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Is a sustainable future possible?

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Abstract

Simulations of the real economy at both global and national scales highlight the unsustainable path we're on — modelled respectively in *The Limits to Growth* (LtG) and the Australian Stocks and Flows Framework (ASFF). Global data on actual developments for 1970–2010 support the LtG scenario for business-as-usual that results in near-term collapse. Nationally, the calibration of the ASFF with historical data over six decades depicts how Australia's growth has led to tangled environmental and economic dilemmas. Explorations of Australia's future in the ASFF show that a sustainable pathway would require massive changes to infrastructure (for sweeping efficiency gains and renewable energy), a stabilised population (with fertility rates halved and zero net immigration), and transformed lifestyles (with consumption rates and the working week halved). Considering why sustainable pathways have not been adopted, a review is presented of analysis into the collapse of historical societies. This leads to a summary of recent innovative modelling by others on the critical role of social resistance to change associated with control by a powerful cohort.

Introduction

Every few years or so the question of Australia's population and future economic and environmental sustainability arises in the public domain. The author became involved in this 18 years ago after joining a CSIRO modelling project analysing Australia's sustainability. Almost from the very beginning the CSIRO project was tarred with the brush of the Club of Rome's 'Limits to Growth' (LtG). Critics had claimed that this well-known work from the 1970s had been shown to be wrong, and tried to discredit the Australian work by connection. However, a detailed examination of the LtG shows clearly that the critics were outright lying or regurgitating a myth (Turner, 2012; Turner, 2008). The LtG is worth briefly revisiting in the following section before delving into some key findings from the detailed Australian modelling. The section on Australian sustainability first summarises the historical path that has led to Australia's challenging contemporary position, then documents the impacts of future alternative population trajectories under 'business-as-usual' conditions, and subsequently explores a range of strategies aimed at achieving long-term sustainability. Finally, this paper considers analysis of collapse in historical societies, which leads to the importance of understanding our social system, since resistance to the changes required to achieve sustainability has proved so powerful despite the clear and much repeated evidence for change.

Global sustainability

A quantitative, modelled account of the global predicament was first promulgated by the Club of Rome in the 1972 publication "The Limits to Growth" (Meadows et al., 1972). Their 'System Dynamics' approach covered global population, agriculture, industry, services, resources and environment linked through various responses, sometimes with delays. The model was calibrated with data over 1900 to 1970 (Meadows et al., 1974), and then various scenarios simulated to the end of the 21st century.

A key scenario was their "standard run" or 'business-as-usual' which basically continued the same policy and development settings as evident in the calibration period. In summary, over the historical calibration period (to 1970) and continuing to about 2010 in their BAU scenario (Figure 1, left to right):

- the industrial revolution leads to growth in industrial output per capita (and consequently, material wealth);
- which supports the so-called "green revolution" in agriculture, so that food per capita increases;
- as well as supporting exponential growth in services per capita, such as health and education;
- and consequently natural resources are drawn down, to about half the original endowment;
- while at the same time pollution, such as GHG, increases but from a very low level;
- so that the death rate falls because of better food and services;
- and increasing wealth leads to a fall in the birth rate;
- but population grows because births exceed deaths.

From about now onward (to the end of this century):

- resources continue to be extracted;
- but increasing extraction difficulty diverts capital away from the industrial system, so the industrial output per capita falls;
- pollution grows for a few decades;
- and the combined effect of pollution and weakening industry undermines both the per-capita food and service outputs;
- so that both birth and death rates reverse their trend and grow;
- leading to a collapse in the population later in the century.

Since the modelled scenarios start in 1970, there are decades of reality that we can compare with the simulation (Figure 1). Overlaying four decades of data from 1970, shows that the agreement with the modelled scenario is remarkably good. There were many other LtG scenarios modelled — such as comprehensive, adaptive technology and a stabilised world — but comparison of the data with these is poor. While this doesn't prove beyond doubt that the LtG BAU scenario is unfolding, it certainly refutes the critics and says we should take the work seriously. Still, acceptance of the LtG has been hindered by the complex 'spaghetti and meatball' nature of their model, and its very coarse resolution.

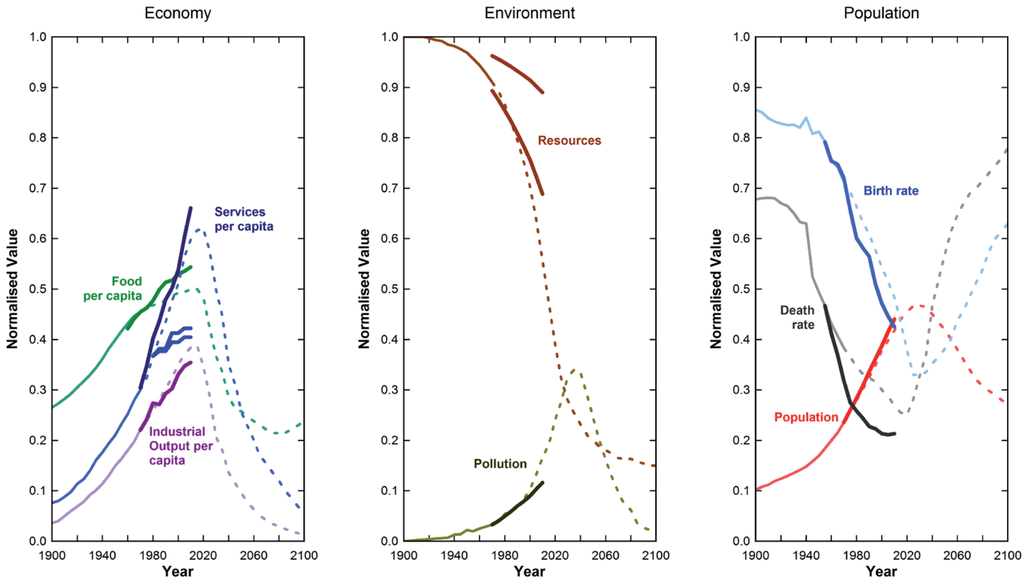

Figure 1: LtG BAU (Standard Run) scenario (dotted lines) compared with historical data from 1970 to 2010 (solid lines) — for demographic variables: population, crude birth rate, crude death rate; for economic output variables: industrial output per capita, food per capita, services per capita (upper curve: electricity p.c.; lower curves: literacy rates for adults, and youths[lowest data curve]); for environmental variables: global persistent pollution, fraction of non-renewable resources remaining (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 2008a]).

Australian sustainability

In order to study the sustainability question, and in contrast to the System Dynamics approach of the LtG, CSIRO adopted a 'Stocks and Flows' approach (originally developed in Canada) that models the physical activity (effectively via mass and energy balance) of the vast array of economic and environmental processes across the nation (Turner et al., 2011). In the Australian Stocks and Flows Framework (ASFF), scenarios of the future are explorations of the physical implications of settings for lifestyle choices, technology developments and policy directions, similar to modelling of climate change scenarios. The ASFF is a massive framework now comprising about 1700 variables, most of which are large data cubes, and is calibrated with a huge volume of historic data.

How did we get here? — the historical picture

The historical calibration of ASFF has produced a detailed complete and coherent quantitative account of Australia, reproducing the historical data and filling in the gaps, from the end of the Second World War through to about 10 years ago (Turner, 2016 (draft)). The graphical picture of the State of Australia over some six decades paints a disturbing story.

The Australian economy has grown enormously over the six decades, driven by population growth and increases in productivity (in roughly equal share). Economically we appear exceptionally wealthy compared with our forebears, but inequality is accelerating. Further, our international financial position has steadily deteriorated, with the trade balance continuing to head in an unhealthy direction. This is despite massive flows of export commodities, most recently iron ore, first to Japan and now to China, and natural gas. Paying off international debt — which is mostly private debt — would involve unprecedented changes to our economy and lifestyle.

A transition in the composition of the economy is evident from about 1970, with a move away from industrial manufacturing toward ever increasing services (principally health and commercial services), and construction (along with agricultural employment continuing to decline, mirroring the demographic shift toward the coast). Consequently, the Australian economy is already largely a service economy, indicating that there is little scope for environmental salvation by suggestions of further structural change. We are also increasingly reliant on imports of value-added goods, with obvious implications for our trade balance, as well as decreasing our resilience to international shocks.

Despite the past structural shift, the growth in wealth, and ongoing efficiencies and productivity improvements, dramatic impacts on the natural resources and environment have occurred that leave us exposed to future shocks. This is a result of population growth combined with per capita consumption.

Increasing rates of per capita consumption of materials and energy have occurred through the recent housing boom, high levels of travel, and purchase of goods and consumable items. This combines with steady population growth to produce escalating volumes of resource use, as well as wastes and greenhouse gas emissions. These rates of consumption have been financed by apparent accelerating growth in national and household wealth, though in reality this has been founded on borrowed money, which has grown even faster than GDP.

Our contribution to global greenhouse gas emissions has grown steadily in hand with the size of our economy. Through further climate change, this is likely to exacerbate dramatic reductions in water availability already seen in the SW and SE of Australia, with serious implications for many capital cities, food production and electricity generation.

Australia's apparent growth in wealth has been built on escalating debt that is mostly private (not public). Australia's environment and resources have been degraded to an extent that already impacts on the economy. Crop land degradation is reducing yields and requiring higher intensity of inputs for farmers, though expansion of area has helped to mask this in the past. Fish stocks have fallen to levels where many species remain under serious pressure. Natural water resources for many capital city catchments are seriously threatened through the combined effects of increasing extractions converging on the falling volumes of rainfall and runoff. These pressures are likely to worsen due to ongoing climate change, fuelled by rising greenhouse gas emissions. Domestic oil resources have passed the point of peak production, so that Australia is increasingly reliant on international supplies for this crucial commodity that underlies the movement of people and freight. Having let our manufacturing industry deteriorate constrains our ability to create alternative strategies (e.g., electric vehicles).

These resource pressures constrain the Australian economy. When combined with the demise of the domestic manufacturing sector, the ability for the Australian economy to increase its productive capacity in order to pay off its debt is seriously compromised. Instead of investing in a more self-reliant productive economy and transitioning to renewable energy forms and more diversified transport, we have used borrowed money to fuel a housing boom and consumptive lifestyle habits.

Rescuing Australia from our predicament of a high level of debt and environmental degradation will not be easy. Due to the inter-related nature of the economy and environment, unintended consequences typically arise from traditional strategies. Physical realities must be observed: you can't have your cake and eat it too (although some economists believe that this physical law can be ignored).

Attempting environmental remediation using just technological fixes would require rates of progress well beyond any historical precedent, confirmed in the detail of the Australian National Outlook (Hatfield-Dodds et al., 2015a). Even if these were achieved, greater efficiencies lead to lost jobs. Creating new jobs through growth of consumption and the economy undoes the intended environmental gains. Additionally, depending on imports of expensive equipment worsens our international debt.

Trade balance and international debt issues would be alleviated somewhat by a major turnaround in Australian manufacturing — back-tracking from the service economy. However, Australian-made products would be more expensive, not simply in dollar terms, but also in energy, material and water costs locally.

Alternatively, relying on further expansion of the service economy for lower environmental impacts may be naive. Many services have hidden or indirect environmental impacts, sometimes of a substantial nature. The financial sector, for example, supports investment in physical infrastructure.

Even substantial reductions in population growth and consumption rates would be insufficient on their own to achieve sustainability. Lower consumption demand directly threatens jobs, leading to further inequality and possible social unrest.

Australia's challenging contemporary predicament discussed above suggests that any solution would most likely have to involve a comprehensive suite of strategies. The Australian Stocks and Flows Framework (ASFF) was designed for exploring such futures, and has been used in a wide range of studies (summarised in Turner et al., 2011), and most recently in food security (Turner et al., 2017; Candy et al., 2019).

What does business-as-usual entail?

A convenient reference case for exploring alternative futures in ASFF was developed from a study of the environmental impact of alternative population trajectories for the Department of Immigration and Citizenship (Turner, 2010) — though this report was effectively buried. The scenarios involved a business-as-usual future, without substantial change to lifestyles, behaviours and policies. (Hence it generally employed projections of historical trajectories for many of the ASFF inputs, and therefore obviating modelling of prices.)

The population trajectories reproduced the Australian Bureau of Statistics projections (ABS, 2008) based on different immigration and fertility rates (Figure 2). Higher immigration and contemporary fertility rates are in the upper curve, leading to 40 million Australians by mid-century. Australia is approximately on that trajectory now. But it's quite possible to stabilise and even reduce Australia's population as the lower curve shows. This will be investigated in the next section.

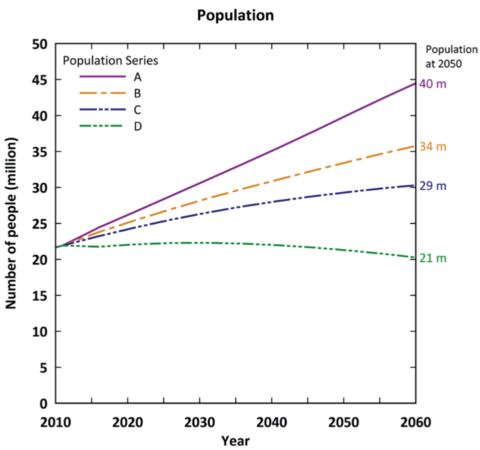

Figure 2: Population trajectories reproduce the ABS series based on different immigration and birth rates.

The scenarios included some ongoing productivity and efficiency advances; a transition toward cleaner electricity generation; and some climate change impacts on water resources. The scenarios also targeted an 'optimal' unemployment rate of 5%, via endogenised economic growth (which is discussed later in this section).

Interestingly, all scenarios produce economic growth, even the stabilised population, as shown by growth in GDP (Figure 3a). Critically though, as shown by per capita GDP (Figure 3b), average wealth is essentially the same irrespective of the population scenario.

There are however, somewhat different environmental outcomes. For example, GHG emissions (Figure 3c) are higher for bigger populations, and rise for all population scenarios, except for a modest reduction in the stabilised population. This is despite all of these scenarios employing greener power and wide-spread efficiencies.

In terms of fuel security, our reliance on overseas oil (Figure 3d) increases dramatically as Australia's domestic production falls. That could be a challenge depending on availability and price.

Water security is increasingly threatened with larger populations. Water use (Figure 3e) actually begins to be dominated by urban consumption in the higher population scenarios. These pressures combined with some climate change, force some river flows, such as the Murray-Darling, into the red (Figure 3f) — their average flow would be negative if we kept trying to extract.

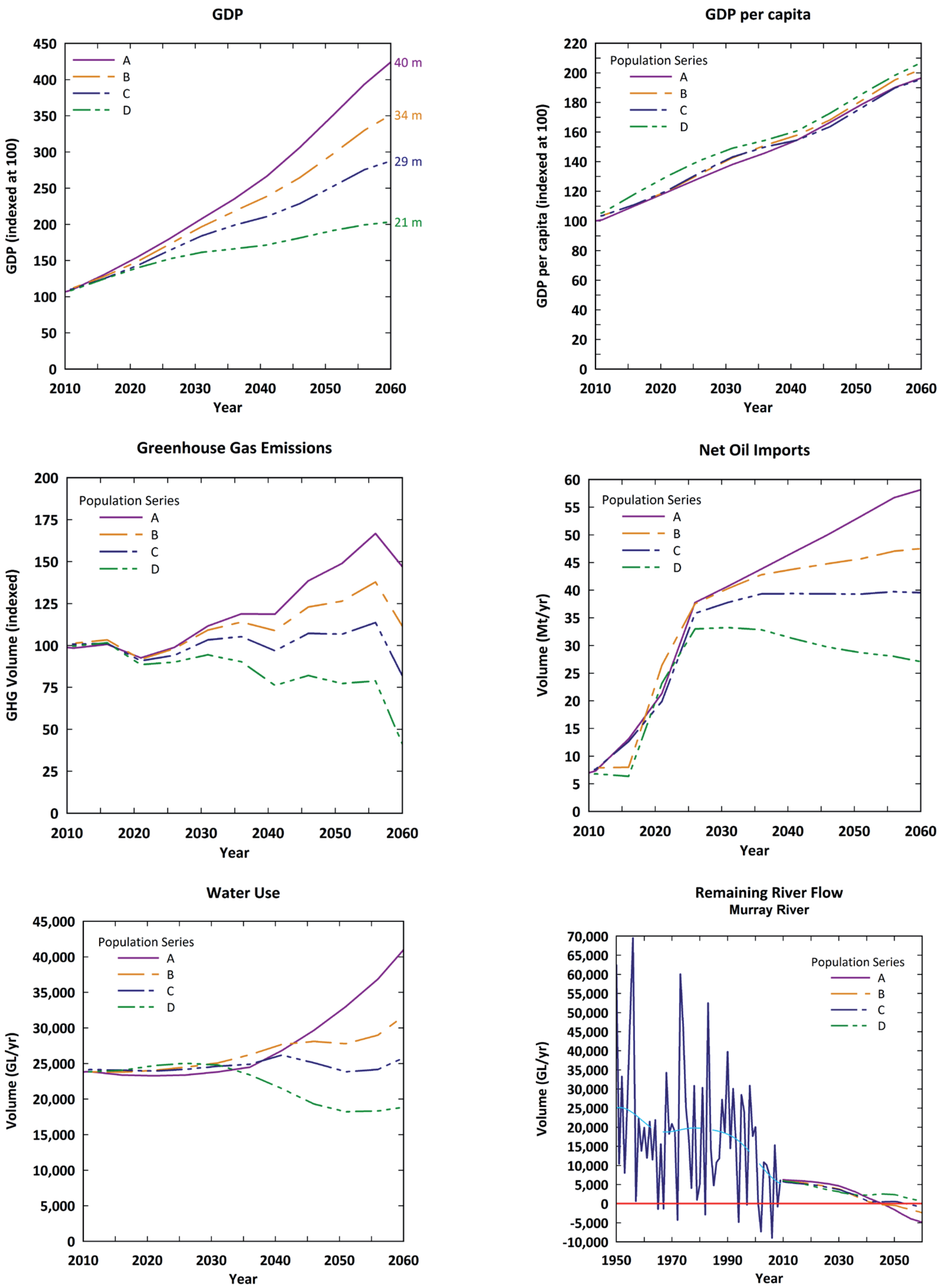

Figure 3: Several key economic and environmental outcomes under BAU conditions for four alternative population trajectories (see Figure 2).

These and other impacts come about despite technological improvements. In particular, the Carbon intensity for the economy (i.e., volume of GHG emissions for the whole economy per dollar of GDP) over time for each of the population scenarios falls significantly (from approximately 0.65 kg/$ to 0.25 kg/$). That is, Australia becomes cleaner in a *relative* sense, but our total GHG emissions increase, so Australia becomes dirtier in an *absolute* sense.

This apparent paradox is not an artifact of the modelling or something peculiar to Australia. Over the past 1–2 centuries, carbon intensity for the world economy has decreased (i.e., efficiency increased) (Grubler, 1998), while GHG emissions have simultaneously increased, at an exponential rate. This is just one aspect of technology as a double-edged sword, and the apparent paradox can be understood by considering the focus of modern developed economies, like Australia's, on achieving economic growth of typically 3% pa.

Such economies target 3% — and not other rates — because our populations typically grow at about 1.5% pa, and technological progress and productivity advances also at about 1.5% pa. If there were no other change made, both of these factors combined would create unemployed labour at the rate of 3% pa, and lead to massive unemployment levels within decades.

To prevent such social disruption, we have traditionally adopted the growth model — grow the economy through investment and increasing consumption at 3% pa to create new jobs for those that would have been unemployed. This growth mechanism was employed in the ASFF modelling of business-as-usual to maintain an optimum unemployment level (5%). As the system-wide outcomes of the modelling and historical evidence clearly show, we've undermined the environmental gains we thought we'd get from technology. Unfortunately, this mechanism is not well understood or acknowledged (e.g., even the Chief Scientist for Australia openly adopts an optimistic position regarding impacts of technology (Finkel, 2015)).

Pathways to sustainability

Nevertheless, human societies are inherently innovative. Consequently, to examine the possible strategies for alleviating the environmental/resource stresses identified above, ASFF was used to model ambitious technological, population and lifestyle changes in succession (Turner, 2016):

- sweeping efficiency gains are made, across every sector of the economy;
- the power sector was also transitioned to mostly renewables;
- population was stabilised by halving the fertility rate and imposing a zero net immigration rate — so the number of people entering Australia matches those leaving; on the lifestyle front, in order to avoid unemployment:
- personal and household consumption rates were halved, and;
- crucially, the labour force shifts over decades to a 3-day working week, though the four days of "leisure" would be quite different from contemporary experience.

The modelling shows it takes the whole collection of ambitious strategies to achieve meaningful change (Figure 4). For GHG, the upper rising curve shows the growing emissions from the earlier scenario with population growth and economic growth

(Figure 4c). The lower green curve incorporates all of the strategies (of the "alternative" scenario) and gets GHG emissions down to approximately recommended levels for climate security (assuming a similar global response). Our oil security is much better with all of the strategies, though not complete (Figure 4d). Clearly, water use is reduced dramatically (Figure 4e), and the Murray-Darling average river outflow is by-and-large prevented from drying up (Figure 4f).

Other strategies would be needed for some other environmental challenges, like moving to regenerative agriculture to tackle land function degradation (Turner et al., 2017; Turner et al., 2016; Larsen et al., 2011).

The implications of this alternative scenario (with all strategies implemented) in the ASFF modelling contrast in many ways with the recent CSIRO Australian National Outlook 2015 report (Hatfield-Dodds et al., 2015a). The message promulgated by the ANO report's authors, including an article in the prestigious journal *Nature*, explicitly suggests that a sustainable environmental outcome can be achieved without sacrificing a consumption-based lifestyle and continuous economic growth (Hatfield-Dodds, 2015; Hatfield-Dodds et al., 2015b). Their research uses a collection of interacting models to produce a large number of scenarios at both the global and Australian level. Key elements for achieving the outcome (of their "Stretch" scenario) are:

- escalating price on carbon;
- large dependence on carbon capture and storage (CCS);
- huge transfer of agricultural land to forestry plantings for bio-sequestration and biodiversity; and
- unprecedented growth in energy/resource efficiency.

The ANO modelling has been criticised (including by a co-author) on a number of grounds, many of them related to the extreme or unsubstantiated nature of key assumptions such as those above (Lenzen et al., 2016; Alexander et al., 2018). Such criticism has validity in terms of questioning the likelihood of the scenario and the ANO authors' suggestion that a transformation in public values is not needed (criticised by Diesendorf (2015)). However, it does not necessarily invalidate the modelling per se.

In terms of the validity of the ANO scenarios/model — and of the contrast with the alternative ASFF scenario above — it appears that the ANO modelling omits the effect on unemployment from exponential growth in efficiency, perhaps due to missing links between the ANO models dealing with labour and resource efficiencies. The importance of this relationship was demonstrated in the ASFF modelling: first, in the business-as-usual scenario, where consumption (and investment) increased to generate new jobs that mitigated the unemployment created through efficiency gains (and hence endogenised economic growth); and second, in the alternative scenario where a three-day working week was imposed (and consequently growth is unnecessary).

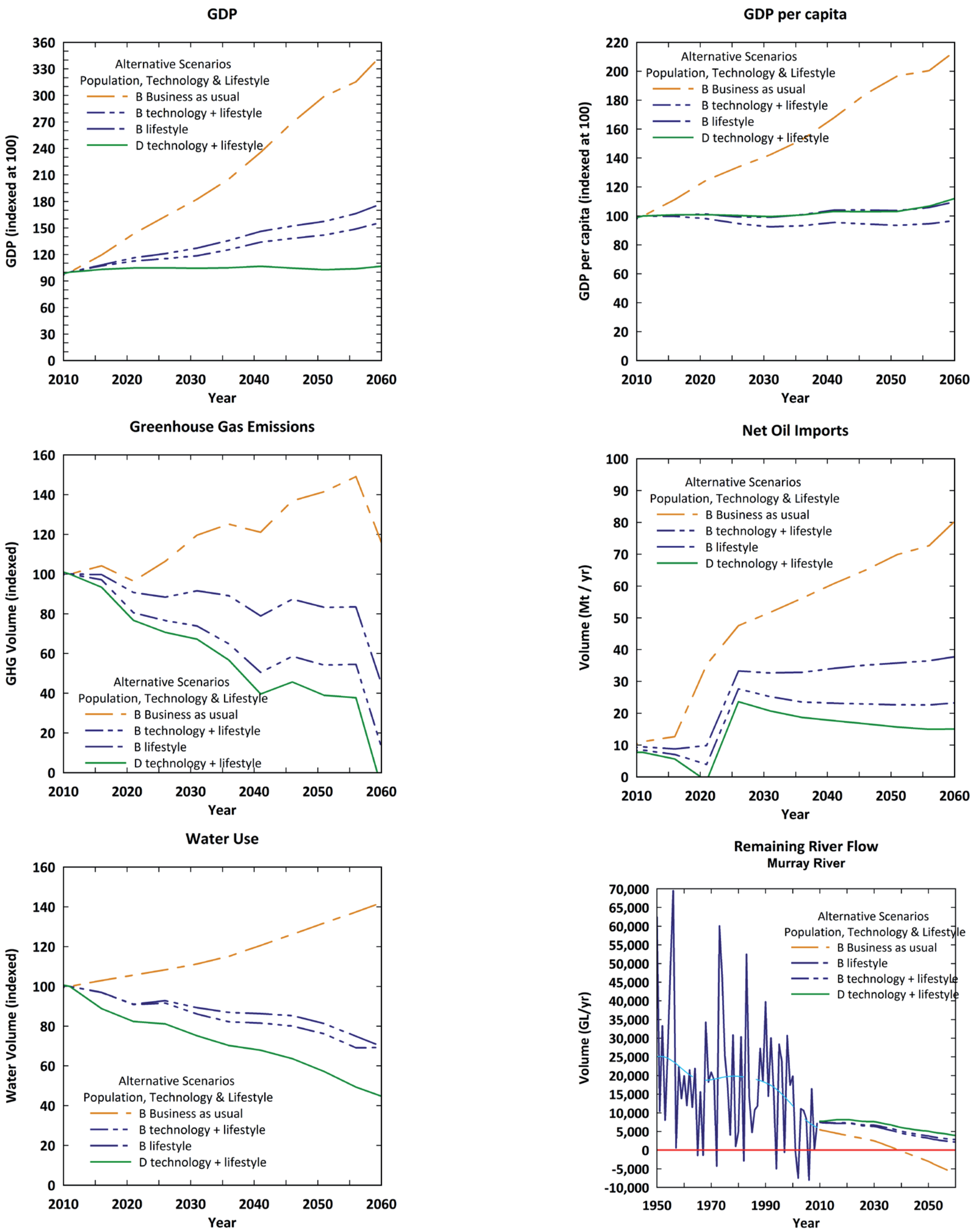

Figure 4: Effect on key economic and environmental outcomes of changes in population, technology and lifestyle. BAU with modest population growth (B) (orange single dash line) provides a reference (see Figure 3). Only the combination of stabilised population (D), sweeping efficiencies, renewable power, reduced household consumption and shorter working hours (green solid line) approaches a sustainable future.

The lack of such a relationship between efficiency and unemployment in the ANO creates an erroneous decoupling of economic growth from environmental impact. Additionally, the decoupling argument (Schandl et al., 2016), and associated conclusion of ever-growing consumption-based lifestyles is based on growth in GDP per capita, and is questionable since a large but unspecified part of GDP should be attributed to investment in new capital/infrastructure (at least partially funded by the high price of carbon), and hence not available as income to labour (see comment on ASFF below).

Compared with the view of the ANO report, the alternative ASFF scenario (above) could sound draconian to growthists, but it does not mean going back to living in a cave according to the simulated GDP figures. Under all of the imposed strategies GDP (Figure 4a) remains constant, and since population is also stabilised, the per capita average also flat-lines (Figure 4b). Although not an aim of the explorations, the scenario has effectively produced a sustainable "Steady-State Economy".

There are of course issues with using GDP as an indicator of wealth, and the per capita average hides questions of inequality and distribution. For instance, the stabilised GDP per capita outcome (Figure 4b) appears to contradict the lifestyle changes of the scenario, where household consumption rates and the working week have been halved. The paradox is explained by recognizing that a growing segment of GDP is associated with the capital investment that supports the technological change also embodied in the scenario. Consequently, a reduced portion of GDP is associated with income to workers. This reduction in average wealth is consistent with the lifestyle setting of the scenario, and could mean that households would have to return to mid-20th century wealth levels.

So, technically, we know how we could be sustainable, and it does involve truly massive transformation, but it doesn't necessarily involve living in a cave. (That said, the scenario simulation hasn't dealt with the problem of growing international debt, which might be required to fund the technological capital investment.) Despite the sociological and economic challenges, such a potential approach to achieve sustainability has been known for decades, at least from the time of the LtG — and hence raises the question why sustainable pathways have not been adopted despite the evidence for catastrophic environmental degradation.

Possible insights from history

Other researchers have sought to shed light on our failure to take sustainably pathways through the use of historical analysis. Substantial literature exists on the study of collapse and instability of past societies, and naturally the overwhelming majority of this has focused on agrarian societies. Some notable reviews summarised in Table 1 have been made on ensembles of past social collapse/instability, seeking to draw more general conclusions on causation than can be afforded by studies on single cases (Diamond, 2005; Goldstone, 1991; Goldstone and Bates, 2010; Tainter, 1988; Tainter, 2006; Turchin, 2003b; Turchin, 2009; Turchin, 2012).

Table 1. Summary of key historical reviews of societal collapse, conflict and instability

Societies		Method	Type of Societal Collapse	General Thesis
A. Western Roman Classic Maya T Chacoan Collapse avoided:- Byzantine Europe	-300–500 -100–900 500–1300 ??? ???	Review of archaeological evidence for detailed case studies (from tens of cases overviewed)	Rapid change from complex to simple society with deleterious effects.	Increasing societal complexity (in response to earlier stresses) yields diminishing returns, which reduces or eliminates resilience to shocks.
B. Classic Maya Anasazi (SW NthAm) Greenland Norse Easter Island Polynesian Pitcairn Is Haiti Rwanda genocide Collapse avoided:- Tokugawa-era Japan Tikopia (Pacific Is) New Guinea highlands	-250–900 600–1200 1000–1400 700–1700 800–1500 1800–2000 1900–2000 1600–1870 -900–2000 1400–2000	Comparative assessment of archaeological evidence	Extinction or dramatic fall of population and societal conditions.	Poor decision-making and mismanagement of environmental problems can be categorised as failure to: • be aware; • recognise (denial); • respond at all; • respond correctly; • respond early enough

Table 1. Summary of key historical reviews of societal collapse, conflict and instability (continued)

Societies	Method	Type of Societal Collapse	General Thesis
C. England 1500–1640 Ottoman 1500–1650 Ming-Qing 1500–1650 France 1700–1790 Global (141 episodes) 1955–2003	Statistical analysis of political, social, and economic factors	Violent conflict, adverse regime shifts, and genocide/politicide.	Short-term prediction of instability through a combination of: • political regime (e.g., partial democracy with factionalism), • infant mortality, • neighbouring conflict, and • state-led discrimination.
D. Rome (Republican,Principate) -350–285 France (Capetian,Valois) 1150–1660 England (Plantagenet,Tudor-Stuart) 1150–1730 Russia (Muscovy,Romanov) 1460–1920 China (E & S Asia) 1780–2010	Mathematical modelling and statistical analysis	Fall of the state	Demographic-structural model interplay between: a) the state's resources, b) elites, and c) commoners, and the existence of diminishing returns produces approx. 200-year secular cycles of rises and falls (with 50-year bi-generation cycles of civil unrest superimposed).

A Tainter (1988, 2000); B Diamond (2005); C Goldstone (1991), Goldstone & Bates (2010); D Turchin (2009, 2003b, 2012).

Perhaps due in part to the abundance of cases, analysis of common cases represents a relatively short list. Considerable differences in the methods employed are also obvious. Recent availability of electronic databases on historical variables has enabled statistical analysis to dramatically extend the spatial and temporal coverage and rigour of analysis (e.g., Goldstone, and Turchin). Attention has only more recently moved toward modern societies of the industrial revolution era. Additionally, definitions of what constitutes societal collapse/instability also differ in detail. Despite these points of difference (and perhaps in view of them), it is valuable to compare these reviews due to their focus on finding generalised laws of societal collapse/instability.

At one level, the generalisations reached appear unrelated, and some researchers view alternative proposals in an explicitly competitive light. This is probably an artefact of inappropriately searching for ultimate causes of collapse within a system resplendent with feedbacks.

For example, Tainter (2006) is critical of Diamond and others ascribing environmental causes to collapse, instead conjecturing that societies have coped with environmental and other stresses by (technological) adaptation, which increased the complexity of the society and subsequently yielded diminishing returns. Consequently, according to Tainter, the society may succumb to a new environmental or other shock because effectively the low-hanging fruit has already been exploited. Tainter (2000) suggests that some societies avoided collapse, such as the Byzantine Empire, through a strategy of simplification; or through substantial innovation and geographic expansion, such as the Industrial Revolution of the late 18th century, when Europe transitioned from an agrarian society based on wood and animal power to an industrial society dependent on coal (combined with the steam-engine).

Diamond (2005) also conjectures that societies may avoid collapse, but that many fail due to poor decision-making and mismanagement of environmental issues, which he suggests are a common but not universal problem (noting also trade issues and cross-border conflict). The hierarchy he proposes of five levels of failure to manage environmental stresses effectively includes Tainter's (as a failure to respond correctly), even though Diamond evidently criticises Tainter (p. 420).

In contrast to these largely agrarian-based studies, Goldstone et al (2010) utilised extensive databases on conflict in modern states to undertake a comprehensive statistical analysis of a suite of social, economic and political variables. Environmental factors were not directly incorporated in the analysis, evidently because earlier research indicated that these factors had an insignificant contribution to violent conflicts (Goldstone, 2001; Goldstone, 2002). (This is in contrast to other research e.g., indicating the influence of climate on human conflict (Hsiang et al., 2013).) The statistical analysis showed that initiation of conflict within states could be predicted a few years in advance at about 80% accuracy by four socio-political factors, namely: the type of political regime (based around the degree of democracy and factionalism), the presence of conflict in multiple neighbouring states, the existence of state-led discrimination, and the extent of infant mortality. This socio-political model contrasts with that of Tainter and Diamond (although a common theme is political mis-management) by abstracting environmental conditions even further away as potential driving factors. Crucially, it is also essentially a static perspective compared with the alternative multi-century timescales considered by Tainter and Diamond. The static model leaves open the question of interaction between the polity, population and environment, and how each of these may be bound up in long-term dynamics of mutual influence (and hence not actually independent variables).

The dynamics of denial and the role of power

Recently, two separate and innovative modelling efforts address the issue of static analysis by modelling social dynamics of whole societies linked to resource and environmental status. The quantitative nature of the mathematical modelling provides an opportunity for rigorous testing and deriving insights. Crucially, both approaches incorporate modelling of demographic structure, specifically the influence and control that powerful cohorts have over the general populace. While one study (Harich) is on contemporary society, and the other (Turchin) is more based on analysis of historical societies, both models produce dynamics that see societies grow over some 200 years beyond a sustainable level and then collapse.

Harich has constructed a System Dynamics model (among other analyses) to investigate societal resistance to change when faced with potential environmental problems (Harich, 2010; Harich, 2012). Although the model incorporates substantial detail, the crux of it involves two competing processes that seek to influence a general populace to different views of environmental issues. One process involves a dynamic loop that models academics, activists and virtuous politicans attempting to educate the general populace by promulgating facts about forthcoming environmental problems. The second process models "degenerate" politicans, corporations and vested interests that create "false memes" about the problems, and if the falsities are not detected by the general public (which may include a degree of denial), then no change occurs to mitigate the environmental problems.

Exploring the dynamics of this system by varying parameters shows that the second process based on false memes inevitably dominates, resulting in environmental problems growing to critical levels. This is because "you can always tell a bigger lie, but you can't tell a bigger truth." The truth is just that, but false memes come in many forms and extents, such as: spreading fear; confusing the issue; exaggeration; demanding certainty from science; hiding the truth. In the model, a dramatic transformation occurs in public understanding when environmental reality eventually bites so hard that it can't be ignored or denied, though too late for effective change.

In the other innovative modelling, Turchin's work sheds further light on the transformation, based on historians' insight that revolutions by the populace are typically quelled while the powerful cohort remain united, but revolutions erupt when the hard times force the powerful to clash among themselves and consequently lose control over the populace. By using dynamic modelling, Turchin (2003b); (Turchin, 2003a) has avoided the static and qualitative nature of historical analysis (summarised above). Turchin takes Goldstone's (1991) insights about the involvement of "elites" i.e., the cohort with power, and incorporates processes involving diminishing returns on state resources, into a dynamic "demographic-structural" model of state rise and fall (summarised below).

The diminishing returns concept parallels that of Tainter's, and is essentially a Malthusian view of population effects. This model and its variants, which has population, polities and state resources (ultimately an environmental factor) influencing each other, has mostly been applied to the understanding of a wide range of agrarian societies. With appropriate parameter settings it produces state collapse and periods of state rise and fall with "secular cycles" (Turchin, 2009) of about 200 years, in keeping with much of the historical accounts. The model may be extended to modern industrial societies, as Turchin's (2013) analysis of the US from 1780 to 2010 suggests. Criticism of Turchin's model appears to focus on points of detail (Tainter, 2004) rather than acknowledge the more general understanding generated, including ironically, the importance of diminishing returns in state collapse.

In Turchin's demographic-structural theory, the extent of total resources produced in a society, such as food from land (particularly in agrarian states), increases with growth in population because more people are available to work the land. However, the rate of increase with population is likely to slow i.e., there are diminishing returns, due to crowding for example, particularly as the "carrying capacity" is approached (which is a function of state geography and technology, potentially advanced through state support). The resources needed by the population grow at least linearly with the number of people, so that surplus production should initially grow, peak and then fall to zero as population grows toward the carrying capacity. Surplus production supports more rapid population growth through higher fertility rates. Further population growth can lead to "persistent price inflation, falling real wages, rural misery, urban migration, and increased frequency of food riots and wage protests". This is the demographic or Malthusian part of the theory involving environmental factors, which alone is insufficient to explain the rise and fall dynamics.

During this period of growth, the state assets are enlarged through taxes on the production of surplus resources, and this initially exceeds the state expenses. These expenses, such as the maintenance of the military and bureaucracy, scale linearly with the population. Likewise, the "elite" cohort of the population (this being the "structural" and crucial part of the theory) extract rent from the commoners, and expand in numbers and wealth due to growth of the population, over-supply of labour and resource surplus. This leads to depressed wages and un- or under-employment for commoners, as well as a golden age for elites rapidly accumulating wealth, attracting more to this cohort.

Subsequently, over-production of elites encourages rivalry and factionalism among that cohort. Meanwhile, the state attempts to increase revenues (taxes) to offset escalating expenses, but falling surplus production leads to state fiscal crisis, bankruptcy and loss of military control. As conditions deteriorate, popular discontent among the commoners is harnessed by competing groups of elites. Competition among elites allows or even fuels popular uprisings, breakdown of central authority, potential conflict and state collapse. The deteriorating environmental/resource and social conditions during this period of descent force population numbers and growth rates down i.e., a collapse (in effect allowing the dynamic system to return to the conditions at the start of the cycle).

An important implication of the demographic-structural model is that an ultimate cause does not exist for the collapse, since the factors involved interact through feedbacks. This lack of independence has implications for any statistical analysis of societal conflicts, and may explain why different studies come to conflicting conclusions about the role of the environment. Nevertheless, societal inequality (in terms of a hierarchy of economic/political power) appears to be a necessary ingredient for collapse. Further, a critical point in the dynamics is reached when surplus production (due to diminishing returns) has peaked, since subsequent attempts by the state to maintain the system perpetuate the problem by increasing pressures, rather than decreasing them, thereby leading to rapidly deteriorating conditions. This dynamic is present in the Limits to Growth model, e.g., when increasingly difficult resources are extracted, as is the case in the business-as-usual scenario presented above.

Conclusions

This paper has examined the question of whether a sustainable future is possible, by drawing together a range of different analyses. Historical analysis by others was summarised covering past societal collapse, as well as the modern development of Australia that depicts the interacting dilemmas we currently face. Modelling was also described at the global level (Limits to Growth) and for Australia (ASFF), which highlight that a business-as-usual approach (such as economic growth and reliance on technology) appears destined to lead to collapse. Indeed, control systems theory shows that in a system with positive (accelerating) and negative (restraining) feedbacks, overshoot and subsequent collapse is inevitable when delays are present in the negative feedbacks. A modelling exploration of an alternative future for Australia demonstrates that sustainability may be feasible, but only if massive transformations occur in virtually all economic/societal aspects — technological, population, lifestyle (and probably also financial).

The sheer breadth, rate and scale of change required for sustainability appears far too much of a challenge to be realistic given historical and recent experience. This view is strengthened by innovative modelling of social dynamics by others that explains the resistance to change. In light of the comprehensive evidence presented, the most rational course of action is to prepare as best as possible for a collapse of some nature. Ironically, if such preparations were broadly adopted, synergies with sustainable strategies might provide some hope of avoiding collapse.

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