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# How long can global ecological overshoot last?

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## Abstract

The ability of the Ecological Footprint to communicate complex environmental information in a clear and accessible way is well known; however, with growing environmental complexity, we will require increasingly sophisticated environmental indicators to inform our decisions. We have developed an integrated and dynamic global model to investigate future trajectories of the Ecological Footprint. Under a range of futures and without the mitigation of human resource demand, we find that the discrepancy between global demand and renewable supply of resources is likely to increase. Continued overshoot, although possible in the short term, means the global community is increasingly exposed to risks of environmental collapse due to the approach of at least two planetary boundaries relating to land use expansion and climate change. We show that, the Ecological Footprint trajectory and the time between the commencement of ecological overshoot and ecological collapse is sensitive to global policy decisions in relation to technological, economic and population. Importantly, this work presents a tool which can be used to support transdisciplinary decision-maker collaborations examining the risk associated with alternative policy options in the face of uncertainty at multiple scales.

## Keywords

Uncertainty; Ecological Footprint; scenario; resilience; complexity

# 1 Introduction

The Ecological Footprint is an indicator of the human demand for biotic resources (those formed by the sun's energy through photosynthesis). The Ecological Footprint shows that, at a global scale, human populations have been using more biotic resources than the planet can renewably produce since at least the mid 1970s (McLellan et al., 2014).

As an indicator developed to track changes in human consumption and the earth's ability to supply these demands, the Ecological Footprint has had significant success (Nourry, 2008). It is widely acclaimed for its ability to communicate ecological limits, equitable resource distribution and interconnectedness across scales; however, its ability to influence policy has been more limited (Collins and Flynn, 2015).

Indicators such as the Ecological Footprint were not designed to answer questions such as - 'What are the most important drivers which affect the size of the Ecological Footprint? How does societal risk vary as a result of different decisions? How do decisions made elsewhere in the world, and over which we have no control, affect our local decision making context?

This is because environmental issues are some of the most complex issues that face humanity. They are characterised by a number of key characteristics: increasing interconnectedness/interdependence, increasing rates of change, cross scalar influences, non-linearity and unpredictability, growing uncertainty and risk, multiple equally legitimate and value laden perspectives, many legitimate solutions, local nuance and increasing variability (Batie, 2008, Galanter, 2003, Brennan, 2004, Calvano, 2004).

Previous studies have begun to investigate such aspects in relation to the Ecological Footprint. For instance, Van Vuuren and Bouwman (2005) used the IMAGE model to investigate future Ecological Footprints to 2050 under the IPCC SRES scenarios for 17 world regions. Moore et al. (2011) also present a Footprint Scenario Calculator which can be used to convert projected consumption and emission quantities into Ecological Footprint and Biocapacity trends up to 2050. They note that the model has limitations because it does not incorporate feedbacks (i.e. is not dynamic). Lenzen et al. (2013) also developed a blueprint methodology that analysed global Ecological Footprints disaggregated by country to 2050 under one baseline scenario.

Further development of such approaches is required to allow us to assess the risks associated with decisions affecting resource use. This paper presents an approach complementary to the static Ecological Footprint which bridges the gap between the readily accessible and unique information the indicator can provide and the needs of complex policy development. Here we present a validated modelling approach which is able to:

- consider holistic (environmental, economic and social) causal drivers;
- account time and system inertia;
- identify risks associated with uncertain futures; and
- evaluate the ability of the system to respond, adapt or transform.

Our global Ecological Footprint model continues the indicator's existing legacy of accessible information but, at the same time, also addresses the growing sophistication required of environmental indicators to inform complex policy questions. Below we describe the integrated, dynamic model structure used to calculate future Ecological Footprints. We then apply a set of case study scenarios to demonstrate how model output can be used in conjunction with data on planetary boundaries to identify the consequences of alternative but uncertain global policy settings. Ultimately we show that continued and growing overshoot cannot be maintained indefinitely. However, even without policy to mitigate human resource demand, human choices have significant influence on the trajectory of future Ecological Footprints and the timing of impending ecological collapse.

# 2 Material and Methods

We developed an integrated, dynamic model with which to calculate global Ecological Footprints and Biocapacity under different scenarios to 2070. We interpret the findings from the model together with research on planetary boundaries (Rockstrom et al., 2009) and demonstrate how the Ecological Footprint can inform policy development.

## 2.1 The Model

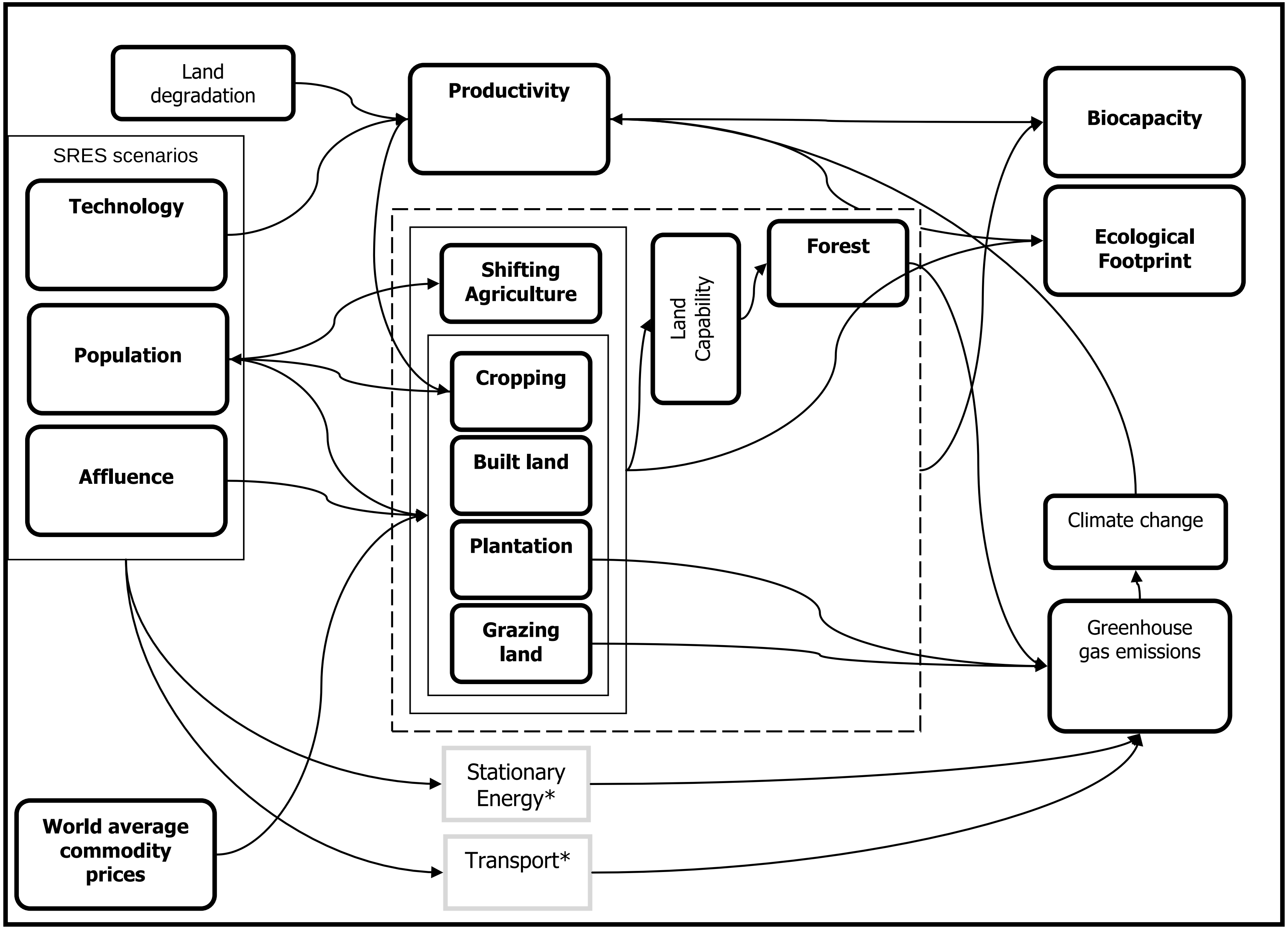
All our model variables are fully integrated into a tensor framework as outlined in Lenzen and McBain (2012). We apply an iterative finite-difference formulation representing changes in tensor variables resulting out of non-linear cause–and–effect relationships. More specifically we populate a 6-dimensional tensor structure that allows cause-and-effect to occur 1) between different variables 2) between different locations and 3) from impacts that happened in the past. In short, the model structure is a mathematical representation of a socio-ecological system that is fully interconnected in space and time. Variables are advanced in annual time steps. Global regions are represented as 116 individual countries (a full list can be found in the Supplementary Information).

The variables used were adapted from Lenzen et al. (2013) and their relationships are diagrammatically represented in Figure 1 and described in the text below. Note that we do not outline the methodology used to model stationary energy use and transport as they are outlined in detail in McBain et al. (submitted-a) and McBain et al. (submitted-b), respectively.

At its basis the model has an IPAT framework (Ehrlich and Ehrlich, 1990) where I (representing environmental impact) is taken to be the product of P (population), A (affluence), and T (technology). Rather than a linear IPAT structure, our model structure also accounts for critical feedbacks which are responsible for the system state e.g. note the pathway in Figure 1, where increasing greenhouse gas emissions leads to greater impacts on agricultural productivity which, in turn, leads to greater demand for additional land clearing which then feeds back into greater greenhouse gas emissions. It is these critical feedbacks which are commonly implicated in systems crossing thresholds (Walker and Salt, 2006).

Below we outline the individual variables and their relationships within our model. We describe the data sources used for historical validation (1980-2000) and future assessments (2015-2070) and provide further detail about the modelling approach in the Supplementary Information.

**Figure 1. The relationships outlined by the conceptual model structure are described in more detail below in the sections 2.1.1 to 2.2.**



### *2.1.1 Area cropping, grazing, plantation, shifting agriculture and built land*

Land use and land cover change the dashed box in Figure 1) is a key determinant of many environmental changes (be they atmosphere, biodiversity, water quality). It is critical for continued biotic resource provision on which human populations rely. There are many potential drivers of land use and land cover change (Rounsevell et al., 2005). Geist and Lambin (2002) and Ali (2007) document six main drivers of deforestation which are also relevant for land use change in general. The first three - demographic, economic and technological factors - form the basis of the IPAT approach. The second three - environmental, policy/institutional and socio-political/cultural - often operate within feedback loops upon IPAT making the response of LUCC more dynamic in nature.

Policy, institutional, socio-political and cultural drivers of land use change are very difficult to measure (Geist and Lambin, 2002). They tend to involve personal interactions among sometimes large numbers of people, over long periods, and incorporate different underlying divergent world views (Raskin et al., 2002, Gallopín et al., 1997, Nakicenovic and (eds), 2000). This means that they are very seldom incorporated within models but rather are accounted for by using scenarios which make defined assumptions about the future and human decisions that are made (Raskin, 2005).

### *2.1.2 Land Capability*

Land capability represents the ability of land to produce goods. For activities such as the clearing of land for agriculture it is important to account for the ability of the newly cleared land to be able to produce the agricultural goods required of it. For example, clearing a smaller area of land with high land capability will generally allow the production a greater quantity of agricultural output compared to an equivalent marginal piece of land. Therefore, a country that has already used its most fertile land is likely to require much greater relative land areas for future agricultural land expansion to produce comparable quantities of resources for its population.

### *2.1.3 Productivity*

Recent increases in agricultural production have come predominantly from yield increases rather than land expansions (Nelson and al..... 2005, Hughes and Hillebrand, 2006, Hafner, 2003). For example, between 1961 and 1991, the production of cereals more than doubled but total cropland increased by only 11% (Kemp-Benedict et al., 2002). Alcamo et al. (2005a) note that total cropland is not likely to expand significantly. Rather, increases in the demand for food are likely to be met by increases in productivity. Cropland productivity can be separated into two factors: *yield per harvest* and *cropping intensity* (the number of harvests per year on a given piece of cropland), of which yield increase are the most important contributor to increases in production in recent history (Kemp-Benedict et al., 2002).

Below we consider three drivers of crop productivity in more detail:
1. land degradation in agricultural areas;
2. technological improvements in yield; and
3. climate change.

#### **2.1.3.1 Technology**

Technological aspects of agricultural productivity change include all measures related to crop management (Ewert et al., 2005). Yields can be raised by, for example, reducing the impact of pests and diseases, increasing or supplementing inputs such as nutrients/chemicals, water and technology, adopting practices to retain soil and water, improved machinery, improved agronomic knowledge of farmers and genetic improvement (Kemp-Benedict et al., 2002, Hafner, 2003, Ewert et al., 2005)..

#### **2.1.3.2 Land Degradation**

Land degradation diminishes productivity due to falling organic soil carbon content, increased erosion rates and salinisation (UNEP, 2007). The effects of land degradation on yields are poorly understood (Kemp-Benedict et al., 2002) and tend to be measured on local rather than landscape scales. Where assessments have been made, productivity losses due to land degradation have been significant (Scherr and Yadav, 1996). The most recent global estimate of land degradation is an initiative by the GEF/UNEP/FAO project Land Degradation Assessment in Drylands (LADA) which indicated that 24% of the global land area has been degraded to some extent over the previous 22 years (Bai et al., 2008)

#### 2.1.3.3 Effect of Climate Change on Productivity

The potential impacts of climate change on agriculture include the timing of growth, flowering and maturing of crops, and the impacts of (and on) pollinators, water resources and the distribution of rainfall (UNEP, 2007). The biophysical effects of climate change on agricultural production will be positive in some agricultural systems and regions, and negative in others, and these effects will vary through time (Parry et al., 2004). Alcamo et al. (2005a) notes that the regional impacts of climate change on productivity are very uncertain due to the uncertainties associated with regional climate change patterns.

### *2.1.4 Greenhouse gas emissions from forest clearing*

The accumulated impacts of land use change is the second most important source of atmospheric carbon after fossil fuel use (Prentice et al. 2001) in (Olofsson and Hickler, 2007). The majority of carbon released from land use change originates from forest clearing.

When forest is cleared it is commonly burned after useable timber is removed from the site (Fearnside, 2000). Incomplete burning means that slash remains on the site and decays more slowly. The harvesting and burning of the site also results in significant emissions from soils (Fearnside, 2000). Timber products taken from the forest decay over varying time periods (depending on what the products are manufactured into). Emissions of greenhouse gases occur at varying times after harvesting.

### *2.1.5 Greenhouse gas emissions from grazing land*

Agricultural activity accounts for about a fifth of total greenhouse-gas emissions (McMichael et al., 2007) and livestock are the most significant source of methane emissions in recent history (Stern and Kaufmann, 1996). Methane is produced from the digestion of vegetative matter by livestock, known as enteric fermentation (de Araujo et al., 2005). Although some monogastrics (pigs and poultry) produce $CH_4$, ruminants (such as cattle, sheep, goats) are more significant producers (de Araujo et al., 2005). Emissions of $N_2O$ also result from manure management and nitrogen excretion due to the processes of nitrification (ammonium is oxidized to nitrate producing $N_2O$) or denitrification (reduction of nitrate and nitrite to produce NO, $N_2O$, and $N_2$ by bacteria) (Minami, 2006).

### *2.1.6 Greenhouse gas sequestration from forests and plantations*

Where the extent of forests is increasing, there will be net increases in carbon dioxide sequestration. Forest growth for newly established forests (and hence carbon uptake) follows a sigmoidal pattern whereby initial carbon uptake is slow but increases rapidly in the first period of growth. As forests age, their growth rate then slows so that forests approaching maturity do not take up much further carbon.

### *2.1.7 Climate Change*

We use the revised model of Meira and Miguez (2000) and Rosa (Rosa, Ribeiro, Muylaert, & de Campos, 2004) to progress net emissions of CO2, N2O, and CH4 from energy production, land clearing, livestock, and sequestration from forest growth to final global average temperature change.

The work of Harvey (2007) was used to determine the variation due to climate sensitivity - the change temperature resulting from a doubling in concentration of GHG. The mean relative standard deviation was found to be 70.5%.

### 2.1.8 Ecological Footprint and Biocapacity

.The Ecological Footprint was calculated as in Ewing et al. (2010) as the sum of built, cropping, grazing, shifting agriculture, and carbon land (in units of global hectares, gha). Biocapacity was calculated as the sum of the same land uses together with the extent of natural forest and unused non-forest.

## 2.2 SRES Scenarios

We used the IPCC SRES scenarios (Intergovernmental Panel on Climate Change, 2000) to provide exogenous data for a range of plausible futures in relation to these main drivers. The IPCC SRES scenarios were used in preference to the newer RCP scenarios because high-resolution spatial socio-economic data (GDP and population) was required as input data to the model. This is because multi-scale policy analysis often requires information where boundaries of policy interest do not necessary align with national jurisdictional boundaries.

For the purposes of this research, the choice of these particular scenarios was also a somewhat arbitrary one. It would have been equally valid to choose from a large range of possible scenario sets (Fritsche and Eppler, 2013) and decision makers wishing to investigate particular contexts would do so. The choice of the most helpful set of scenarios is a decision that depend on the aims of the actual policy question being asked. In this knowledge, we use the SRES scenarios as a demonstration of how multi-scaled scenarios are valuable in informing robust decisions.

We included three future scenarios: revised A2r, B1 and B2. In the A2r storyline population growth is high. Economic development is primarily regionally oriented and medium-low. Technological change is more fragmented and slower than in other storylines. The B1 storyline describes a medium-high global population with rapid changes in economic structures and medium income growth. There is a globally coordinated emphasis on global solutions to economic, social, and environmental sustainability. The B2 storyline describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. Global population size is low and income growth is medium. Technology growth is less rapid.

These scenarios can be used to investigate global, national and sub-national uncertainty. This is because there is no particular SRES scenario that is considered to be more likely than another. Furthermore, these scenarios do not incorporate data in relation to the implementation of any specific climate change (or, by inference, Ecological Footprint) policy change or management action. Scenarios such as this are helpful baseline to gauge future uncertainty.

Because we used exogenous data for population and affluence based on the SRES scenarios we were unable to model internal feedbacks between these variables. However, these scenarios were developed on the understanding that population, affluence and technology do not progress independently of one another but have strong influences on one another's trajectories. For example, the level of affluence is likely to change the amount of investment in, and adoption of technology. Each SRES scenario is, therefore, developed so that its internal coherence accounts for these interrelationships.

## 2.3 Planetary Boundaries

Planetary boundaries describe points at which the risk of thresholds being crossed becomes increasingly high and unacceptable in terms of human well-being and survival (Rockstrom et al., 2009). They are the lower end of an uncertainty range for each threshold estimate to ensure a precautionary and robust policy approach is taken which prioritises the safety of society in uncertain decision-making environments. How feedbacks influence the functioning of certain parts of a systems and the time between overshoot occurring and a planetary boundary being crossed is still largely unknown (Rockstrom et al., 2009). Rockstrom et al. (2009) identify two planetary boundaries directly implicated in our model – land use change and climate change.

A global mean temperature change of 2°C above pre-industrial levels is currently considered a *scientific and political* compromise/consensus to an appropriate climate change threshold after which humanity risks unacceptable, irreversible change to the climate system. Even at 2°C deleterious climate effects will be unavoidable. On this basis (Rockstrom et al., 2009) propose a climate change boundary of 350 ppm $CO_2$ concentration.

Land system changes occur slowly and incrementally and are driven primarily by agricultural expansion. About 12% of the ice-free global land surface is currently cultivated crop land. Rockstrom et al. (2009) propose a planetary boundary of no more than 15% of global ice-free land surface to be converted to crop land. In absolute terms, this is a three percent increase in cultivated crop land area from the current state of 12% (or change equivalent to a fifth greater than the initial percentage starting point). Due to minor differences in land use data used in our modelling compared to that used by Rockstrom et al. (2009) we begin with a current total cropping area of around 10% of total land area instead of 12%. For this reason we have translated the planetary boundary as a 12% increase in crop area (i.e. 0.2 * 10) and we use this percentage change in the extent of cultivated land to indicate at which point the land systems planetary boundary is crossed.

# 3 Results & Discussion

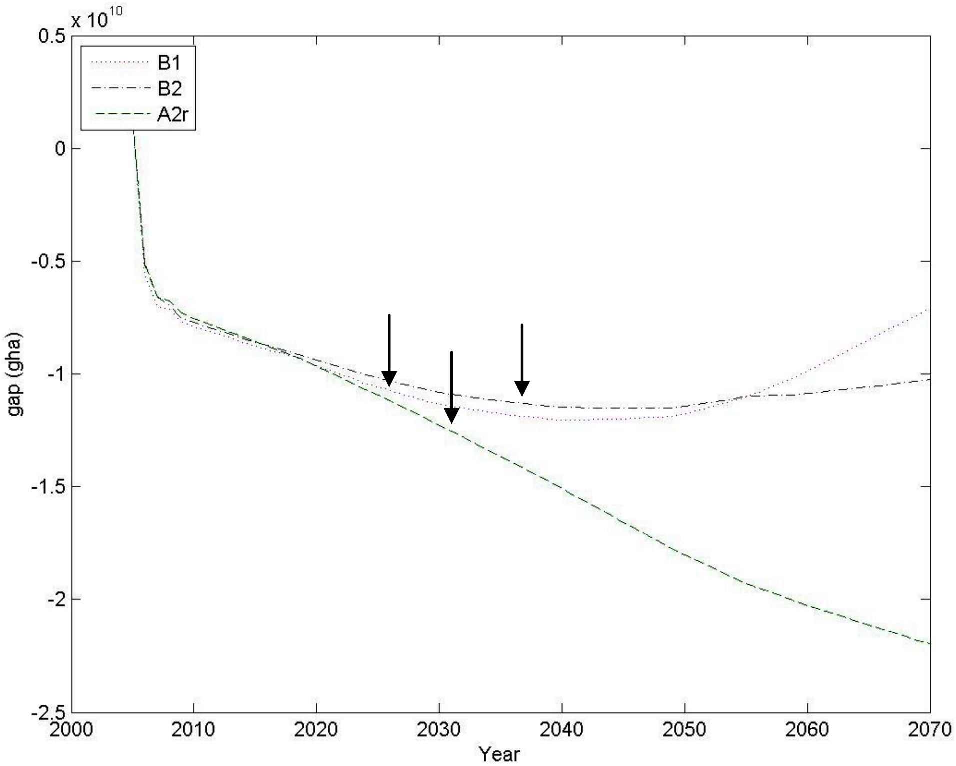
Despite increasing evidence of smaller-scale environmental thresholds being crossed around the world (Resilience Alliance database), data on the historical global Ecological Footprint overshoot (McLellan et al., 2014) shows that it is possible for humanity to extract resources at a greater rate than the planet can renew them in the short term.

This systemic inertia is typical of complex systems. Using a simple stocks and flows model (where stocks are the biocapacity of the earth, outflows are their use by human populations - the Ecological Footprint - and inflows are the renewable regeneration by natural systems), it is possible to adjust flows relatively quickly but stocks change more slowly – they act as buffers and exhibit time lags or delays in responding. (Meadows, 2008) explains: *'The presence of stocks and flows allows inflows and outflows to be independent of each other and temporarily out of balance'.* This is what gives a complex system stability.

As a result, the earth's natural systems demonstrate significant resilience by continuing to provide biotic resources at this global scale; but, as human impact cumulatively increases, questions arise as to how long these natural systems can continue to do so. The length of time ecological overshoot can continue unabated has, however, not been previously investigated. By investigating both the separate components that make up the Ecological Footprint and the Ecological Footprint as a whole, we can start to answer this bigger question.

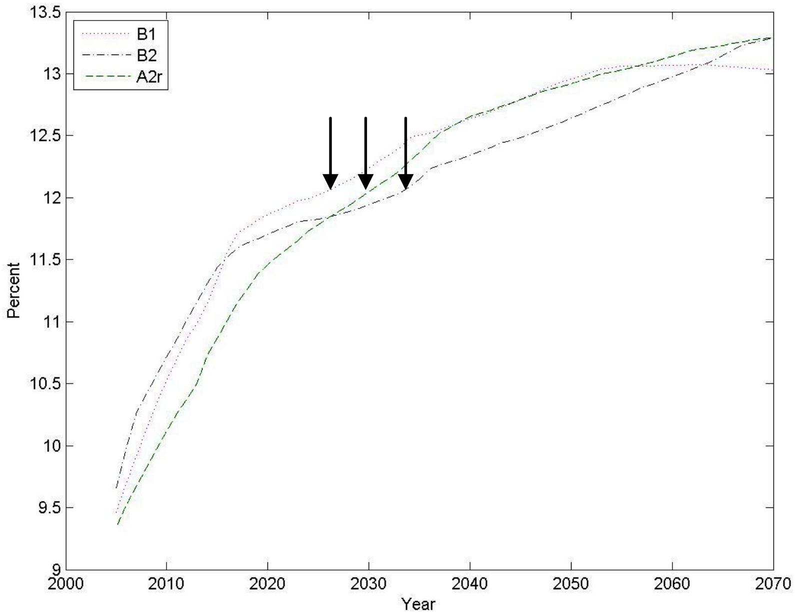
Our findings confirm the likelihood of continued and growing overshoot (Figure 2) without specific policy to mitigate resource demand. Under an A2 scenario this discrepancy continues unabated over the study period. Under a B1 or B2 scenario the discrepancy stabilises around 2050 and begins to reverse after this point (more so under a B1 scenario). The latter two results for B1 and B2 point to good news about the trajectory of future Ecological Footprints and the possibility of ending overshoot without the need for policy to mitigate human resource demand (the SRES scenarios used do not consider such policy); however, we must first investigate the separate components of the Ecological Footprint in the context of data about planetary boundaries (Rockstrom et al., 2009).

Figure 2. Global overshoot (the gap between Biocapacity and the Ecological Footprint) under three SRES baseline scenarios. The arrows indicate the point at which the planetary boundary for the expansion of cropping land is crossed.




Our findings show that the future extent of the cropping footprint is likely to be significantly more than 12% under all the future scenarios examined. The twelve percent cropping land extent occurs first in the B1 (2025) then A2r (2030s) and five years later in B2 (2035) (see arrows, Figure 3).

Figure 3. Change in global extent of cropping land as a percentage of global ice-free land area



This occurs in the context of carbon dioxide concentrations in the earth's atmosphere which have already crossed a planetary boundary of 350 ppm $CO_2$ concentration (Rockstrom et al., 2009) in the late 1980s and increase to 450, 500 and 570 ppm for B2, B1 and A2r by 2070, respectively (Figure 4a). In consequence, global temperatures increase between 1-2$^oC$ (Figure 4b) by 2070 and approach the 2$^oC$ threshold under an A2 future (a scenario with higher population growth, lower technological investment and medium-low regional economic development).

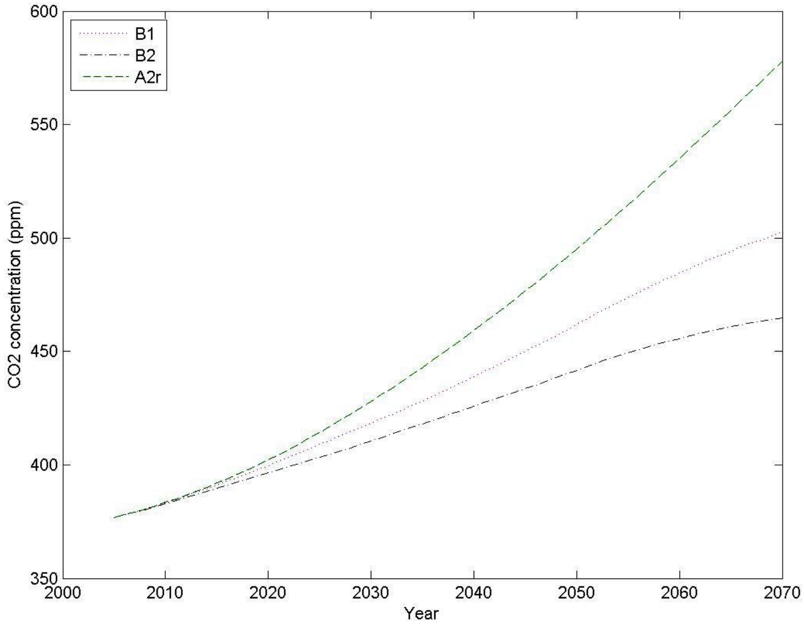
It must also be noted that the planetary boundaries proposed by Rockstrom et al. (2009); were derived in isolation from one another and presume that no other boundaries are simultaneously contravened. Simultaneous tipping points could mean that complex and unpredictable interactions between different parts of the overall Earth system are likely to change boundary values significantly. With future global Ecological Footprints unconstrained by policy, not only do we risk a trajectory that is swiftly moving towards a dangerous land clearing threshold, but we could be exacerbating this situation by, at the same time, moving rapidly towards a second climate planetary threshold, whose interaction with the first is completely unknown.

Furthermore, modelling show a high likelihood of continued expansion of agricultural and urban land at the expense of forest area. It is well known that tropical rain forests provide habitat for approximately two thirds of all species on earth (Brooks et al., 1997), making an interaction with a third planetary boundary also possible. Although the boundary position of biodiversity loss proposed by Rockstrom et al. (2009) is considered by the authors to be highly uncertain and evidence for the link between biodiversity and ecosystem services is unclear (Cork et al., 2012), it's interaction with the land systems and climate change thresholds introduces another, dangerous risk associated with the unmitigated growth of the global Ecological Footprint.

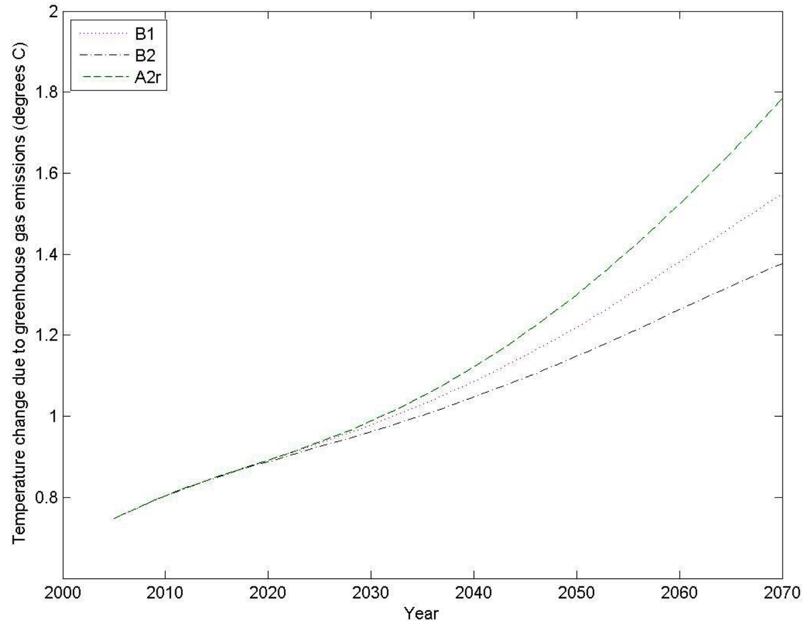
A final point must also be made in relation to the ensuing risks associated with human wellbeing and survival - that being the possibility of other threshold interactions. Due to the interconnectedness of environmental, economic and social variables in systems, Kinzig et al. (2006) have found that the crossing of one environmental threshold typically leads to the subsequent crossing of economic and social tipping points at other scales. They identified possible economic tipping points such collapses in the viability of commodity markets, farm viability and property rights, as well as social tipping points such as large-scale migration, rural town viability and individual well-being. The approach of environmental planetary boundaries due to continued overshoot will have consequences for resilience of these systems too.

Figure 4. Future global a) $CO_2$ concentrations and b) temperature change due to carbon emissions under three baseline SRES scenarios

a)




b)




Our findings indicate the value of the Ecological Footprint both in its aggregated and disaggregated form – both contribute vital but different information. As we have shown in this analysis, use of the Ecological Footprint in its aggregated form only, might have suggested that overshoot trajectories may in time be reversed without requiring specific policy to mitigate human resource demand (see trajectories for scenarios B1 and B2 in Figure 2). A disaggregation of the Ecological Footprint enabled us to incorporate data on planetary boundaries. In doing so we were able to reveal the consequences of not implementing Ecological Footprint mitigation policy i.e. the likelihood of approaching ecological collapse before more positive trajectories eventuate (see the arrow noted on each scenario trajectory in Figure 2).

Our analysis also reveals the power of aggregated indicators as compared to a reliance on single indicators such as climate change or the Carbon Footprint on their own - a trend increasingly evident in policy development (Collins and Flynn, 2015). The true risks faced by society as a result of interacting planetary boundaries would not have been revealed without combining the different landuse and carbon contributors to the overall Footprint.

# 4 Conclusion

Continued trends of increasing 'ecological debt' (McLellan et al., 2014) have implications for the resilience of humanity and increase the risk that we disturb natural systems to such a degree that we cause them to very rapidly cross irreversible thresholds to completely new and less desirous environmental states. The incremental but cumulative increase in human environmental impact means that human populations are rarely aware of the dramatic increase in risk they bear because the consequences are not clear until it is too late.

Our study shows that global ecological overshoot, although possible in the short term, cannot be maintained in the longer term. This is the first analysis to reveal when these constraints may occur under a range of equally possible, future global contexts.

Our study also reveals that a continuation of the historical global Ecological Footprint trajectory is not a fait accompli. Even in the absence of specific policies to mitigate human resource demand, the SRES scenarios show that Ecological Footprint trajectories are sensitive to the choices the global community make in relation to global economic, population and technological policy. The timing of risks society faces from global ecological collapse can vary in response to these choices. In answering the question posed in the title of this paper, the length of time ecological overshoot can continue will depend in part on the choices human societies make about global technology, population and economic trajectories.

It is important to note that modelled scenario analysis of global socio-ecological systems, like that presented here, do not constitute predictions of the future (UNEP, 2007, Alcamo et al., 2005b, Hughes and Hillebrand, 2006) – incomplete knowledge inherent in all complex issues means that it is unrealistic to expect that scientific data will ever provide high levels of certainty for decision making (Gunderson et al., 2008). The use of scenarios allow us to undertake 'what if, then' experiments (Nakicenovic et al., 2003) which paint a picture a future, not the future (Davies et al., 2001). Therefore, scenarios should not be taken as the most likely of the myriad of possible futures (UNEP, 2007). Rather than predicting the future, modelled scenario analysis can be used to enhance understanding (Clarke et al., 2008).

For local policy makers our findings and the model itself may seem to have little relevance because their influence on global trajectories is limited. However, ignoring the possibilities of larger scale impacts on the success of local policy decisions inadvertently increases the risk of local policy failure. To minimise this risk, local policy makers can 1) select policies which are likely to succeed irrespective of which global future scenario eventuates and/or 2) build policy that strategically plans to adapt and respond to changing conditions. By asking questions of themselves such as 'will my policy decision be effective under a range of plausible future scenarios' or 'what should trigger a revision of the policy approach in the future', local policy makers maximise the likelihood that their policy decisions are responsive to future global uncertainty rather than ignoring it.

Models like that presented here can be used as decision support tools (Verdon-Kidd, 2013) in conjunction with transdisciplinary decision making processes to identify areas of understanding and uncertainty associated with highly complex socio-ecological issues (Gunderson et al., 2008). They are tools that can be used to increase social learning (Keen et al., 2005) amongst collaborating decision-makers as they test their own and the model's assumptions and begin to examine alternative policy hypotheses (Gunderson et al., 2008, Randall et al., 2012).

Importantly, use of a model in transdisciplinary decision-making processes such as this does not mean that the model remains separate from the process itself. Questioning the validity of the model (Gunderson et al., 2008) and making changes to model parameters allows decision-making collaborations to customise inputs and model structure to the particular local decision making context. Local decision makers require such new, relevant tools and methods to be able to address varied end user needs. It will enable them to make more robust decisions that acknowledge rather than ignore uncertainty at multiple scales (Kiem et al., 2014).

# 5 Acknowledgements

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# Highlights

- Without the mitigation of human resource demand, the Ecological Footprint and ecological overshoot is likely to continue increasing in the future
- Continued global ecological overshoot increases the risk associated with ecological collapse with the approach of at least two planetary boundaries
- Global economic, technological and population policy have influence over the trajectory of future Ecological Footprints and the timing of impending ecological collapse
- We present a decision making tool that supports robust policy decisions which acknowledge the uncertainty of future Ecological Footprints at multiple scales