change in one can cause large effects in others. It seems like the current situation is approaching a situation similar to the one on the right with limits of fossil fuels, the potential environmental impacts, and economic effects of growth.These issues of energy, environment, and economics (social system) were highlighted in two of the seven core research questions identified for sustainability science [11]:

- "How can today's operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition towards sustainability";
- "How can today's relatively independent activities of research planning, monitoring, assessment, and decision support be better integrated into systems for adaptive management and soicietal learning".

Figure 1. The -diagram shows a conceptual early growth system (**left**) and a later nonlinear system (**right**) after growth approaches limits.



Since much research, development, and deployment must be done over a long period, an energy bridge is necessary as the sustainable technologies are tested and either accepted, rejected, or modified. Fortunately, there are still major gains to be realized in efficient use and generation of energy [12,13]. While not energy sustainable, the substitution of natural gas for coal generation of electricity has led to reduced amounts of carbon dioxide being emitted, which is a step in the right direction for environmental sustainability. Based on life-cycle analysis of production, distribution, and conversion, a 45% reduction in carbon dioxide emmission from natural gas use compared to coal [14]. However, since methane is a more potent climate change gas, care is needed to ensure minimal leakage from these activities.

During the bridge period, decisions at all levels will need to be made concerning the viability and sustainability of the system of technologies. The recent debate over the efficacy of using corn-based ethanol as a substitute for gasoline demonstrates the complexity of the issues. This paper identifies several tools that might facilitate measurement, analysis, and understanding in the three areas of energy, environment, and economy [15].

2. Energy Bridge

Currently, there is no consensus solution. Energy experts recommend a range of potential paths, including continuation of fossil fuels, nuclear, wind, improvement in energy efficiency, and the development of new technologies [13,16]. Economic viability is a major criterion for an energy solution. There is insufficient knowledge to determine the technology viability, environmental impacts, and economic implications of many new technologies over a long enough period at large-scale deployment. Since this knowledge, research, and experience take time to gather and implement, it seems that a bridge is needed to link current energy efficiency with newer fossil fuel extraction and use methods. The measurement of energy return on energy invested is one tool that is helpful in constructing this bridge. For example, corn-based ethanol production requires a large amount of energy input for the fertilizer, mechanical farming equipment, transportation, and processing. The energy extracted compared to the energy invested in this production is almost equal. Another example is the investment in equipment to increase efficiency. In hybrid cars, the battery is expensive and heavy with more complicated controls. At what point is the investment in this equipment energy cost effective? This bridge give us some time to solidify our understanding and processes, to apply foresight techniques, and develop long-term solutions [17]. The scope and timing means that this is not an isolated problem to be solved independently with engineering certainty but rather requires new views, new collaborations, and planning methods that come with significant uncertainty.

While fossil fuels will probably dominate as a source of energy for another generation, much has been done recently to increase their efficient use [13]. In fact, it seems like energy efficiency has been growing as a substitute for raw energy. This continues the pattern of substituting different fuel sources and technologies (wood, coal, oil, and natural gas) to generate energy from the mid-1800s. The efficiency trend started to gain traction in the 1970s when two oil price shocks hit the economy. Many businesses, governments, and people realized that funds could be better invested in saving energy rather than continual normal use. The energy used now is almost half what it would have been without those efforts [18]. Significant progress could be made in capturing waste heat and combined electricity and heat generation as many countries such as Japan have demonstrated [19].

However, efficiency will only go so far. Eventually, the energy must come from other sources that include solar, wind, hydro, and nuclear. Uncertainties still exist with regard to each energy source's viability in terms of economics, capacity, and integration into the power system. Often a change in one system component is dependent on the upgrade of another. For example, the renewable energy sources that are dependent on weather conditions would be more productive if reliable transmission, storage, and distribution were improved. These systems, however, require much infrastructure development and present transmission or technological obstacles, such as the large storage systems required to implement a viable system.

3. Potential Foresight and Analysis Techniques

This tightly coupled system of energy, environment, and economic issues involves a wide range of interested groups over a long period of time under significant uncertainty [20–22]. Issues with this set of conditions, sometimes referred to as "wicked problems", often require trial solutions that are monitored and then modified since no detailed solution can be predetermined. The feedback and iteration improves the solution as uncertainty is reduced. This type of approach requires many foresight techniques such as multiple scenario development, identifying and measuring progress indices, updating flexible road maps, and the inclusion of multiple perspectives and objectives [23]. While foresight techniques have often been applied in defense strategies, the importance of these complicated issues in energy, environment, and the economy suggest that these techniques could be beneficial. Many countries and regions are applying foresight techniques to decision making [24,25]. Recent projects involving foresight techniques in the United States include the National Intelligence Council's Global Roadmap [26] and a framework to incorporate such techniques at many governance levels [27]. The following sections look at each component (energy, environment, and economy) to identify scenarios, measurements, flexible roadmap tools, and new organization and collaborations [28–30].

3.1. Energy Technology

Energy transition decisions require consideration of many foresight techniques such as (1) scenario construction; (2) redefining the roles of governments, private industry, and collaborations; (3) approaching the problem as an integrated system; (4) continuing assessment with scanning for surprises; (5) development of tools to incorporate uncertainty; and (6) investigating new ways to measure resource use.

Scenarios include those from government, industry, and think tanks, which often include assumptions that range from business as usual, rapid transformation with efficiency gains and renewable sources, and muddling through with a slower development and transition [13]. A major question is the level of government investment in basic research and development. While investments have been made in basic science and technology research, such as the national laboratories and universities, connections with industry have been growing, such as the Energy Innovation Hubs, in the areas of building energy efficiency, solar fuels, energy storage, nuclear design, and critical materials [31]. Direct investment by the government in start-up companies has had some difficulties as the market for electrical transportation and renewable energy generation did not grow as expected after the 2008 recession. Historically, the defense market has provided a bridge from early development to public commercialization. In fact, the defense sector has recognized the larger cost of energy in deployments and in many respects is leading the way in utilizing new energy technology [32].

Revamping the energy systems is a daunting task. Many of the components are interconnected, such as the ability to generate, convert, transport, and use energy. Each requires quite a large investment in infrastructure such as smart grids, renewables that are capital intensive, transportation networks, and integration. These developments require coordination to match the energy characteristics to the reliability and varying demand. Many projects investigate how to transition from the current system to an alternative one; however, most agree the transition will take decades to accomplish [33]. For example, renewables cannot supply much more than 20% before large improvements are made in transmission and storage capabilities.

In addition to systems transitions and integration, the basic components of energy are being developed and assessed. While the U.S. traditionally has not focused on long-term energy policy, some lessons are being learned from abroad and incorporated into its approach of energy technology research. For example, the U.S. Department of Energy (DOE) issued its first quadrennial review of energy technologies in 2012 [31]. Many developed and developing countries contribute to energy related research [34]. There could be many surprises along the way, such as fracking technology, with the potential to expand natural gas and oil development but with uncertain environmental impacts.

Other areas of potential surprise include the application of laser drilling, insight into the nature of deep natural gas, techniques to develop methane hydrates, and the potential for broader, safer development of nuclear energy.

A recent Nature paper [35] written by the (then) U.S. Secretary of Energy Steven Chu and the head of the U.S. DOE Advanced Research Projects Agency-Energy (ARPA-E), Arun Majundar, explored opportunities and challenges for a sustainable energy future. They argue for the need for another Industrial revolution to replace the fossil fuel dependency along with energy conservation and efficiency. A path to this goal is the development of cost-effective replacements for fossil fuels accomplished through research and development of new technologies along with the cost reductions through learning during deployment. Great success has been accomplish through the U.S. DOE Sunshot initiative to reduce the cost of solar power to $1 per installed watt for utility capacity of which 40% cover permits and installation. Another possible area for efficiency is in the design of lighter cars and trucks using new materials and improved computer-assisted designs of internal combustion engines. The development of alternative liquid transportation fuels include approaches such as genetic engineering and artificial photosynthesis supported in the Electrofuels program of E-ARPA and the DOE hub, Joint Center for Artificial Photosynthesis, led at CalTech. Analysis by Bloomberg New Energy Finance of recently completed energy projects showed that onshore wind energy and nuclear were competitive when comparing the unsubsidized levelized cost. While Asia is expanding its nuclear power capacity, setbacks have occurred in the developed countries, specifically Japan and Germany. A possible way to reduce the financial risks of licensing and construction delays is the development of factory manufactured small nuclear reactors. Another promising technology for energy efficiency is using Brayton supercritical CO_2 cycle. to convert heat from power plants into electricity. The efficiency of conversion might approach a 50% conversion efficiency compared to the current average conversion efficiency of generators of about 33%.

One tool to help understand both the trends and their uncertainty is real options analysis [36]. This analysis is similar to the net present value tool but also has the ability to consider possible futures under uncertainty. A number of authors have applied this technique to a range of energy research and development cases, including those for solar power satellites, thorium-based nuclear power, and federal renewable energy research. The key for these tools is to have a good estimate for the scenarios, then track the progress of the research and cost reduction through experience.

Another tool is to refine the measurement of energy. Exergy is an energy measurement that includes the quality of the input and used energy of a process. Energy in the form of slightly heated water is low quality, whereas higher-temperature steam is high quality, and electricity is highest. These tools can be applied to industrial processes to determine the energy use of an industrial ecosystem [37]. Basing economics on such energy and thermodynamics concepts was begun in the 1970s by Georgescu-Roegen and continued by others, including Herman Daly [38]. Recent economic analysis has identified this useful energy measure as a major impact in determining economic productivity [39,40]. Recent analysis which integrates energy and sustainable economics suggests the fundamental importance of energy as a factor in the economy and may explain the "technological factor" seen in 20th century economic growth. However, there are major challenges to implementing a useful sustainable measure to guide decisions. Ayers sees a sequence of phases towards eco-efficiency. First is the efficiency of treatment of pollutants addressed by mitigating the effects of emissions, addressed by many developed countires national environmental laws in the early 1970s. Next is the efficiency of production which reduces the amount of materials and energy required for the same production. Such efficiency was started to be realized after the 1970 oil prices shocks. Finally there is the issue of what really has to be produced to deliver an outcome, *i.e.*, efficiency of service delivery. Some electrical generating plants and states such as California have begun to explore the possibilities in this phase.

3.2. Environmental Impacts

Environmental impacts include those that affect air quality, food, water, disease, and land use. A determinant in many of these is the climate, including temperature and precipitation; however, climate is also affected by the rate of soil loss and the application and subsequent pollution of fertilizers and chemical pesticides [41]. There is a concern that widespread economic growth has led to unsustainable resource consumption and use, including fisheries, lumber, energy, soil, and freshwater. An attempt to outline basic environmental measures was made in 2009, with the nine planetary environmental boundaries which include natural resource use (land and water), atmospheric disturbances (ozone, climate change, and aerosols), and releases impacting biological activity and diversity (ocean acidity, chemical pollution, phosphorus, and nitrogen release). Estimates were made for each boundary's natural level, the current level, and the level at which impacts might rapidly rise. Some of these already have impacts much greater than their boundary action level, while a few others have greater uncertainty with undefined boundaries [42].

Environmental scenarios include greater climate change leading to flooding, droughts, and crop changes; biodiversity collapse leading to reduced ecosystem services such as water filtering and pollination; and widespread disease due to rapid contact and migration of species into new climate areas. In addition to these basic resources, pressure has been mounting concerning mineral resources, such as rare earth elements. These are currently frequently used in green energy technologies such as solar cells, energy-efficient electronics, magnets for motors, and advanced batteries [43–45].

The combinations of advances in non-fossil fuel sources along with potentially slower growth in China might lead to a greener Chinese energy solution [46]. Some estimate that the recent rapid construction of coal power plants in China might end as demand increase slows due to the slower economy, movement to an a more consumer economy, and reduction in need for large energy intensive infrastructure projects. If this scenario were realized, it might lead to pressure other countries to more quickly adopt cleaner energy. The Chinese are facing issues related to emissions from coal including carbon dioxide particulates, and other pollutants such as mercury. The recently completed Minamata International Treaty on mercury emission highlights the environmental impacts of its emission of which coal power plants are a major contributor. While many developed countries implemented many air and water environmental regulations in the early 1970s, mercury release from some coal plants still emit relatively large amounts.

There has been much discussion about the feasibility and impact of a cost placed on carbon dioxide emissions. Such a cost could act as an insurance against potential environmental damage [47]. The costs would impact the relative costs of carbon emitting fuels with those that do not. While it has been difficult to obtain international or national agreement on a way to implement a carbon cost, some countries and more local states and organizations have developed carbon trading markets. One issue with a non-global agreement is the relative cost advantage in trade. The impact of a carbon price would not only shift the relative prices of energy sources but would also encourage the development of alternative and improved technologies. A similar situation was seen in the 1970s when many countries had higher prices on gasoline fuel for cars because of regional availability and higher taxes. This encouraged the development of more efficient cars in those countries. When the oil prices increased in the U.S. during this period, the more efficient imported cars found a relative advantage compared to less energy efficient domestically produced cars, leading to a large shift in the market share among the global automobile makers. This demonstrates that higher prices, even at a regional level, can encourage technology development that can be advantageously applied in global markets as the costs decrease though innovation, learning, and scaling production.

The U.S. EPA recently proposed new regulations to allow 1100 pounds of carbon dioxide per megawatt-hour which would be similar to a new natural gas driven power plant [48]. The current additional cost for carbon capture and storage (CSS) on new coal plants is estimated to be $0.04 per kilowatt-hour, a substantial increase. Very few coal power plants with CSS have been constructed. One new facility in Kemper County Mississippi has demonstrated a process of converting coal into gas, capturing 60% of the carbon dioxide, and then using it for enhanced oil recovery[49]. It is expected that costs could come down through learning and developing larger scales, so the U.S. DOE has funded eight CCS projects along with funds for loan guarantees, and promoting its programs in ARPA-E to improve novel CCS technologies.

Various government activities are investigating possible approaches to environmental impacts. The preamble of the U.S. National Environmental Policy Act (NEPA) of 1969 already highlights many aspects of sustainability and environmental security: "To declare national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation..." NEPA has led to the generation of environmental impact statements (EISs) for government projects and the formation of the President's Council on Environmental Quality (CEQ). Recent EISs have been prepared for the licensing (or relicensing) of nuclear power plants; the siting of wind and solar plants on government lands, such as federal land in the western United States; and the leasing of Outer Continental Shelf areas for energy development purposes such as offshore oil platforms. Some view the NEPA preamble as suggesting a mechanism to broaden consideration of other government activities [50]. Government agencies have been involved with identifying, refining, and testing new indices that realize environmental impacts on air, water, ecosystems, and land use [25,51].

3.3. Realigning the Economic Compass

The conventional gross domestic product (GDP) measure of economic progress has been used to guide businesses, governments, and investors for more than 75 years. However, a measure like this is sometimes similar to using a magnetic compass, usually pretty good but difficult if trying to reach limits like the poles. At some point, the compass will lead the voyage in circles, never getting to the poles. Similarly, the GDP has been useful, but its limitations are now apparent. Perhaps we need a refined compass to ensure future progress.

While the GDP measures market economic activity, there are problems in its ability to account for wider activities such as social well-being, and, in a larger sense, environmental sustainability. In 1968, Robert Kennedy stated: "It (our gross national product) measures everything, in short, except that which makes life worthwhile."

It would be nice to evaluate progress toward effectiveness of actions, policy robustness, and potential actions to help decision makers. Such a system would allow greater guidance to preferred future scenarios. An ideal system is a dream; currently, decisions are guided by imperfect systems of information and indices. These current tools have many limitations, thus alternatives are being identified, explored, and tested in many different settings. However, new indices for guiding decisions are difficult to define, measure, and deploy. Such a system requires numerous measurements, interpretation, models, and validation [24,52,53].

Many countries developed national strategies for sustainability after the first Earth Summit in 1992. The United States formed a President's Council on Sustainable Development that developed recommendations in the 1990s. In 1998, an interagency group developed a set of potential alternative (or experimental) indices [51]. In 2008, the French sponsored the Commission on the Measurement of Performance and Social Progress to review alternative economic measures and implementations led by Joseph Stiglitz [24]. In 2010, the British released a report of alternative sustainable indicators. In 2011, the U.S. Government Accountability Office compared various regions' approaches to defining and using alternative indices. Many nongovernmental organizations (NGOs) have formed to advocate for various indicators and uses, including EthicalMarkets, wikiprogress, and Citizens Network for Sustainable Development.

A recent paper [54] continued investigating the Genuine Progress Indicator by extending it to 17 countries representing over half the global population and GDP. The world's GPI/capita trend from the 1950s the present was then estimated. The GPI, similar to the Index of sustainable Economic Welfare (ISEW) proposed by Daly and Cobb in the late 1980s, includes consideration of GDP, volunteering and housework while excluding environmental costs, and costs of crime and income inequality. They found most developed countries had parallel increases of GPI/capita and GDP/capita from the 1950s to the mid 1970s. After that the GDP/capita continued to climb by about 80% up to 2010, while the GPI/capita remained relatively constant or slightly decreasing. Exceptions to this were Japan where the parallel growth continued to about 1990, followed by stalls in both GDP/capita and GPI/capita. China's parallel growth continued to about the mid 1990s, followed by rapid GDP growth and GPI/capita relative constancy. The estimate global GPI/capita rose by a factor of 2 since 1950 to about $4000 (2005 $USD) maintaining a value about 2/3's that of the GDP until 1975. Since then the GDP/capita has risen by almost another factor of 2 while the GPI/capita has remained almost constant with a slight decrease of about 10%.

4. Next Steps

Richard Smalley, from Rice University and the 1996 Nobel Prize winner in chemistry for his discovery of fullerenes in the mid-1980s, offered a possible way to tie these transitions together to hopefully take advantage of their benefits while managing or at least reducing the possible risks. He suggested that the U.S. should lead an international effort to explore the possibilities of using nanotechnology in the energy sector. He argues that energy is the key to many international problems, such as water, food, environment, poverty, terrorism and war, disease, education, democracy, and population [55].

Various countries are participating in science and technology research for energy and environmental areas [34]. Large projects include the International Thermonuclear Experimental Reactor (ITER), which is exploring magnetically confined fusion energy. Other examples include the sharing of approaches to energy efficiency between China and the United States by Lawrence Berkeley National Laboratory. Collaboration among countries and among various types of organizations, for example, universities, national laboratories, and industry, to search for new solutions ensures that basic research is shared, but it does raise issues regarding maintaining the incentive for funding research, especially at more applied levels. In the case of advanced battery research, the difference between basic and applied research is diminishing. Organizational and collaborative structures are being explored to enhance discovery and motivate greater participation. Each organization has a different prospective and potential benefits with royalties for discovering, profits for producing, jobs for manufacturing location, and energy and environmental benefits from its use [56].

While there has been great progress in understanding and coordinating information, energy, environmental, and economic issues require continual exploration and refinement as they involve new domains in both the time and spatial scales. The interaction among energy, the environment, and the economy can also be likened to the difficult task of squeezing a balloon. Any irregularities in the compression will result in parts of the balloon popping out, just as the way to the integrated solution of this problem will cause difficulties at different points in development. Continual refinement and flexibility in addressing the issues are required.

The knowledge, measures, tools, organizations, trials, and feedback discussed above are just part of the work being done to tackle, frame, and resolve these issues. It is a very interesting and exciting experiment. The process will take a long time, similar to other major transitions in history.

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Conflicts of Interest

The author declares no conflict of interest.

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