On the Cusp of Global Collapse?

Updated Comparison of *The Limits to Growth* with Historical Data

Global data continues to confirm The Limits to Growth standard run *scenario, which forecasts an imminent collapse in living standards and population due to resource constraints. Further, the mechanism underlying the simulated breakdown is consistent with increasing energy and capital costs of peak oil. The diversion of energy and capital away from industrial, agricultural, and service sectors is a greater problem than climate change in the modelled scenario since it leads to global collapse by about 2015.*

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Abstract

The Limits to Growth standard run scenario produced 40 years ago continues to align well with historical data that has been updated in this paper, following a 30-year comparison by the author. The scenario results in collapse of the global economy and environment, and subsequently the population. Although the modelled fall in population occurs after about 2030 – with death rates reversing contemporary trends and rising from 2020 onward – the general onset of collapse first appears at about 2015 when per capita industrial output begins a sharp decline. Given this imminent timing, a further issue this paper raises is whether the current economic difficulties of the global financial crisis are potentially related to mechanisms of breakdown in the *Limits to Growth standard run* scenario. In particular, contemporary peak oil issues and analysis of net energy, or energy return on (energy) invested, support the *Limits to Growth* modelling of resource constraints underlying the collapse, despite obvious financial problems associated with debt.

Keywords

collapse, energy return on (energy) invested (EROI), limits, peak oil

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Although it has been about 40 years since *The Limits to Growth (LtG)* was first published (Meadows et al. 1972, 1974), it is more pertinent than ever to review what this ground-breaking scenario and modelling study can tell us about the sustainability, or collapse, of the global economy and population. Through a dozen scenarios simulated in a global model *(World3)* of the environment and economy, Meadows et al. (1972, p. 125) identified that "overshoot and collapse" was avoidable only if considerable change in social behaviour and technological progress was made early in advance of environmental or resource issues. When this was not achieved in the simulated scenarios, collapse of the economy and human population occurred in the 21st century, sometimes reducing living conditions to levels akin to the early 20th century.

Despite the *LtG* initially becoming a best-selling publication, the work was subsequently largely relegated to the "dustbin of history" by a variety of critics (e. g., Lomborg and Rubin 2002). These critics perpetuated the public myth that the *LtG* had been wrong, saying that it had forecast collapse to have occurred well before year 2000 when the *LtG* had not done this at all.

Over the last decade, however, there has been something of a revival in the awareness and understanding of the *LtG*. A thorough account of the *LtG* as well as associated debates and developments is provided by Bardi (2011) (box 1). Most recently, Randers (2012 a), a *LtG* co-author, has published his forecast of the global situation in 2052 and renewed the lessons from the original publication (Randers 2012 b, in this issue). A turning point in the debate occurred in 2000 with the energy analyst Simmons (2000) raising the possibility that the *LtG* modelling was more accurate than generally perceived. Others have made more comprehensive assessments of the model output (Turner 2008 a, Hall and Day 2009); indeed, we found that 30 years of historical data compared very well with the *LtG* baseline or *standard run* scenario. The *standard run* scenario embodies the business-as-usual social and economic practices of the historical period of the model calibration (1900 to 1970), with the scenario modelled from 1970 onwards.

The following paper presents an update on our data comparison, to coincide with the 40 years since the original *LtG* publication. In addition, an update is worthy because of questions raised about the economic downturn currently being experienced – commonly associated with the global financial crisis (GFC) – and the onset of collapse in the *LtG standard run* scenario. Is it possible that aspects leading to the collapse in the *LtG standard run* scenario have contributed to the GFC-related economic downturn? Could it be that this downturn is therefore a harbinger of global collapse as modelled in the *LtG*?

We begin with briefly reviewing the data that is available for our update, comparing it then with three key scenarios from the *LtG*, namely the *standard run*, *comprehensive technology* and *stabilized world* scenarios, the latter avoiding collapse. On the basis of the comparison, we discuss what the modelling might mean for a resource-constrained global economy. In particular, the paper examines the issue of peak oil and the link between energy return on investment (EROI) and the *LtG World3* model. The findings lead to a discussion of the role of oil constraints in the GFC, and a consideration of the link between these constraints and a general collapse depicted in the *LtG*.

BOX 1: ***The Limits to Growth Revisited***

Ugo Bardi's *The Limits to Growth Revisited* (2011) comprehensively details the various efforts to discredit the *LtG* study. He draws parallels with documented campaigns against the science of climate change and tobacco health impacts. Three economists – Peter Passel, Marc Roberts, and Leonard Ross – initiated criticisms in a *New York Times Sunday Book Review* article in 1972. They made false statements (e.g., "all the simulations based on the Meadows world model invariably end in collapse"), and also incorrectly claimed that the book predicted depletion of many resources by about 1990. US economist William Nordhaus made technically erroneous judgements (in 1992) by focusing on isolated equations in *World3* without considering the influence that occurs through the feedbacks in the rest of the model.

In 1973 a critique of the *LtG*, edited by physicist Sam Cole and colleagues at the University of Sussex, contained a technical review of the *World3* modelling and essays based on ideology that attacked the authors personally. According to Bardi, the technical review fails because it largely concerned how the *World3* model could not be validated from the perspective of simple linear modelling, which is an inappropriate test for a non-linear model. The review also established that the model could not run backwards in time, though this is an unnecessary requirement for the model to run forward properly. Criticism of the study continued for about two decades, including other noted economists such as Julian Simon, along the vein of such misunderstandings and personal attacks.

For the last decade of the 20th century, however, criticism of the *LtG* centred on the myth that the 1972 work had predicted resource depletion and global collapse by the end of that century. Bardi identifies a 1989 article titled *Dr. Doom* by Ronald Bailey in *Forbes* magazine as the beginning of this view. Since then it has been promulgated widely, including through popular commentators such as the Danish statistical analyst Bjørn Lomborg, and even in educational texts, peer-reviewed literature, and reports by environmental organizations.

Data Update

The data presented here follows that of our 30-year review (Turner 2008 a) (box 2). This data covers the variables, i.e., demographic variables and five sub-systems of the global economic system, displayed in the *LtG* output graphs:

- population (and crude birth and death rates),
- industrial output per capita,
- food supply per capita,
- services per capita,
- persistent global pollution, and
- fraction of non-renewable resources available.

Data sources are all publically available, many of them through the various United Nations (UN) organizations (and websites). In our review, we discuss details on these data sources and aspects such as interpretation, uncertainties and aggregation (Turner 2008 a). However, some additional data and calculation were necessary since measured data to 2010 was not always available (and

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BOX 2: **A Comparison of *The Limits to Growth* with 30 Years of Reality**

In our 30-year data review, a comprehensive comparison of three *LtG* scenarios from the 1972 publication was made with publicly available historical data (for 1970 to 2000) (Turner 2008 a, 2008 b). This provided a useful test of the scenarios and *World3* model used in the *LtG*, since the model was originally calibrated with data for 1900 to 1970, and the scenario simulations run over 1970 to 2100. Our approach is different to the model revisions provided in Meadows et al. (1992, 2004), which recalibrate the *World3* model rather than making an independent validation.

The data review describes the eight output variables in the *World3* model. In particular, non-renewable resources and global pollution deserve scrutiny due to their aggregate nature and interactions with other parts of the *World3* model. Data on non-renewable resources were estimated by us for energy resources only, therefore assuming that non-energy resources are effectively unlimited. Estimates of upper and lower bounds on the original resource base were made to allow for considerable uncertainty in this data. All energy resources were aggregated to give a total, effectively assuming that different energy types can be readily substituted for each other. Data on global pollution needed to be expressed as a pollutant volume in the environment that would impact food production and human health. This pollution data was provided by the atmospheric volume of the greenhouse gas CO_2, while the impacts remain limited for 1970 to 2000. Historical data was generally normalized to the 1970 value of the *LtG* output since the implications of the variables in the model depend on their relative magnitude and long-term trends. In addition to the graphical data comparison with the three scenarios, a statistical summary measure was also provided (normalized root mean square deviation, n-RMSD).

These different comparisons clearly identify that the *standard run* scenario compared well with the global data for the majority of the variables. The comparison was poor with either the *comprehensive technology* or *stabilized world* scenarios; the n-RMSD was typically several times larger than for the *standard run*.

even when it is the data may be forecast estimates). A summary of the data is provided in the following.

Population data is readily available from the Population Division of the Department of Economic and Social Affairs of the UN Secretariat (obtained via the online *EarthTrends* database of the World Resources Institute);[1] but data from 2006 onwards is a forecast. Given the short gap to 2010 and typical inertia in population dynamics, the 2010 estimate will be sufficiently accurate for the comparison made here.

Industrial output was available only to 2007 directly from the UN *Statistical Yearbooks* (UN 2006, 2008), now accessible online.[2] Industrial output per capita is used as a measure of material wealth in the *LtG* modelling, but the industrial output also supplies capital for use in other sectors, including agriculture and resource extraction.

Food supply was based on energy supply data (calories) from the Food and Agriculture Organization (FAO),[3] with the extension to 2009/2010 generated from comparison with production data, which was scaled to the energy supply data for each corresponding food type in the production data.

Service provision has been measured by proxy indicators: electricity consumed per capita and literacy rates. In the former case, for the most recent data it was necessary to scale electricity generation data (from BP 2011) to consumption values, and hence account for electricity transmission losses. Literacy rates were updated from the United Nations Educational, Scientific and Cultural Organization (UNESCO) *Statistics database*,[4] which is the source for the *EarthTrends* data. Values are provided for time ranges rather than single years.

Global persistent pollution was measured by the greenhouse gas CO_2 concentration, available to 2008 on the *EarthTrends* database, with latest measurements to 2010 from Pieter Tans, National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL), and Ralph Keeling, Scripps Institution of Oceanography.[5] The 300 ppm CO_2 concentration at 1900 was subtracted from the measured data to represent an effective background of zero global pollution in 1900.

Finally, the ***fraction of non-renewable resources*** available is estimated from production data on energy resources, since other resources are conservatively assumed to be infinitely substitutable or there to be unlimited resources. Energy production data to 2010 was obtained from the BP *Statistical Review* (BP 2011), which was subtracted from the ultimate resource originally available to obtain the remaining resources. To account for considerable uncertainty in the ultimate resource, upper and lower estimates were made based on optimistic and constrained assessments, respectively (Turner 2008 a). Hence, two data curves are provided for the fraction of non-renewable resources remaining.

Comparison of Data with *LtG* Scenarios

This section presents a graphical comparison of the historical data with three scenarios from the original *LtG* modelling. The three scenarios effectively span the extremes of technological and social responses as investigated in the *LtG*.

The ***standard run*** represents a business-as-usual situation where parameters reflecting physical, economic and social relationships were maintained in the *World3* model at values consistent with the period 1900 to 1970.

The ***comprehensive technology*** approach attempts to solve sustainability issues with a broad range of purely technological solutions. This technology-based scenario incorporates levels of resources that are effectively unlimited, 75 percent of materials are recycled, pollution generation is reduced to 25 percent of its 1970 value, agricultural land yields are doubled, and birth control is available world-wide.

For the ***stabilized world*** scenario, both technological solutions and deliberate social policies are implemented to achieve equilibrium states for key factors including population, material wealth, food and services per capita. Examples of actions implemented in the *World3* model include: perfect birth control and desired family size of two children; preference for consumption of services and health facilities and less toward material goods; pollution control technology; maintenance of agricultural land through diversion of capital from industrial use; and increased lifetime of industrial capital.

The graphical comparisons of data with scenarios are presented in figure 1 to figure 3 (pp. 119 ff.). The statistical analysis undertaken in our 30-year review (Turner 2008 a) was not reproduced here as the changes would be minor, and add little further to the assessment. There are some other points of detail on the data comparison to be noted below.

It is evident that the data generally continues to align favourably to the *standard run* scenario (for most of the variables), and not to the other two scenarios. This comparison demonstrates that the original work cannot be dismissed as many critics have attempted (box 1), and increases confidence in the *LtG* scenario modelling. In contrast, there do not appear to be other economy-environment models that have demonstrated such comprehensive and long-term data agreement. Nevertheless, this agreement is not a complete validation of the model (partly due to the non-linear nature of the *World3* model) or the *standard run* scenario.

1 http://earthtrends.wri.org and www.un.org/esa/population/ordering.htm
2 http://unstats.un.org/unsd/syb
3 http://faostat3.fao.org/home/index.html#DOWNLOAD_STANDARD
4 http://stats.uis.unesco.org/unesco/TableViewer/document.aspx?ReportId=136&IF_Language=eng&BR_Topic=0
5 www.esrl.noaa.gov/gmd/ccgg/trends/ and scrippsco2.ucsd.edu

Achieving validation requires at least that key inputs and non-linear (or threshold) assumptions also be verified. This verification is partially initiated in the *Discussion* section with an examination of the imposts of resource extraction. It is noteworthy that despite the non-linearity of the *World3* model, the general outcomes of the scenarios are not sensitive to reasonable uncertainties in key parameters (Meadows et al. 1974).

The demographic variables displayed in figure 1 continue to show the same comparisons as seen in our 30-year review (Turner 2008 a), so that population would peak somewhat higher than the *standard run* by 2030 or later according to an extrapolation of the difference between the birth and death rates. It is more evident now, however, that the crude death rate has leveled off while the birth rate continues to fall, which are general trends seen in the three scenarios, albeit at different values. Notably, the death rate reverses its monotonic decline and begins to climb in all scenarios within a decade – significantly so in the *standard run* (and *comprehensive technology*) scenario by 2020.

Outputs of the economic system (figure 2, p. 120) show trends mostly commensurate with the *LtG standard run*. Importantly, any downturn in industrial activity due to the GFC has not been captured in the historic data since these were only available to 2007. Nevertheless, the observed industrial output per capita illustrates (figure 2 a) a slowing rate of growth that is consistent with the *standard run* reaching a peak. In this scenario, the industrial output per capita begins a substantial reversal and decline at about 2015. Observed food per capita (figure 2 b) is broadly in keeping with the *LtG standard run*, with food supply increasing only marginally faster than population. Literacy rates (figure 2 c) show a saturating growth trend, while electricity generation per capita (upper data curve) grows more rapidly and in better agreement with the *LtG* model.

Global pollution measured by CO_2 concentration is most consistent with the *standard run* scenario (figure 3 a, p. 121), but this ten-year data update indicates that it is rising at a somewhat slower rate than that modelled. This could be due to a number of factors, which cannot be separately identified in this analysis. For instance, in comparison with the *standard run* model output, lower observed industrial output per capita is consistent with lower observed pollution generation, though this effect will be offset by the slightly higher observed population levels. It is also possible that the dynamics of persistent pollution generation by different economic activities or assimilation in the environment are not parameterized in the *World3* model precisely in terms of actual CO_2 dynamics (which is still a topic of active research). In this possibility, the recent data are consistent with a slightly higher assimilation rate, or alternatively, a lower pollution generation rate in the agriculture sector compared with the industrial sector (since the relative rate of food production is greater than industrial output). Regardless of the explanation, the level of global pollution is sufficiently low (in all scenarios, and the data) to not have a serious impact neither on the environment nor human life-expectancy (Turner 2008 a). In the *World3* standard setting, current pollution levels decrease life expectancy by less than one percent.

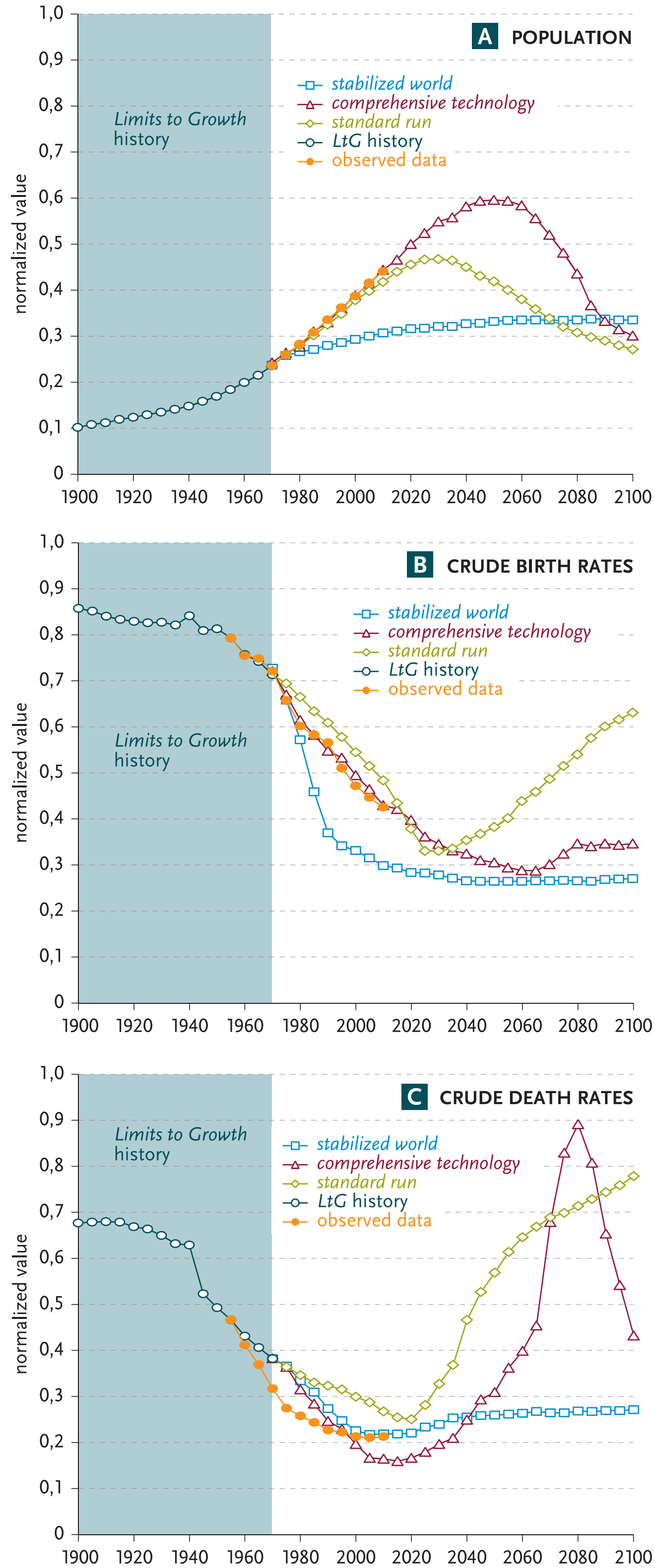

FIGURE 1: Comparison of historical data with three *Limits to Growth* scenarios, for demographic variables: **a)** population, **b)** crude birth rates, **c)** crude death rates. Crude birth and death rates are per 1000 persons per year, with observed data normalized to 1955 *Limits to Growth* values.

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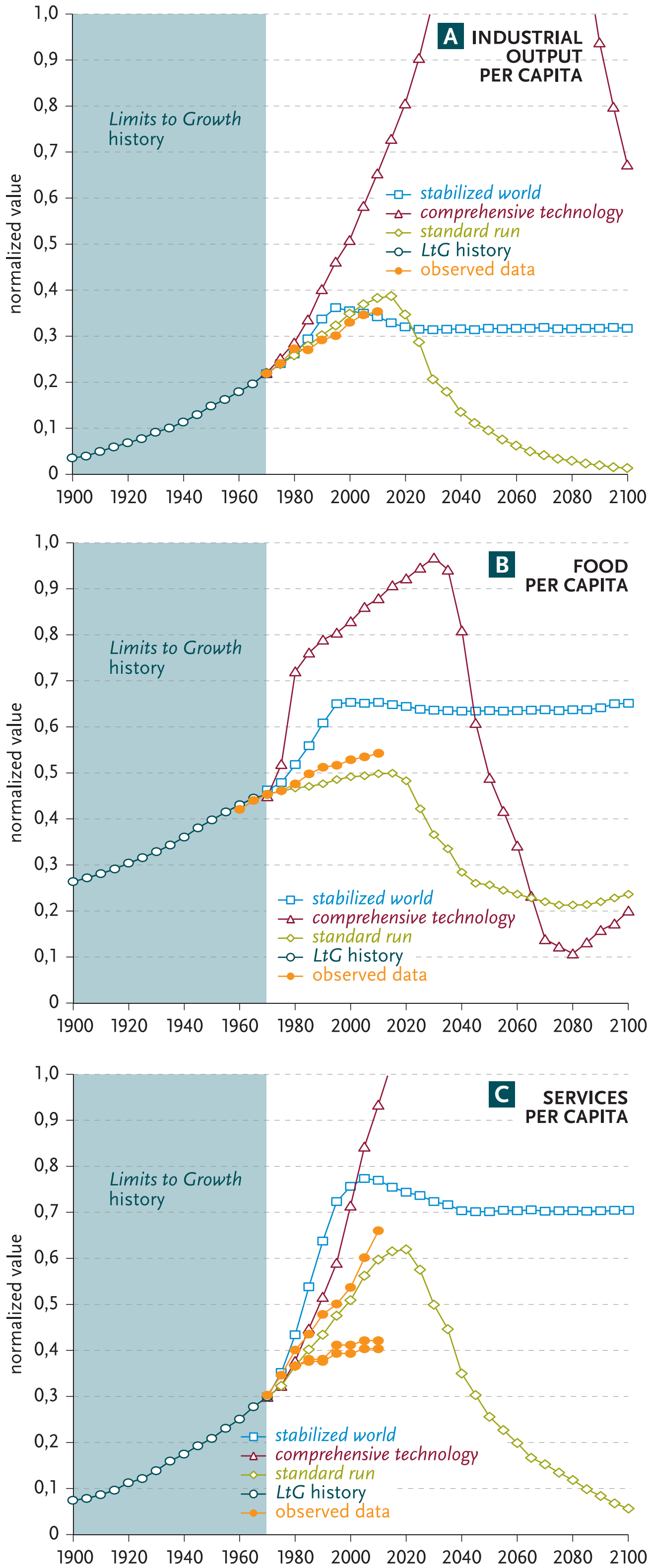

FIGURE 2: Comparison of historical data with three *Limits to Growth* scenarios, for economy output variables: **a)** industrial output per capita, **b)** food per capita, **c)** services per capita (observed data: upper curve: electricity per capita; lower curves: literacy rates for adults and youths [lowest data curve]).

In contrast, of the two data curves of non-renewable resources remaining, the lower estimate demonstrates (figure 3 b) a closer alignment with the *standard run* while the upper estimate aligns well with the *comprehensive technology* scenario. The lower estimate also shows a significant fall toward the point (50 to 60 percent of the original resource) when the *World3* model incorporates a growing diversion of capital toward the resource sector in order to extract more difficult resources (Meadows et al. 1974, figure 5-18). This is the primary cause of collapse in the *standard run* scenario, as described below. The observed data is based on energy resources (see discussion in Turner 2008 a, pp. 405–407), conservatively assuming full substitution potential among the different primary energy types. The assumption may not be entirely accurate, for instance, in the case of transport fuels essential for the smooth functioning of the economy; the following section reflects upon this question further.

Discussion – Is Collapse Imminent?

Based simply on the comparison of observed data and the *LtG* scenarios presented above, and given the significantly better alignment with the *standard run* scenario than the other two scenarios, it would appear that the global economy and population is on the cusp of collapse. This contrasts with other forecasts for the global future (e. g., Raskin et al. 2010, Randers 2012 a), which indicate a longer or indeterminate period before global collapse; Randers for example forecasts collapse after 2050, largely based around climate change impacts, with features akin to the *LtG comprehensive technology* scenario. This section therefore examines more closely the mechanisms behind the near-term *standard run* collapse and explores whether these resemble any real-world developments.

Essentially, the collapse in the *standard run* scenario is caused by resource constraints (Meadows et al. 1972). The dynamics and interactions incorporated in the *World3* model that play out in this scenario are summarized in the following. During the 20th century, increasing population and demand for material wealth drives more industrial output, which grows at a faster rate than population. Pollution from increasing economic activity increases, but from a very low level, and does not seriously impact the population or environment.

However, the increased industrial activity requires ever increasing resource inputs (albeit offset by improvements in efficiency), and resource extraction requires capital (machinery) which is produced by the industrial sector (which also produces consumption goods). Until the non-renewable resource base is reduced to about 50 percent of the original or ultimate level, the *World3* model assumed only a small fraction (five percent) of capital is allocated to the resource sector, simulating access to easily obtained or high quality resources, as well as improvements in discovery and extraction technology. However, as resources drop below the 50 percent level in the early part of the simulated 21st century and become harder to extract and process, the capital needed begins to increase. For instance, at 30 percent of the original resource base, the fraction of total capital that is allocated in the model to the resource sector reaches 50 percent, and continues to increase as the resource base is further depleted (shown in Meadows et al. 1974, figure 5-18).

With significant capital subsequently going into resource extraction, there is insufficient available to fully replace degrading capital within the industrial sector itself. Consequently, despite heightened industrial activity attempting to satisfy multiple demands from all sectors and the population, actual industrial output per capita begins to fall precipitously, from about 2015, while pollution from the industrial activity continues to grow. The reduction of inputs to agriculture from industry, combined with pollution impacts on agricultural land, leads to a fall in agricultural yields and food produced per capita. Similarly, services (e. g., health and education) are not maintained due to insufficient capital and inputs.

Diminishing per capita supply of services and food cause a rise in the death rate from about 2020 (and somewhat lower rise in the birth rate, due to reduced birth control options). The global population therefore falls, at about half a billion per decade, starting at about 2030. Following the collapse, the output of the *World3* model for the *standard run* (figure 1 to figure 3) shows that average living standards for the aggregate population (material wealth, food and services per capita) resemble those of the early 20[th] century.

The dynamics in the *World3* model leading to collapse resonate with aspects of other conceptual accounts of failed civilizations (Tainter 1988, Diamond 2005, Greer 2005, 2008). Tainter's proposition of diminishing returns from growing complexity relates to the increasing inefficiency of extracting depleting resources in the *World3* response. It also aligns with a more general observation in the *LtG* that successive attempts to solve the sustainability challenges in the *World3* model, which lead to the *comprehensive technology* scenario, result in even more substantial collapse. The existence in *World3* of delays in recognizing and responding to environmental problems resonates with key elements in Diamond's characterization of societies that have failed. And Greer's mechanism of "catabolic collapse," i. e., increases in capital production outstripping maintenance, coupled with serious depletion of key resources, describes the core driver of breakdown in the *LtG standard run*.

The authors of the *LtG* caution that the dynamics in the *World3* model continue to operate throughout any breakdown. This could be realistic, or different dynamics might come to prominence that either exaggerate or ameliorate the collapse, such as wars or alternatively global leadership. Other researchers have contemplated how society might respond to serious resource constraints (e. g., Orlov 2008, Friedrichs 2010, Heinberg 2007, Fantazzini et al. 2011, Heinberg 2011). Various degrees of hostility are foreshadowed, as well as lifestyles in developed countries that revert to greater self-reliance.

Instead, we now consider whether the key dynamics underlying the breakdown described above resemble actual developments.

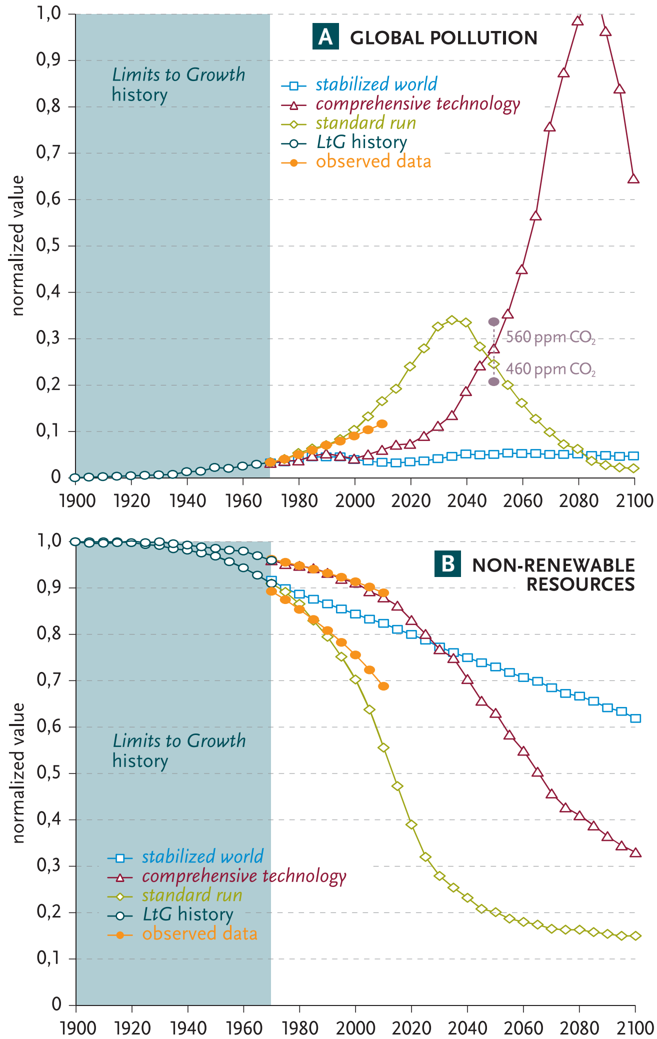

FIGURE 3: Comparison of historical data with three *Limits to Growth* scenarios, for industrial system variables: **a)** global persistent pollution, **b)** fraction of nonrenewable resources remaining (observed data: upper curve uses an upper limit of 150 000 EJ for ultimate energy resources; lower curve uses a lower limit of 60 000 EJ [Turner 2008 a]).

Since the collapse in the *standard run* scenario is predominantly associated with resource constraint and the diversion of capital to the resource sector, it is pertinent to examine peak oil, or other resource peaks. Peak oil refers to the peak in production of oil, as opposed to demand which is generally assumed to increase. Publications on peak oil have flourished in recent years as the possibility of a global peak has become more widely accepted (e. g., by the otherwise conservative International Energy Agency). These publications tend to focus on the question of when the peak will occur and what the oil supply volume will be. Sorrell et al. (2010 b, 2010 a) review many of these and find that independent researchers generally expect peaking to occur within about a decade, or to have occurred recently (e. g., Murray and King 2012); estimates of peaking made by oil industry representatives tend to be decades away. Unfortunately, these oil production profiles themselves say little analytically about the implications of reduced oil supply rates on the economy, though qualitatively a constrained supply of ubiquitous transport fuel is likely to be deleterious to global and national economies (Hirsch 2008, Friedrichs 2010).

What is more relevant than the oil supply rates per se to our analysis of the *LtG* and collapse is the "opportunity cost" associated with extracting diminishing supplies of conventional oil or difficult extraction of non-conventional oil (e.g., tar sands, deep water, coal-to-liquids, etc.) (Murray and King 2012). In the *LtG*, the fraction of capital allocated to obtaining resources (FCAOR) represents this opportunity cost. In the peak oil literature, the relevant measure of opportunity cost is the energy return on investment (EROI), which is related to the net energy available after energy is used extracting the resource (Heinberg 2009, Dale et al. 2011, Murphy and Hall 2011, Heun and de Wit 2012). The EROI is defined as the ratio of gross energy produced, TE_{Prod}, to energy invested to obtain the energy produced, E_{Res}.

1 $$\text{EROI} = \text{energy return on (energy) invested} = \frac{TE_{Prod}}{E_{Res}}$$

The EROI can be related to the FCAOR used in the *LtG*. Since the capital (machinery, e.g., pumps, vehicles) operated in the resource sector, C_{Res}, is basically representative of the overall machinery stock, C_{Ttl}, the energy intensities will be similar and therefore the ratio of capital can be approximated by the ratio of energy used in the resource sector, E_{Res}, to total energy consumed, TE_{Cons}.

2 $$\text{FCAOR} = \text{fraction of capital allocated to obtaining resources} = \frac{C_{Res}}{C_{Ttl}} \approx \frac{E_{Res}}{TE_{Cons}}$$

Since the total energy consumed in any year will be approximately equal to the total energy produced (because stocks of energy stored are relatively small and don't change significantly from year to year), $TE_{Cons} \approx TE_{Prod}$, then equations 1 and 2 give

3 $$\text{FCAOR} = \frac{1}{\text{EROI}}$$

The collated data and model of EROI in Dale et al. (2011) can therefore be converted to FCAOR at corresponding values for the fraction of the oil resource remaining. This can be then be compared against the data used in the *LtG* (e.g., shown in Meadows et al. 1974, figure 5-18). If the peak of conventional oil has occurred, or is about to occur, then approximately half the resource has been consumed, i.e., non-renewable resource fraction remaining, NRFR ≈ 0.5. Contemporary estimates of EROI are in the range 10 to 20 (or 1/EROI of 0.1–0.05). This agrees with the values and trends of the key parameter, FCAOR, used in the *LtG*.

Therefore, in addition to the data comparison made for modelled outputs, this data on oil resource extraction corroborates a key driver of dynamics in the *LtG standard run* scenario. In other words, the key mechanism driving the collapse in the *standard run* is observed in real world data. Further, there are other aspects of constraints in oil supply outlined below that also lend support to the mechanism of collapse.

Oil price rises have been linked to recent increases in food prices (e.g., Alghalith 2010, Chen et al. 2010). There are direct and indirect links between oil and food (Neff et al. 2011, Schwartz et al. 2011), associated with fuel for machinery and transport, both on-farm and in processing and distribution, as well as feedstock for inputs such as pesticides. Also, although nitrogen fertilizer is largely manufactured from natural gas, the price of these commodities is also linked to that of oil. More recently, production of biofuel as an alternative transport fuel, such as corn-based ethanol, has displaced food production and has been a factor in food price increases (e.g., Alghalith 2010, Chen et al. 2010). These developments resemble the dynamics in the *LtG standard run* where agricultural production is negatively affected by reduced inputs. There may also be evidence of global pollution beginning to impact food production (which is a secondary factor in the *standard run* scenario) in the recent occurrence of major droughts, storms and fires (e.g., Russia, Australia) that are potentially early impacts of global climate change driven by anthropogenic greenhouse gas emissions.

The role of oil (and food) prices extends further, into more general economic shocks. For instance, other aggregate modelling of the role of energy in the economy (Nel and Cooper 2009) finds that energy constraints cause a long-term economic downturn, as well as reducing greenhouse gas emissions, which are similar outcomes to those in the *LtG* collapse. Empirically, there is clear evidence (e.g., Murray and King 2012, overviews in Murphy and Hall 2010, 2011) of a connection between many oil price increases and economic recessions (just as there exists a strong correlation between energy consumption and growth in economic indicators). Hamilton's econometric analysis (2009) indicates that the latest (US) recession, associated with the GFC, was different from previous oil-related shocks in that it appears caused by the combination of strong world demand confronting stagnating world production. His analysis downplays the role of financial speculation.

Nevertheless, the overriding proximate cause of the GFC is evidently financial: excessive levels of debt (relative to gross domestic product, GDP), or more accurately, the actual capacity of the real economy to pay back the debt) (Keen 2009). Such financial dynamics were not incorporated in the *LtG* modelling. Das (2011) highlights correlated defaults in high-risk debts, such as sub-prime housing mortgages, as a key trigger of the GFC. The financial models used did not properly account for a high number of defaults occurring simultaneously, being based on statistical analysis from earlier periods which suggest less correlation in defaults. Correlation may be caused by specific aspects of the financial instruments created recently, including for example, adjustments upward in interest rates of sub-prime mortgages after an initial "teaser" period of negligible interest rates. Even so, some spread in defaults would be expected in this case. Another potential factor could be the price increases in oil and related commodities, which would be experienced by all households simultaneously (but with a disproportionate impact on large numbers of households with low discretionary income).

Regardless of what role oil constraints and price increases played in the current GFC, a final consideration is whether there is scope of a successful transition to alternative transport fuel(s) and renewable energy more generally. Due to the GFC, there may be a lack of credit for funding any coordinated (or spontaneous) transition (Fantazzini et al. 2011). And economic recovery may be interrupted, repeatedly, by increased oil prices associated with any recovery. Additionally, even if a transition is initiated it may take about two decades to properly implement the change over to a new vehicle fleet and distribution infrastructure (Hirsch et al. 2005, Hirsch 2008). To transition requires introducing a new transport fuel to compensate for possible oil production depletion rates of four percent (or higher) while also satisfying any additional demand associated with economic growth. It is unclear that these various conditions required for a transition are possible.

Following the corroborated standard run scenario, the issue of resource constraints is a greater problem than climate change, though the latter has received more attention in scientific and public debates.

Conclusion

Our previous comparison of global data with the *LtG* modelled scenarios has been updated here to cover the 40-year period 1970 to 2010, i.e., from when the scenario simulations begin. The data has been compared with the outputs of the *World3* model for three key *LtG* scenarios: *standard run, comprehensive technology,* and *stabilized world*. The data review continues to confirm that the *standard run* scenario represents real-world outcomes considerably well. This scenario results in collapse of the global economy and population in the near future. It begins in about 2015 with industrial output per capita falling precipitously, followed by food and services. Consequently, death rates increase from about 2020 and population falls from about 2030 – as death rates overtake birth rates.

The collapse in the *standard run* is primarily caused by resource depletion and the model response of diverting capital away from other sectors in order to secure less accessible resources. Evidence for this mechanism operating in the real world is provided by comparison with data on the energy required to secure oil. Indeed, the EROI has decreased substantially in recent decades, and is quantitatively consistent with the relevant parameter in the *World3* model. The confirmation of the key model mechanism underlying the dynamics of the *standard run* strengthens the veracity of the *standard run* scenario. The issue of peak oil has also affected food supply and evidently played a role in the current global financial crisis. While the GFC does not directly reflect collapse in the *LtG standard run,* it may well be indirectly related.

The corroboration here of the *LtG standard run* implies that the scientific and public attention given to climate change, whilst important, is out of proportion with, and even deleteriously distracting from the issue of resource constraints, particularly oil. Indeed, if global collapse occurs as in this *LtG* scenario then pollution impacts will naturally be resolved, though not in any ideal sense.

Another implication is the imminence of possible collapse. This contrasts with the general commentary on the *LtG* that describes collapse occurring sometime mid-century; and the *LtG* authors stressed not interpreting the time scale too precisely. However, the alignment of data trends with the model's dynamics indicates that the early stages of collapse could occur within a decade, or might even be underway. This suggests, from a rational risk-based perspective, that planning for a collapsing global system could be even more important than trying to avoid collapse.

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