A critique of the Australian National Outlook decoupling strategy: a limits to growth perspective

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Published as Alexander, S., Rutherford, J., & Floyd, J. (2018). A Critique of the Australian National Outlook Decoupling Strategy: A 'Limits to Growth' Perspective. *Ecological Economics*, 145, 10-17. doi: https://doi.org/10.1016/j.ecolecon.2017.08.014.

1. Introduction

This paper provides a critical commentary on the high profile Australian National Outlook (ANO) Report, published in late 2015 by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Hatfield-Dodds et al., 2015a). The report's findings were also published in the prestigious, peer-reviewed journal *Nature* (Hatfield-Dodds et al., 2015c), suggesting that the conclusions are robust and should be accepted. The report argues that with collective effort and sound policy, Australia can 'achieve economic growth and improved living standards while also protecting or even improving our natural assets' (Hatfield-Dodds et al., 2015a: 12).[1] The report therefore aligns closely with a broader range of literature arguing that economic growth, no matter how environmentally damaging it has been historically, can be 'decoupled' from environmental impacts by way of technological innovation, resource efficiency improvements, pricing mechanisms, and conservation efforts (see Hatfield-Dodds et al., 2015a: 4; see also UNEP, 2011; Grantham Institute, 2013; Blomqvist et al., 2015). The findings of the report are underpinned by several scientific papers that will also be considered throughout our critique (Schandl et al., 2015; Hatfield-Dodds et al., 2015b; Hatfield-Dodds et al., 2015c; Baynes, 2015). We maintain that the ANO Report has not established a convincing case for the decoupling strategy, a conclusion that has implications beyond the Australian context.

In order to offer a balanced critique, we specifically focus on the report's most ambitious sustainability scenario (the '*Stretch*' scenario), which in effect represents the CSIRO's best case for 'green growth' via decoupling. If the *Stretch* scenario can be shown to fail from a sustainability and justice perspective, then obviously the less ambitious scenarios, which involve progressively more modest reductions in environmental impact, fail as well. After summarising the ANO Report, we outline a series of criticisms regarding major speculative assumptions contained within the *Stretch* scenario.

[1] In the supplementary material the authors note that 'environmental pressures' do not factor in the potential for critical resource scarcities. This is potentially a key oversight given emerging concerns about resource scarcity generally (Bardi, 2014), and specifically the peaking of production rates for fossil fuels in the foreseeable future (e.g. Mohr et al., 2015). As the ANO authors write: 'in most cases the modelling accounts for environmental pressures but not the state of underlying environmental assets or natural capital, and so we are not able to provide a detailed stock-based assessment of sustainability (defined as non-declining stocks of human, built and natural capital)' (Hatfield-Dodds et al., 2015c, Supplementary Methods SM-7, page 8. See: http://www.nature.com/nature/journal/v527/n7576/extref/nature16065-s1.pdf).

2. Overview of the ANO Report

The ANO Report includes 20 different scenarios for Australia's future development for the period 2010-2050, intended to provide guidance for Australian policy makers on the achievement of long-term 'sustainable prosperity.'[2] Each scenario is characterised in terms of multiple interrelated variables at both the national and global level, which together impact on sustainability outcomes. At the national level these variables include: energy and resource efficiency; agricultural productivity; individual consumption; working hours; and new land markets related to energy and ecosystem services. These national variables are then combined with four different levels of global greenhouse gas emission abatement effort (from 'no abatement' through to 'strong abatement'), to produce 20 future scenarios for Australia through to 2050. Each scenario has different environmental outcomes with respect to five main variables: greenhouse gas emissions, resource use, water stress, native habitat and biodiversity. Depending on the scenario, environmental impacts for each of these variables more than double, stabilise, or fall.

In the *Stretch* scenario, the input assumptions result in Australian GDP increasing by 2.6 times by 2050, compared with the 2015 baseline, while at the same time, dramatic absolute decoupling in carbon and resource use occurs (Hatfield-Dodds et al., 2015c: 14). From 2040 onwards Australia's net greenhouse gas (GHG) emissions fall below zero, mainly due to carbon sequestration, making Australia a 'net emissions sink, withdrawing more GHG emissions than it emits' (Hatfield-Dodds et al., 2015b: 76). This huge reduction in emissions occurs despite a continuous rise in energy demand and ongoing fossil fuel use, albeit at a lower rate than in other scenarios, but still reaching approximately double current energy supply by 2050 (Hatfield-Dodds et al., 2015c: 25). The scenario also projects a 36% reduction in Australian domestic material extractions by 2050 (Hatfield-Dodds et al., 2015c: 50). Given the economy is forecast to multiply 2.6 times by 2050 this implies almost a 70% reduction in resource use per unit of GDP. Comparative data relating to GHG emissions and energy use are presented in a series of five tables contained in an appendix to this paper, in order to illustrate the scale of, and relative contributions to, the decoupling task envisaged in *Stretch*.

Despite the ambitious nature of these decoupling projections the ANO Report claims that this decoupling strategy is feasible, but only if dramatic government policy interventions, both in Australia and globally, are implemented urgently (see also, Hatfield-Dodds et al., 2015c: 12). This is mainly in the form of carbon markets that act to give individuals and businesses strong financial incentives to change their consumption and investment choices. The scenario assumes a global carbon price of $50/tonne is implemented from 2015-2020, which then increases by 4.5% per annum to reach $236/tonne by 2050. At the same time, landholders are given a financial incentive to plant fast-growing trees on previously cleared land, in order to biosequester carbon, with payment per tonne of carbon sequestered starting at 15% below the carbon price. These policies act to incentivise five main processes that it is claimed will together achieve the decoupling outcomes reviewed above:

[2] The report defines 'sustainable prosperity' as 'economic development that improves human wellbeing and social resilience, while significantly reducing environmental risks and damage to scarce natural resources and ecosystem services' (Hatfield-Dodds et al., 2015a: 4). This definition leaves open the possibility that environmental risks and damage could be 'significantly reduced' while environmental stocks on which the economy depends continue to deplete, only at a reduced rate.

1. *Carbon-sequestration* in the form of carbon and environmental plantings[3] covering up to two-thirds of Australian land within Australia's agricultural 'intensive use zone'[4] (Grundy et al. 2016: 71);
2. *Carbon Capture & Storage (CCS)* technology applied to the coal and gas stationary energy sectors;
3. *Energy and resource efficiency* improvements across the economy;[5]
4. *Uptake of renewable energy*, for proportions of electricity and transport;
5. *Changes in individual work and consumption patterns*, such as a reduction in average working hours and a shift towards 'experiential' consumption choices (e.g. travel, eating out) that are assumed to be less energy and materially intensive.[6]

In the ANO Report the reliance on carbon capture in the form of both CCS and land, sequestration is crucial to the overall achievement of net zero or even negative emissions by 2050. Without these two strategies, the projected carbon reductions would not be possible given that all scenarios assume continued burning of significant amounts of fossil fuels through to 2050. The *Stretch* scenario, for example, still depends on over 1000 PJ in non-CCS fossil fuel use for the transport sector alone, which is only a small reduction on current fossil fuel use for transport (Hatfield-Dodds et al., 2015c: 55). The viability of these practices is thus critical to the CSIRO's decoupling strategy, as it significantly reduces the costs and problems associated with the transition away from fossil fuels and toward alternative, low-carbon energy sources.

The authors of the ANO Report argue that the above changes 'will not require a shift in societal values' (Hatfield-Dodds et al., 2015c: 52), let alone a challenge to growth-based global capitalism. Most of the changes in individual behaviour, for example, are said to result from financial incentives brought about through collective government policy. The report's lead author states that 'none of the scenarios we modelled assume change in values or a new social or environmental ethic' and it does not require 'rejecting consumerism' (Hatfield-Dodds, 2015).

Below we outline a range of reasons why the conclusions of the ANO Report are certainly not established. But even if they were, we argue that the report would still not

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[3] Carbon plantings are defined as fast growing monocultures designed to rapidly absorb carbon i.e. Eucalyptus monocultures. Environmental plantings, by contrast, are typically mixed, local native species, designed to provide maximum biodiversity services in a given area (Bryan et al., 2015: 10).

[4] The most productive Australian agricultural land, totalling 85 million ha, 'stretching from central eastern Queensland to the wheat belt of southern western Australia' (Grundy et al. 2016: 71).

[5] According to the modelling done by Schandl (2015) used by the ANO report, the 4.5% per annum resources efficiency rate is mainly driven by the carbon price, however, it should be noted that reference is also made to the need for 'additional measures at the company (product) and macro-economy level…to avoid unintended consumption growth enabled by efficiency gains' (Schandl, 2015: 47). Hatfield-Dodds et al. (2015c: 49) cite UNEP (2014) as the primary source in support of their view that 'substantial physical and economic decoupling is possible.' While UNEP (2014) provides historical evidence for absolute decoupling of water use and local air pollution from economic growth in response to policy measures including price changes, no such historical evidence in relation to resource and energy efficiency is provided. Absolute decoupling of economic growth from resource and energy use is presented as far more challenging, with complex requirements that would need to be satisfied for success.

[6] It should be noted that these changes to work and consumption patterns, which have already been underway for some time in rich countries have not led to much, if any, overall dematerialisation especially when the resources embedded within imports are taken into account (see e.g. Trentman, 2016; Wiedmann et al., 2015). That said, we agree that such changes will be important elements in the transition towards a sustainable economy. However, the analysis in this paper suggests that they will be insufficient if the commitment to ongoing growth in GDP, rising affluence and population etc. remains in place, as is taken for granted in all ANO scenarios.

have made a convincing case that 'green-growth' via decoupling is a plausible route to long-term sustainability and global justice.

3. A Critique of the ANO Report

3.1 The ANO report in historical context

Lenzen et al (2016) have shown with respect to the carbon intensity of the Australian economy that both the medium and high ANO abatement scenarios require a ten-fold acceleration in technologically driven emission intensity improvement compared to the trend rate over the last three decades. They point out that 'there was not a single country that, since 1990, has achieved technology-driven emission reductions anywhere near the level' required in those scenarios (Lenzen et al, 2016: 797). Malik et al (2016) have shown that globally over the same period increases in both affluence and population outstripped technologically driven carbon efficiency gains, resulting in rising emissions. Contrary to the CSIRO, they conclude that supply-side efficiency gains are unlikely to be sufficient to achieve safe carbon reductions and 'governments may need to actively intervene in non-sustainable lifestyles to achieve emission reductions' (Malik et al, 2016, 4722).

The same historically unprecedented gains are required with respect to resource efficiency, with *Stretch* projecting a 4.5% p.a. improvement for the global economy through to 2050. By comparison, a review of the evidence found that resource efficiency improvement from 1980-2009 averaged 0.9% p.a. (Giljum et al., 2009).[7] Furthermore, as that review, as well as a more recent UNEP (2016) report found, this efficiency improvement rate masks a more recent efficiency *decline* since the turn of the century. That is, today the global economy uses *more* resources per unit of GDP than in the year 2000. This means that, far from decoupling – even in relative terms – over the last decade and a half the global economy has undergone a process of absolute material 'recoupling'.

If we narrow the focus to decoupling trends in OECD nations, it has often been claimed that substantial relative, if not absolute, decoupling of resource use has been achieved. However, Wiedmann et al (2015) has shown that this is only true when using the 'domestic material consumption' (DMC) accounting measure which looks at natural resources consumed directly within a given nation. If instead one uses the material footprint (MF) measure, which factors in all the natural resources embedded within imports and exports, and therefore fully accounts for the impact of globalization, the picture looks very different.[8] They found, for example, that across the entire OECD for the period between 1990-2005 'no improvements in resource productivity at all are observed when measured as the GDP/MF' (Wiedmann et al, 2015: 6273).

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[7] According to figures given in Giljum et al. (2009: 328) this represented a per annum efficiency improvement that was less than one third of the rate that would have been needed for 'absolute' decoupling, i.e., growth of GDP without any increase in materials use. As such, despite the efficiency gains, between 1970 and 2010 annual global material use trebled, reaching 70.1 billion tonnes in 2010, up from 23.7 billion tonnes in 1970 (UNEP, 2016: 31).

[8] Although, it should be noted, a recent study has used a variant of the DMC methodology, comparing DMC to GDP *per capita*, rather than DMC to GDP, as has been the standard. The study looked at a subset of natural resources, which excluded fossil fuel use. When using this refined DMC methodology the study found, in a similar way to the material footprint evidence, that across the 20th century one can observe "a strong linkage between income and mass inputs, and therefore a dependency of the economic process on mass resources" (Bithas and Kalimeris, 2016: 14). In other words, very little, if any, decoupling of resource use, from per capita income was found.

3.2 Carbon budget assumptions

A fundamental critique of the ANO Report can be made in terms of its carbon budget assumptions, which risk dangerous levels of climate change, even in its *Stretch* scenario. The carbon budget used in the ANO Report is derived from the IPCC's RCP2.6 scenario that is estimated to give the world a 66% chance of staying within the 2-degree C target. For this level of risk, the IPCC (2013) calculates the mean remaining global carbon budget for 2012-2100 to be 990 $GtC0_2$. However, many scientists have grave concerns about adopting a carbon budget that may give humanity a one-in-three chance of exceeding safe warming levels (e.g. Anderson and Bows, 2011). This arguably contravenes the United Nations Framework Convention on Climate Change's own adoption of the precautionary principle (IPCC, 2001). If we were to opt for a lower level of risk, the budget would be greatly reduced. The Australian Climate Council, for example, has found that for a 75% chance of achieving the 2-degree target, the budget needs to be lowered to 672 $GtCO_2$. At the current rate of global emissions, humanity will exceed this budget by about 2030 (Climate Council, 2015). Adopting this budget would therefore require a rapid and unprecedented reduction in global emissions, at an even faster rate than the *Stretch* scenario, which, as noted, already requires an increase of ten times the emissions efficiency improvement rate, compared to recent trends in Australia (Lenzen et al, 2016).

We also note that, since the Paris Agreement on climate change, it is now internationally accepted that the 2-degree target is too risky, and that the world should be aiming to stay within the safer target of 1.5 degrees above pre-industrial levels. Again, this would reduce the available carbon budget considerably.[9]

Despite the reservations above, for present purposes we will assume the validity of the carbon budget stipulated in the ANO Report, as even that budget presents extremely thorny problems for the green growth vision.

3.3 Carbon sequestration assumptions

One of the defining elements in the ANO Report is its biosequestration assumptions. In *Stretch* this requires Australia to grow new forests on between approximately 35 to 59 million hectares (Mha) – that is between 45% to 70% of Australia's best agricultural land – in order to reach net zero or even negative emissions by 2050, despite still burning significant amounts of fossil fuels (Bryan, 2015: 17). On top of this, an additional unstated amount of land, albeit relatively small, is required to provide the projected 10% of transport fuel from biomass.

An obvious concern with carbon planting on the scale envisioned is the potential for competition with other sustainable land-use practices. A report by the Australian Climate Council (2016), summarising the recent literature on land based carbon sequestration points out the major risk of 'displacing land for food production, energy generation or conservation' (29). With regard to food, the ANO Report claims that, despite the greatly diminished land base, crop production, if not livestock,[10] can be

[9] It's true the ANO Report was published in advance of the Paris summit, and therefore cannot be expected to have anticipated its outcome, but it remains the case that the assumptions upon which the ANO Report are based are no longer in accordance with the stated objectives of the international consensus post-Paris.

[10] The technical report (Bryan, 2015: 25) shows that in both the 'biodiversity' and 'balanced' planting scenarios, beef and sheep livestock production drops dramatically over the modelled timeframe. Indeed

increased from present rates as long as trend agricultural productivity rates are maintained on the remaining one-third of land that currently produces over two-thirds of output (Hatfield-Dodds et al., 2015b: 37). There are strong reasons to doubt this claim, especially given that, as the report's authors acknowledge, the modelling only accounted for the impact of climate change on agriculture in 'a limited way' (2015b: 48). Due to uncertainties, it does not account for the negative agricultural productivity impacts that are likely to result from factors such as above-trend declines in average rainfall, changes in seasonal temperatures, and particularly increases in extreme weather events such as droughts, floods, storms (Tran et al, 2016; Qureshi et al, 2013). If, due to such factors, trend productivity agricultural rates are not achieved, then food production costs are likely to rise much higher than the ANO forecasts, with problematic social and economic flow-on effects. The authors also note that the projected provision in *Stretch* of 10% of transport energy supplied by biofuels is critically dependent on this productivity assumption, otherwise 'potential biofuel supplies are very limited' (Hatfield-Dodds et al., 2015b: 50).

The report also seems to downplay the uncertainties to which the anticipated net carbon sequestration benefits are subject. For example, the Climate Council (2016: 30) points out that large-scale carbon plantings risk causing 'carbon leakage'. For example, setting aside grazing land for carbon forests in one location may result in the clearing of forests to make grazing land available elsewhere, reducing or eliminating carbon sequestration gains. Another major concern is the risk posed by severe weather events or unanticipated climatic excursions reducing or even eliminating carbon gains. While the ANO Report has deducted fire and drought losses from its overall carbon accounting (Bryan et al., 2015), the indeterminacy of the occurrence and effect of extreme drought or fire events makes it impossible to apply conventional risk management techniques to compensate for carbon leakage from plantations back to the atmosphere (Lohmann, 2006). As such, the size of the deductions in the ANO Report cannot be regarded as better than a guess.

One deep uncertainty associated with the ANO's biosequestration strategy is how, exactly, to convert up to 59 Mha of land to biosequestration as envisaged by the ANO Report. The ANO strategy is to use financial incentives, at a rate 15% below the carbon price, to reward landowners for planting up their land with fast growing, carbon-sequestering trees. The strategic assumption here is that landowners, in this new policy context, will make economically rational decisions. While that strategy accords with the tenets of neoclassical economic theory, the practical transition is far less certain. What if farmers do not act as rational, self-interested, utility maximisers? What if farmers are content to make decisions on the basis of satisficing and simply do not want to plant up their farmland with trees? (Grubb et al., 2014). Granted, a financial incentive is likely to facilitate the uptake of biosequestration to a significant extent, but the confidence with which it is assumed that 59 Mha of land will be converted to carbon planting cannot be supported in a situation such as this in which the decision environment is characterised by both irreducible uncertainty and indeterminacy (Lohmann, 2006). It is possible, but the ANO modelling has not adequately addressed the *likelihood* of this transition occurring in reality – it has just assumed it will occur.

Figure 3 of the technical report (Hatfield-Dodds, 2015b; 43) shows that the *Stretch* scenario results in a *doubling* of livestock prices by 2050. This will surely have major social and political implications, none of which are discussed.

Finally, at the global level, *Stretch* assumes a highly optimistic cumulative land sector abatement of 56 Gt of carbon between 2010-2050 (Hatfield-Dodds et al., 2015b: 125). By contrast, a comprehensive literature review (Canadell and Schulze, 2014) found that the global potential for land sector abatement was much lower when the goal of sustainable integrated land management was taken into account. The study found that after factoring in competing future demands for food, timber, energy, and biodiversity conversation, a cumulative global emission reduction of 26-38 Gt by 2050 was the maximum realistic reduction that could be expected from land sector abatement strategies i.e. about half the reduction assumed in *Stretch.*

3.4 CCS assumptions

The ANO Report also places great faith in carbon capture and storage technology (CCS) as a means of extensively reducing carbon emissions. The technology is obviously attractive, in theory, because it holds out the hope of prolonging the consumption of coal and gas in power stations – while capturing most of the emissions – and therefore delaying the need for a transition to 100% renewable energy. There is, however, no discussion of the many unresolved problems with the technology. And even if it proves technically feasible at scale, future CCS costs are subject to such great uncertainty that it is impossible, at this stage, to assess economic feasibility in any definitive way.

The report does acknowledge that despite two decades of research and pilot projects, CCS has 'not yet been demonstrated at commercial scale'[11] (Hatfield-Dodds et al., 2015b: 50). This is not just with respect to the capturing of carbon from power plants, but also transportation via pipelines and storage in permanently safe geological sites (Scott et al., 2015; Hamilton, 2016). To date, most storage pilot projects have been abandoned because they ran into technical problems and cost blowouts (Hamilton, 2016). And yet, despite the lack of progress to date, the *Stretch* scenario assumes CCS compatible coal and gas provides 50% of both Australian and global electricity by 2050. At the global level this requires about 2,500 GW of CCS electricity generation, which seems highly optimistic (Hatfield-Dodds et al., 2015b: 54). By comparison, the IEA's (2008) most ambitious CCS implementation target, known as the BLUE map scenario, assumes about 1,500 GW of CCS compatible power generation by 2050 (IEA 2008: 69).

In addition, heavy reliance on CCS could still result in a significant release of $C0_2$ emissions, exacerbating global warming. Lenzen (2011) reviews estimates of life-cycle carbon emissions for CCS applied to coal and gas power plants and finds a realistic capture rate of 80% emissions across all CCS applications (i.e. capture, transport, injection etc.). He points out that these estimates have typically not factored in the possible contribution of carbon leakage from geological storage sites. He shows that to safely capture 1500 $GtCO_2$ – which is close to the estimated global storage capacity – requires a CO_2 leakage rate no higher than 0.01% per year. Such a low leakage rate, however, is far from certain. He notes (Lenzen, 2011: 2171) that several studies (i.e. Pehnt and Henkel, 2009) have 'emphasised the lack of knowledge and experience of underground storage and have concluded that there is no guarantee for the low leakage rate.' If the rate of leakage turns out to be significantly higher – i.e. between 0.1% to 1% per annum – the additional long-term warming effect from CCS alone would be between 0.15 C and 0.5 C.

[11] Defined as more than 500 MW rated power.

3.5 Efficiency assumptions

The ANO Report's third major decarbonisation strategy is to massively increase energy and resource use efficiency and hence productivity across the Australian economy. In *Stretch*, efficiency gains result in Australian energy demand growing at 0.6% p.a i.e. half current trend rates (Hatfield-Dodds, 2015a: 34) while global resource productivity is expected to improve at the historically unprecedented rate of 4.5% p.a through to 2050 (Schandl et al., 2015: 45). According to Schandl et al. (2015: 47) these ambitious efficiency gains are derived from the well-known 'factor-five' literature (Von Weizsacker et al, 2009; UNEP, 2014). Neither Schandl or the ANO Report, however, give any indication of how such estimates have been applied, or original substantiation of the plausibility of the case for factor-five reductions.

There are several reasons why efficiency gains, in the real world, are likely to be far less than the factor-five literature suggests. First, optimistic claims tend to overlook the implications of ongoing depletion of non-renewable resources. As the most easily accessible resource deposits are produced first, later deposits tend to require increasing time, energy and money to discover and extract. With respect to fossil fuels, this trend is reflected in the declining energy return on energy invested (EROI). Between 1995 and 2006 the global average EROI for oil and gas declined from an estimated 30:1 to 18:1 (Hall et al., 2014), with average EROI of US oil production falling to 11:1 (Murphy, 2013). Further decline in EROI is expected in coming decades, given the increasing reliance of the global economy on non-conventional, lower EROI, sources of oil and gas supply (Hall et al., 2014).[12] The impact of depletion is also evident in the mining sector with declining mineral ore grades and increasing mining waste rock and tailings evident, both in Australia and globally, resulting in higher energy, water and emission costs for mining and ore separation (Mudd, 2009; Deideren, 2009).[13] This means that even if there are efficiency gains in, say, manufacturing processes, to some extent they will be counteracted by efficiency declines in resource extraction. This situation evokes the challenge faced by the Red Queen in Lewis Carroll's *Through the Looking Glass*, who has to run faster and faster simply to stay in the same place (Likvern, 2012).

Second, enthusiastic efficiency claims about technology often attend only to the *gross* reductions, not the *net* reductions, which are often far less. Von Weizsacker et al. (2009) cite a case study claiming factor-five reductions in the ecological footprint of an Australian house, but it is not clear that embodied energy in both building and heating and cooling materials has been adequately accounted for. A recent Australian study using hybrid life cycle assessment for estimating embodied energy found that the additional materials required for heating and cooling often 'require more embodied energy than the operational costs they save' (Crawford et al, 2016: 449). Another example pertinent to *Stretch* is CCS technology which has potentially very large fuel and capital costs making it a potentially large source of future *inefficiency* (Superkar and Skerlos, 2015).

Third, optimistic efficiency projections sometimes fail to factor in the likelihood of diminishing returns over time. Ayres (2009) notes that for many decades there have

[12] Hall et al. note that the recent rapid development of tight oil production in the United States via hydraulic fracturing technology is not likely to reverse this trend (Hall et al., 2014; 146).

[13] Often overlooked is the fact, as Deideren notes, that fossil-fuel and mineral depletion will compound each other in a self-reinforcing feedback loop i.e. more energy is required to extract lower grade mineral ores which will exacerbate energy depletion, and this, in turn, will exacerbate minerals depletion given the 'huge amounts of main and ancillary equipment and consumables needed for mining' (Deideren, 2015, 9).

been plateaus for the production efficiency of electricity and fuels, electric motors, ammonia, iron and steel. While large increases are no doubt possible in certain areas, this does not imply that rapid, large and continuous technical gains can easily be made across all sectors of the economy.

These and other confounding factors, such as efficiency rebound effects (Alcott, 2005), may be mitigated by the financial incentives induced by the high carbon price in *Stretch*. The efficiency improvements that might be realised in practice are nonetheless subject to high levels of uncertainty (Sorrell, 2015). While the study *asserts* that efficiency improvements of 4.5% p.a. are achievable, it does not *demonstrate* that this is the case. The ANO study has shown that *if* certain conditions are met, positive environmental outcomes may result, but this is quite distinct from establishing a plausible case that those conditions *can* be met. We argue that the uncertainties entailed here are such that the likelihood of such an outcome *cannot* be established, and that this should be reflected in the conclusions drawn from the modelling exercise.

The ANO authors (Hatfield-Dodds et al., 2015c) conclude by stating: 'we find that substantial economic and physical decoupling is possible' (49). Such a conclusion, though, does not appear to us to be consistent with the nature of the study. On our interpretation, what the study finds is the model outcome that results when certain assumptions about resource use efficiency improvement, carbon price, CCS, etc. are extrapolated out to 2050. In other words, the study finds the consequences of those assumptions, not that those assumptions are necessarily or definitively realistic or achievable. As such, the authors clearly have not found that sustainability and growth are compatible *in practice* – that is, outside the context of the 'model world' that they have constructed. This context is essential for adequately interpreting the study's significance.

4. Two additional fundamental problems

We move now to making two further criticisms of the ANO report, which apply more generally to the wider green-growth and decoupling literature (Blomqvist et al.; 2015; Grattan Institute, 2013; Green Growth, 2016; UNEP, 2011).

4.1 Global inequality and poverty assumptions

The ANO Report omits a robust assessment of global justice concerns. We take the normative position that it is unacceptable to aim for a future situation in which only a privileged portion of the global population may enjoy the level of affluence currently afforded to rich nations. It is a similar normative assumption that leads the authors of major international reports on sustainability to assume that all nations can and should continue growing their economies and rise to roughly the same level of 'development' as those in the richest nations (e.g. UNEP, 2016). This is essentially the mainstream vision of 'sustainable development.'

The ANO Report's findings imply that a future in which billions of people remain in poverty is compatible with the authors' conception of sustainability. The authors proceed on the assumption that by 2050 three billion people will form part of the global 'consumer class' (Hatfield-Dodds, 2015a: 8), defined as that class of people with annual incomes of at least US$12,000. But this amounts to less than one fifth of the ANO's 2050 Australian per capita income, meaning that even many of those in the consumer class

will be 80% poorer than Australians. Furthermore, in the S*tretch* scenario, by 2050 global population is projected to reach 8 billion people, meaning that a further five billion would be excluded from the consumer class. These figures make it clear that the ANO Report has set itself an inadequate and unjust development goal, presumably in an attempt to make the decoupling task more manageable and avoid redistributive policies.

If the ANO report had adopted the mainstream development goal of affluence for 8+ billion then the decoupling task would obviously have become far more difficult. Tim Jackson (2009) calculates that the global economy would be 15 times larger in terms of GDP if OECD nations grow by 2% per year to 2050 with the poorest having caught up by that time. Taking into account these multiples, plus accounting for the fact that the global economy is *already* in ecological overshoot (WWF, 2016), Trainer (2016) estimates that several key environmental indices would need to be reduced to less than one twentieth of current levels per unit of GDP if the entire global population was to rise to expected Australian 2050 living standards. Compare this factor twenty reduction with the factor four decoupling rate assumed by the ANO report and which we found to be highly questionable. Clearly the rate of decoupling required for this is in the realm of fantasy (Fletcher and Rammelt, 2016; Ward et al., 2016).

If the decoupling required to realise this vision of 'green growth' is unattainable, then poverty alleviation must be addressed via redistribution of wealth and power, rather than growing the economic pie. Space does not permit a detailed engagement with this complex challenge, but there is growing literature on alternative redistributive policies that could ensure the basic needs of all are adequately met, without requiring continuous GDP growth (Hickel 2017; Trainer 2010).

Some may object that this global equity argument is based on the unrealistic expectation that the global population will achieve Australian development levels by 2050. While that may be the case, the ANO report would then need to have shown that beyond 2050, the huge amount of additional green growth needed to eliminate poverty and lift the global population to 'developed' living standards, would be consistent with environmental sustainability. But neither the report itself, nor public statements by its lead authors (see i.e. Hatfield-Dodds, 2015) have attempted to make such a case. This takes us to our final major criticism of the ANO report.

4.2 Sustainability beyond 2050

What happens after 2050? Even if the *Stretch* scenario turns out to be achievable, there are several reasons why the world as a whole would not be on a long-term sustainable path. Consider the following points:

- A major study on global decoupling potential (Schandl, 2015), which was a key source for the ANO study, and used the same carbon price assumptions, found that even the high abatement scenario (equivalent to *Stretch*), would not achieve absolute decoupling in critical domains. The study found that 'while relative decoupling can be achieved in some scenarios, none would lead to an absolute reduction in energy or materials footprint' (Schandl et al., 2015: 49).
- And yet, beyond 2050, Australia (and the world) would still have a growth economy. Ward et al. (2016) have shown that, if you extrapolate the economic growth rate in *Stretch* out to 2100 then, even with a further 50% efficiency

improvement from 2050, 'material extractions and final energy demand are up 29% and 256% respectively on 2015 levels'. In other words, the environmental reductions made over the scenario timeframe would be eliminated by 2100. They conclude that this demonstrates 'categorically that GDP growth cannot be sustained indefinitely' (Ward et al., 2016: 10)

- After 2050 the carbon-planting scheme will be declining in effectiveness, every year, as a carbon sink. After fast-growing plantations reach full maturity they will be saturated and no longer able to absorb carbon. The authors acknowledge that due to this 'saturation effect', after about 50 years the 'flow of carbon sequestration will peak and eventually decline to zero, drawing attention to challenges and opportunities, which we have not fully modelled beyond 2050' (Hatfield-Dodds et al., 2015c; Smith & Torn, 2013).[14] Combined with the fact that by 2050, if not well before, fossil fuel supply will be in decline (Mohr et al., 2015), this will necessitate a difficult and costly transition to mostly, if not entirely, renewable energy supply (Stram, 2016; Trainer; 2014; Mediavilla et al., 2013). As discussed above, this difficulty would be compounded by severely limited bio-fuel potential, given competing land demands (Canadell and Schulze, 2014).
- Globally, by 2050 world energy consumption would have risen to double present levels, inevitably placing more pressure on dwindling resources and the planet's already stressed ecological systems. By then biodiversity loss, soil degradation, ocean acidification, fish depletion, chemical pollution, among other already existing problems would most likely be exacerbated as a result of the decades of economic expansion (WWF, 2016; Rockström et al., 2009).
- And yet, according to the ANO Report, in 2050 there would be at least 5+ billion people still to be integrated into the ever expanding 'consumer class.'

In light of these points, at best the ANO Report provides us with some reason to think that limits to growth will be felt later rather than sooner, but it does not provide any good reason to think that such ecological limits can be avoided or transcended.

5. Conclusion

We have provided wide-ranging reasons for why the ANO Report, and by implication the *Nature* article, draw key conclusions that are not in fact established by the modelling study itself. Our lines of critique have focussed on the historically unprecedented decoupling rates required; misconceived carbon budget assumptions; the extraordinary proposal to plant up two thirds of Australia's best agriculture land with carbon sequestering plants, without presenting a convincing case for how to achieve this; deep reliance on CCS technology which to date is not commercially viable; and highly optimistic assumptions about resource efficiency. We have also noted the unacceptable social justice implications of the work and the fact that its claims about 'sustainability' only extend to 2050. To these criticisms, one could also add the fact that the report boldly assumes that no resource scarcity challenges will interfere with this long-term vision of economic growth. If any one of these assumptions turns out to be misconceived or unachievable, the vision of 'sustainable prosperity' defended in the report will not eventuate. Here we have presented grounds for doubting *all* of the assumptions, such

[14] By 'opportunities' the authors refer to the possibility of using the mature plantations as biofuel combined with carbon capture and storage (BECCS), but this solution, which relies on the viability of highly speculative future technology development including CCS, 'involves large risks and uncertain feasibility' (see e.g. Hansen et al., 2016: 1; Smith et al., 2016).

that cumulatively the report's conclusions must be considered, at best, not established, and, on balance, mostly likely false.

By way of conclusion, we draw attention to two key implications of this critique, which are relevant to future attempts to defend green growth by way of the decoupling strategy.

- The first is the social justice dimension. What does any particular green growth vision assume regarding inequality and global poverty? Defenders of green growth ought to make these assumptions explicit.

- The second is that green growth advocates must explain how the growth paradigm can put humanity on a longer-term path towards sustainability – a path that could conceivably be viewed as open-ended. Even if growth could be 'green' until 2050 – which we doubt – can it remain green if growth continues through to 2100 and beyond? If not, then the deep transformation beyond growth ought to be initiated without delay.

We believe that when these two aspects are brought to the surface, it becomes clear that the decoupling strategy cannot lead to a growing global economy that is just and sustainable for humanity as a whole.

6. Appendix: Comparative data illustrating the scale of, and required contributions to, the decoupling task envisaged in the Australian National Outlook's *Stretch* scenario

Emission category	2050 emissions (Mt CO2e/year)		Approx. difference, Existing Trend to Stretch
	Existing Trend (M2XR)	Stretch	
Land sector sequestration	-5	-615	+12000%
Agriculture	160	65	-60%
Waste	15	15	0%
Industrial Processes	60	50	-15%
Fugitives	55	25	-55%
Direct Combustion	210	105	-50%
Transport	140	95	-30%
Electricity	165	35	-80%
Total emissions exc. land sequestration	**805**	**390**	-50%
Proportion of total emissions from energy use (all fugitives attributed to energy use)	**70%**	**65%**	-5%
Net total emissions inc. land sequestration	**800**	**-225**	-130%

Table A1: Comparison of greenhouse gas emission rates by sector in 2050 for Existing Trend and Stretch scenarios. Emission rates are estimates from Extended Data Figure 6

in Hatfield-Dodds et al. (2015c). Figures of particular note are the increase in land sector sequestration, and reduction in electricity, transport and direct combustion emissions. See caption for Table A2 below for further commentary relating to this.

Final energy supply source/fuel type		2050 final energy supply (PJ/year)		Approx. difference, Existing Trend to Stretch
		Existing Trend (M2XR)	Stretch	
Electricity	Coal	140	0	-100%
	Gas	1170	140	-90%
	Fossil with CCS	200	740	+270%
	Renewable	310	560	+80%
	Total	1820	1440	-20%
	Proportion of total from fossil with CCS (%)	+11%	+51%	+370%
Transport fuel	Petroleum (inc. liquid fuel from gas or coal)	2030	790	-60%
	Natural gas	330	310	-5%
	Biofuel	260	310	+20%
	Electricity	160	370	+130%
	Total	2780	1780	-35%

Table A2: Comparison of energy supply rates by source/fuel type in 2050 for Existing Trend and Stretch scenarios. Energy supply rates are estimates from Extended Data Figure 2 in Hatfield-Dodds et al. (2015c). Figures of particular note are increase in electricity from fossil with CCS (both in absolute terms and as a proportion of total supply); and the overall reduction in electricity supply, despite the large increase in electricity supply for transport. Transport and electricity sector GHG emission reductions shown in Table A1 are particularly sensitive to uncertainties associated with the modelling assumptions driving these relative changes between the Existing Trend and Stretch scenarios.

Year	Australian Gross Domestic Product (A$ billion/year) ($2010 real)		Approx. difference, Existing Trend to Stretch
	Existing Trend (M2XR)	Stretch	
2010	1400	1400	+5%
2050	3550	3700	
Approx. change 2010-2050	+155%	+165%	

Table A3: Comparison of changes in Australian Gross Domestic Product from 2010 to 2050 for Existing Trend and Stretch scenarios. GDP values are estimates from Extended Data Figure 1 in Hatfield-Dodds et al. (2015c). Figures indicate the scale of the decoupling task required in order for environmental and resource use impacts to decrease over this time period.

Year	Total Australian final energy demand (PJ/year)		Approx. difference, Existing Trend to Stretch
	Existing Trend (M2XR)	Stretch	
2010	3850	3850	-20%
2050	8300	6550	
Approx. change 2010-2050	+115%	+70%	

Table A4: Comparison of changes in total Australian final energy demand from 2010 to 2050 for Existing Trend and Stretch scenarios. Energy demand is estimated from Extended Data Figure 2 in Hatfield-Dodds et al. (2015c). The substantial absolute increase in total energy demand even in the Stretch scenario implies significant sensitivity to increase in energy supply costs, and consequential impact of this on GDP growth. The economic futures envisaged in these scenarios are therefore vulnerable to uncertainties in energy supply costs.

Year	Energy productivity of Australian economy (A$ billion/PJ) ($2010 real)		Approx. difference, Existing Trend to Stretch
	Existing Trend (M2XR)	Stretch	
2010	0.36	0.36	+30%
2050	0.43	0.56	
Approx. change 2010-2050	+20%	+55%	

Table A5: Comparison of changes in energy productivity of the Australian economy from 2010 to 2050 for Existing Trend and Stretch scenarios. Data derived from Tables A3 and A4. As indicated by the high proportion of total emissions from energy use (see Table A1), achievement of GDP increase shown in Table A3, while simultaneously achieving GHG emission reductions shown in Table A1, is particularly sensitive to uncertainty in energy productivity.

7. References

Alcott, B., 2005. Jevon's Paradox. Ecological Economics. 54 (1), 9-21.

Anderson, K., Bows, A., 2011. Beyond 'dangerous' climate change: Emission scenarios for a new world. Philosophical Transitions of the Royal Society. 369, 2-44.

Anderson, K., 2015. Duality in Climate Science. Nature Geoscience. Nature Geoscience. 8, 898–900.

Ayres, R., Warr, B.U., 2009. The Economic Growth Engine: How Energy and Work Drive Material Prosperity. Cheltenham, UK and Northampton, Massachusetts, Edward Elgar.

Bardi, U., 2014. Extracted: How the Quest for Mineral Wealth Is Plundering the Planet. Chelsea Green Publishing, White River Junction.

Baynes T., 2015. Assessing the potential for a step change in energy, water and resource efficiency 2010-2015. Report for the Australian National Outlook 2015. CSIRO, Canberra.

Bithas, K., Kalimeris, P., 2016. The Material Intensity of Growth: Implications from the Human Scale of Production. Soc Indic Res, https://doi.org/10.1007/s11205-016-1401-7

Blomqvist, L., Nordhaus, T., Shellenbeger, M., 2015. Nature Unbound: Decoupling for Conservation. Oakland, Breakthrough Institute.

Bryan, B.A., Hatfield-Dodds, S., Nolan, M., McKellar, L., Grundy, J.M., McCallum, R., 2015. Potential for Australian land-sector carbon sequestration and implications for land use, food, water, and biodiversity. Report for the Australian National Outlook 2015. CSIRO, Canberra.

Canadell, J., Schulze, D., 2014. Global potential of biospheric carbon management for climate mitigation. Nature Communications. 5, 5282.

Climate Council 2015. Unburnable Carbon: Why we need to leave fossil fuels in the ground. Steffen, W., http://www.climatecouncil.org.au/unburnable-carbonwhy-we-need-to-leave-fossil-fuels-in-the-ground (accessed 16.08.2017).

Climate Council 2016. Land Carbon: No Substitute for action on fossil fuels. Steffen, W., Rice, M., Fenwick J., http://www.climatecouncil.org.au/land-carbon-report (accessed 16.08.2017).

Crawford, R., Bartak, E., Stephan, A., Jensen, C., 2016. Evaluating the life cycle energy benefits of energy efficiency regulations for buildings. Renewable and Sustainable Energy Reviews. 63, 435-451.

Diederen, A.M., 2009. Metal minerals scarcity: A call for managed austerity and the elements of hope. TNO Defence, Security and Safety. http://hcss.nl/sites/default/files/files/reports/10.03_.2009_-_Metal_minerals_scarcity_A_call_for_managed_austerity_and_the_elements_of_hope_.pdf (accessed 16.08.2017)

Fletcher, R., Rammelt, C., 2016. Decoupling: A Key Fantasy of the Post-2015 Sustainable Development Agenda. Globalisations, http://dx.doi.org/10.1080/14747731.2016.1263077

Giljum, S., Dittrich, M., Lieber, M., Lutter, S., 2014. Global Patterns of Material Flows and their Socio-Economic and Environmental Implications: A MFA Study on All Countries World-Wide from 1980 to 2009. Resources. 3, 319-339.

Grantham Institute. 2013. Halving global CO2 by 2050: Technologies and costs. http://www3.imperial.ac.uk/climatechange/publications/collaborative/halvingglobal-co2-by-2050.

Grubb, M., Hourcade, J.C., Neuhoff, K., 2014. Planetary economics: energy, climate change and the three domains of sustainable development. Routledge: London and New York.

Grundy, M.J., Bryan, B,A., Nolan, M., Battaglia, M., Hatfield-Dodds, S., Connor, J.D., Keating, B.A., 2016. Scenarios for Australian agricultural production and land use to 2050. Agricultural Systems. 142, 70–83.

Hall, C.S., Lambert G.J., Balough, B. S., (2014). EROI of different fuels and the implications for society. Energy Policy. 64, 141–152.

Hamilton, C., 2016. How to think about 1.5 degrees. The Conversation. https://theconversation.com/how-to-think-about-1-5-degrees-66412 (accessed 16.08.2017)

Hansen, J., Sato, M., Kharecha, P., Schuckmann, K.V., Beerling, D.J., Cao, J., Marcott, S., Masson-Delmotte, V., Prather, M.J., Rohling, E.J., Shakun,J., Smith, P., Lacis, A., Russell, G., Ruedy, R., 2016. Young people's burden: requirement of negative CO2 emissions. Earth System Dynamics. https://doi.org/10.5194/esd-8-577-2017

Hatfield-Dodds, S., 2015. Study: Australians can be sustainable without sacrificing lifestyle or economy. The Conversation. https://theconversation.com/study-australians-can-be-sustainable-without-sacrificing-lifestyle-or-economy-50179. (accessed 16.08.2017).

Hatfield-Dodds S., Adams P.D., Brinsmead T.S., Bryan B.A., Chiew F.H.S., Finnigan J.J, Graham P.W., Grundy M.J., Harwood T., McCallum R., McKellar L.E., Newth D., Nolan M., Schandl, H., Wonhas, A., 2015a. Australian National Outlook 2015: Economic activity, resource use, environmental performance and living standards, 1970-2050. CSIRO, Canberra.

Hatfield-Dodds, S., McKellar, L., Brinsmead, T.S., Bryan, B.A., Graham, P., Grundy, M., Harwood, T., Newth, D., Schandl, H., Wonhas, A., Adams, P., Cai, Y., Ferrier, S., Finnigan, J., McCallum, R., Nolan, M., Prosser, I., Stafford Smith, M., Battaglia, M., Baynes, T., Chiew, F., Connor, J., Geschke, A., Grigg, N., Harman, I., Hayward, J., Keating, B., King, D., Lenzen, M., Lonsdale, M., McCrae,R., Navarro Garcia, J., Owen, A., Raison, J., Reedman, L., Smith, M.H., Summers, D., Whetton, P., 2015b. Australian National Outlook 2015 – Technical Report: Economic activity, resource use, environmental performance and living standards 1970-2050. CSIRO, Canberra.

Hatfield-Dodds S., Schandl H., Adams P.D., Baynes T.M., Brinsmead T.S., Bryan B.A., Chiew, F., Graham, P.W., Grundy, M., Harwood,T., McCallum, R., McCrae, R., McKellar, L.E., Newth, D., Nolan, M., Prosser, I., Wonhas, A., 2015c. Australia is 'free to choose' economic growth and reduced environmental pressures. Nature. DOI 10.1038/nature16065.

Hickel, J., 2014. Exposing the great 'poverty reduction' lie. Aljazeera. http://www.aljazeera.com/indepth/opinion/2014/08/exposing-great-poverty-reductio-201481211590729809.html (accessed 16.08.2017)

Hickel, J., 2017. The Divide: A brief guide to global inequality and its solutions. Cornerstone: William Heinemann.

IEA 2008. Energy Technology Perspectives: Scenarios and Strategies to 2050. IEA/OECD, Paris.

IPCC 2001. Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) prepared by Working Group III: Climate Change 2001: Mitigation. 10.4.2.2 Precautionary Considerations. http://www.ipcc.ch/ipccreports/tar/wg3/index.php?idp=437 (accessed 16.08.2017)

IPCC 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker T.F., Qin D., Plattner G-K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex V., Midgley P.M., (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–30.

Jackson, T. 2009. Prosperity without growth: Economics for a finite planet. London, Earthscan.

Lenzen, M., 2011. Global Warming Effect of Leakage from CO2 Storage. Critical Reviews in Environmental Science and Technology, 41, 2169-2185.

Lenzen, M., A. Malik and B. Foran (2016) Reply to Schandl et al., 2016, JCLEPRO and Hatfield-Dodds et al., 2015, Nature: How challenging is decoupling for Australia? Journal of Cleaner Production.139, 796-798

Likvern, R., 2012. Is shale oil production from Bakken headed for a run with 'The Red Queen'? The Oil Drum. http://www.theoildrum.com/node/9506 (accessed 16.08.2017).

Lohmann, Larry., 2006. Carbon trading: a critical conversation on climate change, privatisation and power. Hällström, N., Nordberg, O., Österbergh, R., (eds.). Vol. no. 48, September, Development Dialogue. Uppsala, The Dag Hammarskjöld Foundation in cooperation with The Corner House.

Malik, A., Lan, J., Lenzen, M., 2016. Trends in global greenhouse gas emissions from 1990 to 2010. Environmental Science & Technology. 50, 4722–4730.

Mediavilla, M., Castro, C.D., Capellan, I., Miguel, L.J., Arto, I., Frechoso, F., 2013. The transition towards renewable energies: Physical limits and temporal condition. Energy Policy. 52, 297 -311.

Mohr et al., 2015 S. Mohr, J. Wang, G. Ellem, J. Ward, D. Giurco. Projection of world fossil fuels by country. Fuel., 141. https://doi.org/10.1016/j.fuel.2014.10.030

Mudd, G.M., 2009. The Sustainability of Mining in Australia: Key Production Trends and Their Environmental Implications for the Future. Research Report No RR5, Department of Civil Engineering, Monash University and Mineral Policy Institute.

Murphy., D., 2013. The implications of the declining energy return on investment of oil production. Phil. Trans. R. Soc. A. 10.1098/rsta.2013.0126

Pehnt, M., and Henkel, J., 2009. Life cycle assessment of carbon dioxide capture and storage from power plants. International Journal of Greenhouse Gas Control. 3, 49-66.

Qureshi, E.M., Hanjra, M., Ward, J., 2013. Impact of water scarcity on global food security in an era of climate change. Food Policy. 38, 136-145

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der

Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L.,. Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley J.A., 2009. A safe operating space for humanity. Nature. 461:472–475. http://dx.doi.org/10.1038/461472a

Schandl, H., Hatfield-Dodds, S., Wiedmann, T., Geschke, A., Cai, Y., West, J., Newth, D., Baynes, T., Lenzen, M., Owen., A 2015. Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions. Journal of Cleaner Production. 132, 45-56 DOI:10.1016/j.jclepro.2015.06.100

Scott, V., Haszeldine, R. S., Tett, S. F. B., Oschlies, A., 2015. Fossil fuels in a trillion tonne world. Nature Climate Change. 5, 419–423.

Smith, L., Torn, M., 2013. Ecological limits to terrestrial biological carbon removal. Climate Change. 118: 89-103.

Smith, P., Davis S.J., Creutzig, F., Fuss S., Rogelj J., McCollum D., Krey V., Grubler A. 2016. Biophysical and economic limits to negative CO2 emissions. Nature Climate Change. 6, 42-50.

Sorrell, Steve., 2015. Reducing energy demand: A review of issues, challenges and approaches. Renewable and Sustainable Energy Reviews.. 47,74-82. http://dx.doi.org/10.1016/j.rser.2015.03.002

Stram, B., 2016. Key Challenges to expanding renewable energy. Energy Policy. 96, 728-734.

Supekar, S., Skerlos, S., 2015. Reassessing the Efficiency Penalty from Carbon Capture in Coal-Fired Power Plants. Environmental Science & Technology. 49, 12576-12584.

Trainer, T., 2010. The transition to a just and sustainable world. Annandale, Envirobook.

Trainer, T., 2016. Another reason why a steady state economy will not be a capitalist economy. Real Word Economic Review. Issue no 76. . www.paecon.net/PAEReview/issue76/Trainer76.pdf (accessed 18.08.2017)

Trainer. T., 2017. Can renewables meet total Australian energy demand: a "disaggregated"approach. Energy Policy, 109 (2017), pp. 539-544

Tran, L.T., Stoeckl, N., Esparon, M., Jarvis, D., 2016. If climate change means more intense and more frequent drought, what will that mean for agricultural production? A case study in Northern Australia, Australasian Journal of Environmental Management. 23:3, 281-297.

Trentman, F., 2016. Empire of Things: How We Became a World of Consumers, from the Fifteenth Century to the Twenty-First. Harper & Collins, New York.

UNEP, 2011. Decoupling natural resource use and environmental impacts from economic growth. Nairobi: United Nations Environment Programme

UNEP, 2014. Decoupling 2: Technologies, opportunities, and policy options. http://wedocs.unep.org/handle/20.500.11822/8892 (accessed 12 June 2017).

UNEP, 2016. Schandl, H., Fischer-Kowalski, M., West, J., Giljum, S., Dittrich, M., Eisenmenger, N., Geschke, A., Lieber, M., Wieland, H. P., Schaffartzik, A., Krausmann, F., Gierlinger, S., Hosking, K., Lenzen, M., Tanikawa, H., Miatto, A., Fishman. T (Eds), Global Material Flows and Resource Productivity. An Assessment Study of the UNEP International Resource Panel. United Nations Environment Programme.

Von Weizsacker, E., Hargroves, E., Smith, K., Desha, C., Stasinopoulos, P., 2009. Factor Five: Transforming the global economy through 80% improvements in resource productivity. Earthscan, London and Sterling, VA.

Ward J.D., Sutton P.C., Werner A.D., Costanza R., Mohr S.H., Simmons C.T., 2016. Is Decoupling GDP Growth from Environmental Impact possible? PLoS ONE 11(10): e0164733.https://doi.org/10.1371/journal.pone.0164733

Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., Kanemoto, K., 2015. The material footprint of nations. Proceedings of the National Academy of Sciences. 112, 6271–6276.

WWF 2016. Living Planet Report 2016. Risk and resilience in a new era. WWF International, Gland, Switzerland.