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Article

Contours of a Resilient Global Future

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Abstract: Humanity confronts a daunting double challenge in the 21st century: meeting widely-held aspirations for equitable human development while preserving the bio-physical integrity of Earth systems. Extant scientific attempts to quantify futures that address these sustainability challenges are often not comprehensive across environmental and social drivers of global change, or rely on quantification methods that largely exclude deep social, cultural, economic, and technological shifts, leading to a constrained set of possibilities. In search of a broader set of trajectories, we combine three previously separate streams of inquiry: scenario analysis, planetary boundaries, and targets for human development. Our analysis indicates there are plausible, diverse scenarios that remain within Earth's safe bio-physical operating space and achieve a variety of development targets. However, dramatic social and technological changes are required to avert the social-ecological risks of a conventional development trajectory. One identified narrative, which is predominant in the scenario literature, envisions marginal changes to the social and cultural drivers underlying conventional growth trajectories. As a result, it requires unprecedented levels of international cooperation, alignment of powerful conflicting interests, and political willpower to bend technological change in a sustainable direction. We posit that a more viable and robust scenario might lie in the coupling of transformative social-cultural and technological changes, which set the necessary conditions for a transition to a resilient global future. While clearly a first step, our analysis points to the need for more in-depth exploration of the mechanisms and determinant forces for such unconventional futures.

Keywords: *Great Transition*; planetary boundaries; sustainability science; transformative scenarios

1. Introduction

Perhaps the key theme in the story of the 21st century will be how humanity addresses multiple threats to the stability of the planetary social-ecological system. Over the past 10,000 years of the Holocene Era, Earth's self-regulating mechanisms have kept climatic and biogeochemical processes within a narrow range, providing relatively stable conditions—a safe operating space—for civilization to develop and thrive [1,2]. The increase of population and economic activity since the Industrial Revolution has ushered the coupled human-environment system into the Anthropocene, a new geological era where humanity plays a dominant role in driving planetary change [3,4]. Further intensification of anthropogenic stress could impel the Earth system out of its safe operating space with dire consequences for society and ecosystems, potentially undermining opportunities for humanity to thrive on Earth in the future [5,6].

At the same time, large disparities in human well-being, both among and within regions persist. In 2005, for example, 99% of Earth's 893 million chronically hungry people and 87% of its 1.7 billion people in water stress lived in developing countries [7]. Moreover, inequitable distributions of wealth within countries have contributed to social instability and public health concerns [8,9], and multiple forms of social deprivations [10]. Yet addressing destitution and inequality within a business-as-usual mode of development would likely exacerbate environmental degradation, with further negative impacts to vulnerable populations. Meanwhile, a rising world population will intensify already severe social-ecological stresses.

Thus, the vital challenge of the 21st century is for society to realize a future course that significantly reduces inequities and delivers widely-shared well-being, while remaining within Earth's safe operating space [11]. In this paper, we summarize an approach for illuminating the broad contours of such a course by combining three streams of inquiry—integrated global scenarios, planetary boundaries, and social goals – and provide quantitative illustrations.

2. Methodology

Statistically meaningful forecasts of the long-term future are precluded by the uncertainty and indeterminism underlying all complex systems, which are particularly acute in social-ecological systems where social development mechanisms and human choice are at play. Recognizing the limits of prediction, scenario analysis has become a key element in the methodological toolkit of sustainably science [12], extensively employed in global change studies to illuminate contrasting possibilities [13–17]. Through qualitative exposition and quantitative simulation, well-constructed scenarios help clarify tomorrow's perils and opportunities, and thus contribute to greater understanding and wise action today [18].

The question of global social-ecological futures requires comprehensive scenarios, e.g., [14,15,19] instead of a focus on one or two environmental or social issues, e.g., [16,17,20]. In addition, illuminating a wide range of interesting global futures, which may involve deep structural shifts, requires flexible quantification methods. Scenarios are created as either a forecast, where current trends are assumed to continue into the future, or as a backcast, where pathways are delineated from the present to meet a pre-determined vision of the future. Both types are abundant in the global change literature [13,16]. Backcasting is especially useful because it allows for a tractable methodology to generate scenarios that dramatically diverge from baseline trends. However, most backcasted scenarios use visions of the future that are limited to aggregate descriptions of technological outcomes, such as greenhouse gas emissions, rather than rich narratives that explore the coupled nature of social-technical-ecological systems [21,22]. Furthermore, standard models that are built on equations calibrated to current and historical patterns essentially build in conventional patterns of development for the long term.

Cognizant of this gap in the literature, we have developed a new framework for creating diverse and comprehensive global scenarios. The aim is to explore alternative development pathways, including the possibility of fundamental structural shifts in human values and institutions, which can achieve broad social-ecological goals in the future. These goals are defined for the present purposes by recent research on planetary boundaries, and the extrapolation of internationally agreed social targets, such as the Millennium Development Goals (MDGs).

The planetary boundary framework [5,6] defines a safe operating space for humanity with respect to the environmental processes that regulate the stability of Earth. This safe operating space emerged in the Holocene inter-glacial period, which constitutes the stable equilibrium of the planet over the past 10,000 years and the concurrent period when humanity has developed modern societies and expanded wealth and population. Nine planetary boundary processes have been identified (climate change, stratospheric ozone depletion, ocean acidification, land use change, freshwater use, rate of biodiversity loss, interference with global nitrogen and phosphorus cycles, aerosol loading and chemical pollution), and boundary level ranges have been proposed for seven of these (excluding aerosol loading and chemical pollution). As the boundary concept is explicitly precautionary, boundary levels are placed at the lower end of the scientific uncertainty range.

By combining global sustainability (defined by planetary boundaries) and social targets, we can explore the plausibility, desirability, and adequacy of conventional approaches to sustainability and the requirements for more fundamental adjustments to the currently dominant development paradigm.

As a point of departure, we draw on the widely used scenario storylines created by the Global Scenario Group (GSG) [23]. These scenarios are both integrated—weaving together major economic, social, cultural, institutional, technological, and environmental themes—and disaggregated, providing regional and sectoral detail. Moreover, they cover a broad range of contrasting futures based on archetypal visions—evolution, descent, and transformation—recurrent in the history of ideas and in the contemporary scenario literature [24].

These narrative storylines are the point of departure for painting quantitative pictures of each scenario's social, economic, and environmental implications. In previous work, one forecasted (*Conventional Development*) and two backcasted (*Policy Reform* and *Great Transition*) GSG scenarios were quantified by Raskin *et al.* [7] using the PoleStar model. PoleStar is an engineering-accounting integrated assessment model (IAM) that is disaggregated into 11 world regions and has detailed coverage of the household, transportation, service, industrial, agriculture, forestry, water, and energy sectors. Because of the emphasis here on the use of backcasting in formulating scenarios as well as the wish to include scenarios that represent structural discontinuity with conventional development patterns, PoleStar contrasts with most IAMs by being highly flexible in constraining simulations to conform to future visions and setting algorithms compatible with the scenario logic. In this manner we go beyond projection ("where are we going?") to the representation of normative outcomes ("where do we want to go?"; "how do we get there?"). Thus, PoleStar does not represent the economy in partial- or general-equilibrium, calculate minimum cost trajectories, or policy costs, since such methods tacitly assume the long-term persistence, or gradual unfolding, of current structural relationships—a premise abandoned here in order to include unconventional scenarios that undergo structural shifts. Instead, it specifies linkages among assumed exogenous driving forces, such as population and GDP, and scenario outcomes through analysis of historical data, meta-analysis of the scientific literature, and expert judgment. Most importantly, the quantifications aim for compatibility with the scenario storylines and assumed end-state vision. While our less structural approach might be critiqued as providing less guarantee of internal consistency, recent work on scenario consistency has shown that more structural modeling approaches share the same potential shortcomings [25].

In recent research sponsored by the United Nations High-level Panel on Global Sustainability [26], we have augmented these scenarios by linking them to planetary boundaries [5,6]. For the forecasted scenario, *Conventional Development*, the boundaries serve as a comprehensive metric for gauging the scenarios likely unsustainable trajectory. In contrast, our backcasted scenarios assume they are adopted as globally implemented targets. This results in backcast targets with social and environmental comprehensiveness that is novel to the literature. We refer the reader to the Supplementary Material for a synopsis of the assumptions used to quantify scenario driving forces from Raskin *et al.* [7] and the methodology used to approximate the linkages between the boundary metrics and their driving forces. For further detail on scenario driving force assumptions, please see the updated Technical Documentation [27] of Raskin *et al.* [7].

3. Results

3.1. Conventional Development

Current conditions set the point of departure for all scenarios. The world today has drifted into a problematic state that is eroding the resilience of the biosphere, as indicated by violation of boundaries for climate, the nitrogen cycle, and biodiversity (Figure 1). Concurrently, international inequity and hunger far exceed desirable levels and the number of people under water stress edges toward an undesirable state. Our *Conventional Development* scenario is a story of the future in which the trends that contributed to current conditions continue to evolve. The scenario assumes mid-range population growth, urbanization, economic growth, and technological change as developing country production and consumption patterns converge toward developed country patterns in a context of continuing globalization (Figures 2–4).

By 2100, population reaches 9.3 billion people (Figure 2a), and global GDP per capita increases to $50,000 per person. Despite significant economic gains in developed and developing regions (Figure 2d), average intra-regional inequity—as measured by the ratio of the income of the richest 10 percent of population to the income of the poorest 10 percent—increases by a factor of approximately three (Figure 2g).

The inertia of current economic institutions, power structures, and value systems dwarf concerns over the effects of global change. As a result, lack of coordinated action on pressing environmental issues such as climate change and agricultural impacts remains the norm, leading to global energy requirements 2.5 times current levels in year 2100, with about 85 percent of energy still produced using fossil fuels (Figure 4a), and food production becomes even more industrialized and resource intensive (Figure 4, Panels g and j).

Figure 1. *Conventional Development* and *Great Transition* scenario results. The bold-lined ring defines planetary boundaries and social targets, while the small innermost ring indicates pre-industrial values of planetary boundaries or "ideal" values of a social target (e.g., no hunger). Green shading indicates the variable lies within the biophysically safe or socially desirable zone; red shading that the planetary boundary is exceeded or the social target not met. The blurred edge on a wedge means that the value is too large to be displayed. The planetary boundaries are climate change (climate), ocean acidification (ocean), nitrogen cycle (N), phosphorus cycle (P), global freshwater use (hydro), change in land use (land), and rate of biodiversity loss (biodiversity). Social targets are the number of chronically hungry (hunger), international inequity (inequity), and water stress (water). The indicative hunger targets for 2025, 2050, and 2100 are 446, 223, and 56 million hungry people. The international inequity target, the ratio of developed country GDP per capita to developing country GDP per capita, is set to a value of 2. A tenacious problem in all scenarios, water stress is now at 1.7 billion people and the target is that this figure does not considerably worsen. We refer the reader to Table S1 in the Supplementary Information for planetary boundary and social target values for all three scenarios.

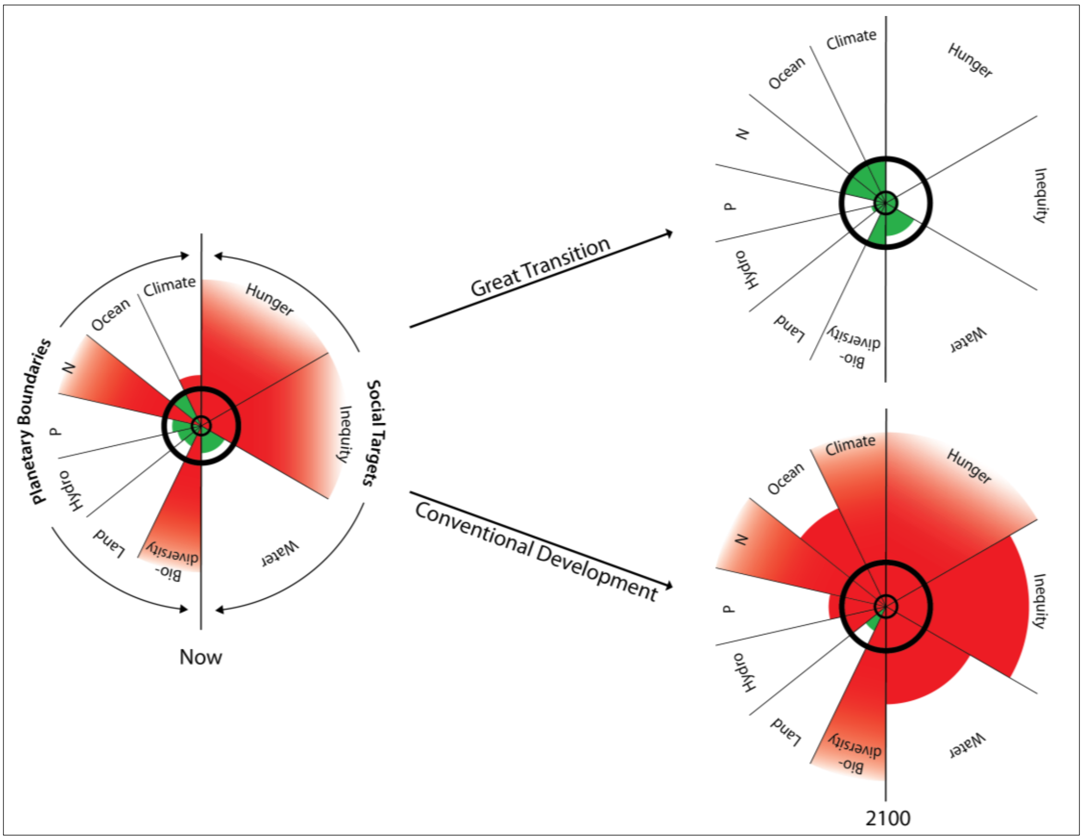


Figure 2. Driving forces grouped by scenario (columns) and variable (rows). Solid lines with black markers represent developed countries and dashed lines with open markers represent developing countries. Intra-regional inequity is measured by the ratio of income of the richest 10% to the poorest 10%, averaged across regions.

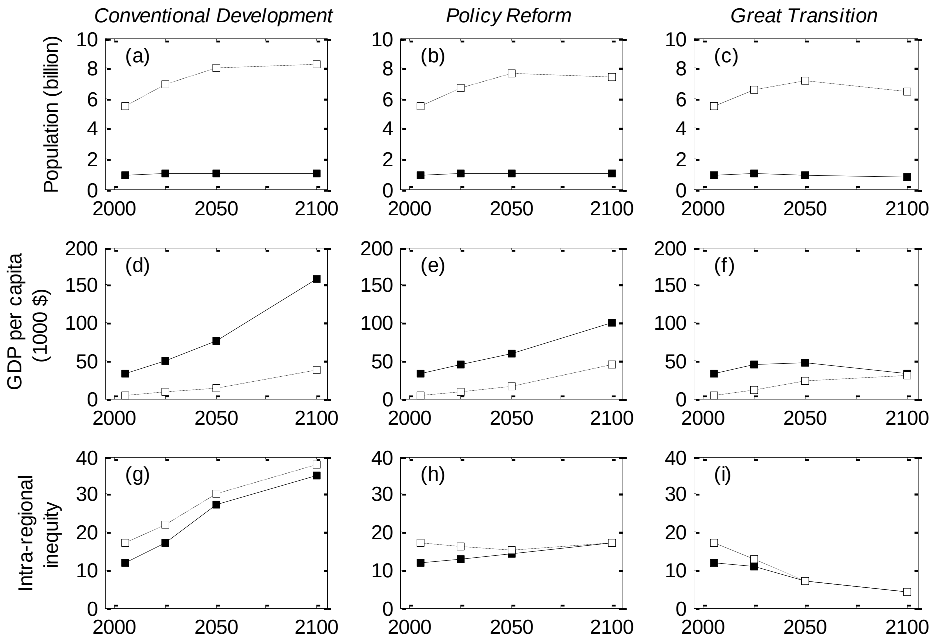


Figure 3. Scenario outcomes related to lifestyle and value choices, arranged by scenario (columns) and variable (rows). Solid lines with black markers represent developed countries and dashed lines with open markers represent developing countries.

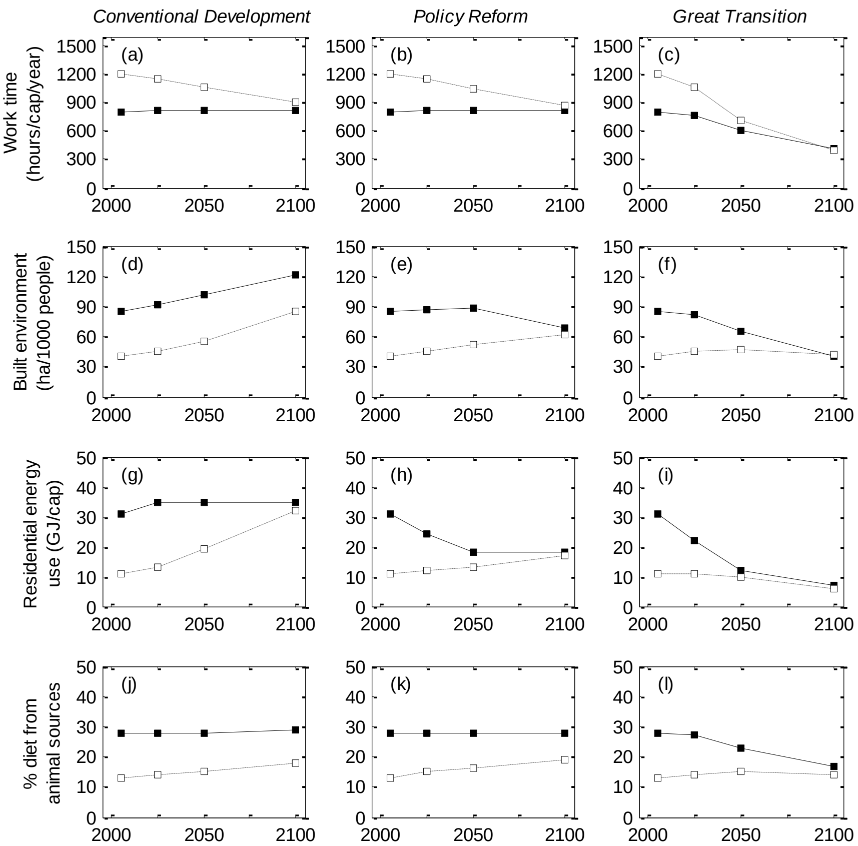
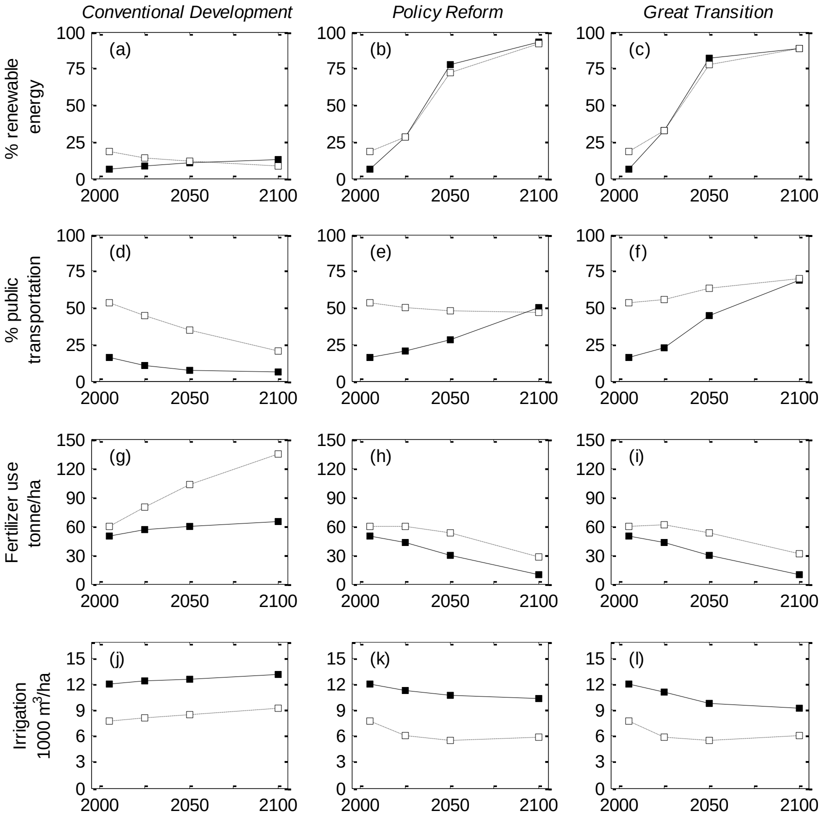


Figure 4. Scenario outcomes related to technology choices, arranged by scenario (columns) and variable (rows). Solid lines with black markers represent developed countries and dashed lines with open markers represent developing countries.



The trends embodied in the *Conventional Development Scenario* would lead to a massive increase in stress on important Earth system processes. By year 2025, five of seven planetary boundaries are transgressed, and at the end of the century, all but one boundary is transgressed (Figure 1). Interference with the nitrogen cycle and the rate of biodiversity loss, already excessive, continues its significant increase. Concomitantly, lack of targeted poverty reduction leads to persistent, if shrinking international inequity and hunger and increasing water stress. Despite the potential for catastrophic impacts and social unrest, society relies on unprecedented technological change and market adaptation to replace degraded ecosystem services and mend social tensions. Down this path, the real danger looms: as gathering crises overwhelm incremental responses, development veers toward darker futures, even a descent into societal breakdown, and civilized norms erode.

3.2. Turning towards Sustainability

The precarious *Conventional Development* scenario, though dominant today, is not necessary locked-in for the future. In moments of deepening crisis, like the present, the grip of conventional institutions and mindsets loosens, and relatively rapid shifts in the development trajectory become conceivable. Plausible alternative pathways to a more fair and resilient global society remain open. Here, we explore two possible forms for changing direction: a sustained process of incremental adjustments to achieve sustainability goals (*Policy Reform*) and a structural shift to a new development paradigm (*Great Transition*).

In a *Policy Reform* scenario, the basic institutional elements and value systems of the *Conventional Development* scenario endure. However, in the early decades of this century, destabilizing events linked to environmental disruption, market volatility, and social unrest create a sense of crisis and trepidation. Actors whose interests lie in continuation of the status quo realize that a strong policy response must be enacted to ensure the stability of the current development paradigm. As a result, an unprecedented level of political willpower and cooperation emerges among special interests and governments to craft and implement a comprehensive set of internationally-binding initiatives. Informed by planetary boundary metrics as the basis for widely adopted global sustainable development goals, together with widely-held social targets, strong policy instruments, such as eco-taxes, market mechanisms, regulation, social programs, and technology development and deployment are introduced, periodically monitored for effectiveness in meeting goals, and adjusted accordingly throughout the century.

Through such policy initiatives, more rapid economic development in poorer countries speeds up the demographic transition, resulting in somewhat lower world population of 8.5 billion (Figure 2b). Although global average GDP per capita is similar to that of *Conventional Development*, gains are distributed more equitably internationally (Figure 2e) and intra-regionally (Figure 2h). Regionally heterogeneous packages of policies geared to meeting social and environmental targets yield a rapid transition in energy-related technologies (Figure 4b,e), end-use efficiencies (Figure 3e), and land use practices (Figure 3e; Figure 4h,k).

In the *Great Transition* scenario, an alternative dynamic is explored. The early 21st century sense of crisis described in *Policy Reform* sparks the beginning of wide-spread re-assessment of lifestyle, values, and human well-being. Rather than ever-increasing consumption, the aim of economic development comes to be seen as a means for providing material sufficiency for all, the basis for a fulfilling life rooted in leisure time, family, and community. Bottom-up diffusion of changes in lifestyle and values, along with the organizational power of more globally-oriented citizens, grow into formidable pressure for change. As a global political community consolidates for the democratic management of the world's shared risks and opportunities, the process of restructuring economic and governance institutions gains momentum. The transition is underway toward a global society of strengthened international governance rooted in human fulfillment, social justice, and respect for nature.

The combination of lifestyle changes and effective policy implementation are assumed to lead to population stabilization in developed and developing regions (Figure 2c). Through 2050, strong and coherent policies lead to prolonged, high economic growth in developing regions—an increase of 3.5% per year in GDP per capita (Figure 2f)—and rapid, global diffusion of more resource efficient and renewable technologies on a scale similar to *Policy Reform* (Figure 4, right column). As a result, global income in *Great Transition* becomes far more equitably distributed: developing country per capita output reaches half of developed country levels by 2050, an achievement that requires 50 more years to accomplish in *Policy Reform*. Once a global basic standard of living has been achieved, all countries approach some form of "quality" driven development compatible with their cultures and predilections. Productivity and efficiency gains are redirected toward reducing work time and resource intensity (Figure 3, right column) and closing the remaining gap in international inequity. Thus, *Great Transition* describes a world that successfully stays in Earth's operating space, meets widely-held social targets, and provides a high quality of life to all.

4. Conclusions

4.1. Scenario Plausibility and Viability

Similar to most scenarios generated to meet ambitious climate change targets, *Policy Reform* engenders a largely technology-focused narrative imposed onto marginal changes in culture and values. As a result, its program of intervention must buck powerful contrary trends: a culture of consumerism, the identification of development with economic growth, and institutional forces underpinning inequality. Under these conditions, the success of *Policy Reform* rests with mounting a strong counterweight: unified political will to prioritize strong social and environmental goals. This requires sustained cooperation among powerful, conflicting interests, and effective formulation, adaptation, and enforcement of international and national policy reforms.

Likewise, the plausibility of a *Great Transition* rests on basic assumptions that may not come to fruition. Key is the widespread three-part value shift it envisions: (i) the re-definition of well-being as fulfillment rather than consumption, (ii) the strengthening of an egalitarian ethos that stimulates efforts to eradicate poverty and create more equal and cohesive societies, and (iii) the recognition of the fundamental importance of a stable Earth system for human resilience and well-being. Moreover, the scenario envisions a corresponding change in economic and political institutions that place primacy on meeting the needs and aspirations of an equitable and democratic world community, while restoring a resilient planet. The social agency for fostering such a systemic shift seems not yet on the world stage; indeed, it is difficult to imagine a *Great Transition* without the emergence of a vast cultural and political citizens movement for one [28,29]. Weighing the relative plausibility and viability of each of these pathways requires considering the potential coupling and feedback among economic, social, cultural, institutional, and technological dynamics. Economic development tends to be coupled with social, cultural, and institutional changes. Despite some degree of cultural path dependency, transitioning from agrarian to industrial societies is marked with a shift from traditional to secular-rational values. Further transition to a post-industrial society has been shown to engender movement towards more trust, tolerance, social equity, and well-being [30]. Similarly, technological change tends to be coupled with economic, social, cultural, and institutional changes [31,32]. As in the unfolding of the Industrial Revolution, large-scale technological and societal changes are likely to be co-evolutionary with neither technological nor societal structures remaining stagnant over time. Therefore, back-casted scenarios that only focus on large technological, but marginal social and cultural changes, such as *Policy Reform*, may be less plausible and ultimately less viable than scenarios, such as *Great Transition*, which posit a comprehensive set of conditions for a resilient future.

4.2. Usefulness of Comprehensive and Transformation Visions

Our scenario analysis of global change is based on back-casted visions of the future that are novel to the literature: a combination of planetary boundaries and development goals. In comparison to many contemporary scenarios, this allows us to investigate a broader span of transformative futures.

For example, the Millennium Ecosystem Assessment's *Adapting Mosaic* scenario shares many of deep value changes of the *Great Transition* scenario [14]. However, *Adapting Mosaic* envisions a world with much less global coordination and relative inattention to issues of inequity. Using a globally aggregated model, the fifth Global Environmental Outlook's Sustainable Worlds scenarios address a wide variety of social and environmental goals, but largely remain in a *Policy Reform* style vision of the future [19]. Finally, van Vuuren and Kok [15] have produced scenarios out to 2050 that are informed by a variety of human development and environmental goals. The development goals in these scenarios are limited to food, water, and energy security targets without explicitly addressing equity concerns, while many of the environmental goals, such as nutrient use, are not informed by hard targets.

Of course, the planetary boundaries concept is a recent scientific advancement, and thus is subject to ongoing inquiries, such as: proposed adjustments in boundary values [33], widening of boundary definitions [34], scientific debate regarding the evidence of regional to global scale tipping points, addressing cross-scale and boundary interactions, and applicability to policy [35–37]. Nevertheless it constitutes a useful framework, building on recent Earth system science and resilience research for constructing a comprehensive environmental end-state for scenario backcasting. Furthermore, the planetary boundaries framework should be viewed as a point of departure for future inquiry into global change science, as has already begun to occur [33,34,38–40].

Our analysis indicates that global development along a conventional pathway will not enable a world within Earth's safe operating space. Much like human society at the precipice of the Industrial Revolution, seeds of discontinuous change have been sown and their precise effect on the future is deeply unknowable. However, plausible narratives can be delineated in order illuminate the contours of a resilient global future. Will a *Policy Reform* narrative emerge? Or, would reliance on this strategic vision be the contemporary equivalent of prognosticating, at the onset of the Industrial Revolution, highly disruptive technological changes without the co-evolving societal landscape that both enabled and amplified the transition from an agrarian to an industrial society? Analogously, for the forthcoming planetary phase of human history, a *Great Transition* may be required: a shift in development paradigm and a restructuring of the economy underpinned by a fundamental change in values, a sharp demographic shift, strengthening of global governance, and massive technological change. To that end, we hope that our initial approximation of pathways to a resilient global future will contribute to continuing investigation of scenarios that are based on understanding of the totality of Earth system dynamics, broad goals for human development, and the coupling among economic, social, cultural, institutional, technological, and environmental drivers.

Supplementary Materials

Supplementary materials can be accessed at: http://www.mdpi.com/2071-1050/6/1/123/s1.

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. Dansgaard, W.; Johnsen, S.J.; Clausen, H.B.; Dahl-Jensen, D.; Gundestrup, N.S.; Hammer, C.U.; Hvidberg, C.S.; Steffensen, J.P.; Sveinjörnsdottir, A.E.; Jouzel, J.; *et al.* Evidence for general instability of past climate from a 250-kyr ice-core record. *Nature* **1993**, *364*, 218–220.
2. Petit, J.R.; Jouzel, J.; Raynaud, D.; Barkov, N.I.; Barnola, J.-M.; Basile, I.; Bender, M.; Chappellaz, J.; Davis, M.; Delaygue, G.; *et al*. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* **1999**, *399*, 429–436.
3. Crutzen, P.J. Geology of mankind. *Nature* **2002**, *415*, doi:10.1038/415023a.
4. Steffen, W.; Crutzen, P.J.; McNeill, J.R. The Anthropocene: Are humans now overwhelming the great forces of nature. *Ambio* **2007**, *36*, 614–621.
5. Rockström, J.; Steffen, W.; Noone, K.; Persson, A.; Chapin, F.S., III; Lambin, E.F.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; *et al.* A safe operating space for humanity. *Nature* **2009**, *461*, 472–475.
6. Rockstrom, J.; Steffen, W.; Noone, K.; Persson, A.; Chapin, F.S.I.; Lambin, E.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; *et al*. Planetary boundaries: Exploring the safe operating space for humanity. *Ecol. Soc*. **2009**, *14*, 1–33.
7. Raskin, P.D.; Electris, C.; Rosen, R.A. The century ahead: Searching for sustainability. *Sustainability* **2010**, *2*, 2626–2651.
8. Pickett, K.; Wilkinson, R. *The Spirit Level: Why Greater Equality Makes Societies Stronger*; Bloomsburg Press: New York, NY, USA, 2009.
9. Kawachi, I.; Kennedy, B.P.; Lochner, K.; Prothrow-Stith, D. Social capital, income inequality, and mortality. *Am. J. Public Health* **1997**, *87*, 1491–1498.
10. Sen, A. *Development as Freedom*; Oxford University Press: Oxford, UK, 1999.
11. Griggs, D.; Stafford-Smith, M.; Gaffney, O.; Rockström, J.; Öhman, M.C.; Shyamsundar, P.; Steffen, W.; Glaser, G.; Kanie, N.; Noble, I.; *et al*. Policy: Sustainable development goals for people and planet. *Nature* **2013**, *495*, 305–307.
12. Swart, R.J.; Raskin, P.; Robinson, J. The problem of the future: Sustainability science and scenario analysis. *Global Environ. Change* **2004**, *14*, 137–146.
13. Moss, R.H.; Edmonds, J.A.; Hibbard, K.A.; Manning, M.R.; Rose, S.K.; van Vuuren, D.P.; Carter, T.R.; Emori, S.; Kainuma, M.; Kram, T.; *et al*. The next generation of scenarios for climate change research and assessment. *Nature* **2010**, *463*, 747–756.
14. Millennium Ecosystem Assessment. *Ecosystems and Human Well-being: Findings of the Scenarios Working Group, Millennium Ecosystem Assessment*; Island Press: Washington, DC, USA, 2005.
15. Van Vuuren, D.P., Kok, M., Eds.; *Roads from Rio+20: Pathways to Achieve Global Sustainability Goals by 2050*; Netherlands Environmental Assessment Agency: Amsterdam, The Netherlands, 2012.
16. Nakicenovic, N.; Swart, R. *Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2000.
17. Arnell, N.W. Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global Environ. Change* **2004**, *14*, 31–52.

18. Schwartz, P. *The Art of the Long View: Planning for the Future in an Uncertain World*; Currency Doubleday: New York, NY, USA, 1991.
19. United Nations Environment Programme (UNEP). *Global Environmental Outlook (GEO-5)*; UNEP: Nairobi, Kenya, 2012.
20. Parry, M.L.; Rosenzweig, C.; Iglesias, A.; Livermore, M.; Fischer, G. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environ. Change* **2004**, *14*, 53–67.
21. Nilsson, M.; Nilsson, L.J.; Hildingsson, R.; Stripple, J.; Eikeland, P.O. The missing link: Bringing institutions and politics into energy future studies. *Futures* **2011**, *43*, 1117–1128.
22. Vergragt, P.J.; Quist, J. Backcasting for sustainability: Introduction to the special issue. *Technol. Forecast. Soc. Change* **2011**, *78*, 747–755.
23. Gallopin, G.; Raskin, P.D. *Global Sustainability: Bending the Curve*; Routledge: New York, NY, USA, 2002.
24. Hunt, D.V.L.; Lombardi, D.R.; Atkinson, S.; Barber, A.R.G.; Barnes, M.; Boyko, C.T.; Brown, J.; Bryson, J.; Butler, D.; Caputo, S.; *et al*. Scenario archetypes: Converging rather than diverging themes. *Sustainability* **2012**, *4*, 740–772.
25. Schweizer, V.J.; Elmar, K. Improving environmental change research with systematic techniques for qualitative scenarios. *Environ. Res. Lett*. **2012**, *7*, 044011.
26. United Nations Secretary-General's High-Level Panel on Global Sustainability. *Resilient People, Resilient Planet: A Future Worth Choosing*; United Nations Secretary-General's High-Level Panel on Global Sustainability: New York, NY, USA, 2012.
27. Electris, C.; Raskin, P.; Rosen, R.; Stutz, J. *The Century Ahead: Four Global Scenarios*; Technical Documentation 2011 Update; Tellus Institute: Boston, MA, USA, 2011.
28. Raskin, P.; Banuri, T.; Gallopin, G.; Gutman, P.; Hammond, A.; Kates, R.; Swart, R. *Great Transition: The Promise and Lure of Times Ahead*; Stockholm Environment Institute: Boston, MA, USA, 2002.
29. Raskin, P.D. World lines: A framework for exploring global pathways. *Ecol. Econ*. **2008**, *65*, 461–470.
30. Inglehart, R.; Baker, W.E. Modernization, cultural change, and the persistence of traditional values. *Am. Sociol. Rev*. **2000**, *65*, 19–51.
31. Smith, A.; Stirling, A.; Berkhout, F. The governance of sustainable socio-technical transitions. *Res. Policy* **2005**, *34*, 1491–1510.
32. Geels, F.; Schot, J. Typology of sociotechnical transition pathways. *Res. Policy* **2007**, *36*, 399–417.
33. Carpenter, S.R.; Bennett, E.M. Reconsideration of the planetary boundary for phosphorus. *Environ. Res. Lett*. **2011**, *6*, 014009.
34. Running, S.W. A measurable planetary boundary for the biosphere. *Science* **2012**, *337*, 1458–1459.
35. Bass, S. Planetary boundaries: Keep off the grass. *Nat. Rep. Clim. Change* **2009**, *3*, 113–114.
36. Lewis, S.L. We must set planetary boundaries wisely. *Nature* **2012**, *485*, doi:10.1038/485417a.
37. Schlesinger, W.H. Planetary boundaries: Thresholds risk prolonged degradation. *Nat. Rep. Clim. Change* **2009**, *3*, 112–113.

38. Barnosky, A.D.; Hadly, E.A.; Bascompte, J.; Berlow, E.L.; Brown, J.H.; Fortelius, M.; Getz, W.M.; Harte, J.; Hastings, A.; Marquet, P.A.; *et al.* Approaching a state shift in Earth's biosphere. *Nature* **2012**, *486*, 52–58.
39. Cardinale, B.J.; Duffy, J.E.; Gonzalez, A.; Hooper, D.U.; Perrings, C.; Venail, P.; Narwani, A.; Mace, G.M.; Tilman, D.; Wardle, D.A.; *et al.* Biodiversity loss and its impact on humanity. *Nature* **2012**, *486*, 59–67.
40. Reid, W.V.; Chen, D.; Goldfarb, L.; Hackmann, H.; Lee, Y.T.; Mokhele, K.; Ostrom, E.; Raivio, K.; Rockström, J.; Schellnhuber, H.J.; *et al*. Earth system science for global sustainability: Grand challenges. *Science* **2010**, *330*, 916–917.