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Professor Ross Garnaut AO
c/- Garnaut Review Secretariat
Level 2, 1 Treasury Place
Melbourne 3002 VIC

Dear Professor Garnaut,

Attached is a copy of a manuscript recently accepted for publication in the Elsevier journal *Energy Policy*, (Mitigating greenhouse: limited time, limited options, Moriarty and Honnery). We believe its contents will be of assistance in preparing the Garnaut Review.

In this paper we argue that technical solutions to climate change—improving energy efficiency, use of renewable and nuclear energy, and carbon capture and sequestration—can only be of minor importance, mainly given the limited time available to take effective climate action. Only curbing energy use, perhaps through 'social efficiency' gains, particularly in the high-energy consumption countries can provide the rapid emissions reductions needed. The social efficiency approach requires a basic rethinking in how we can satisfy our human needs with low environmental impacts. Large cuts in emissions could then occur rapidly, but only if resistance to such changes can be overcome. Particularly in transport, there are also serious potential conflicts between the technical and the social efficiency approaches, requiring a choice to be made.

Yours sincerely,

A/Prof Damon Honnery

Dr Patrick Moriarty

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4 **Mitigating greenhouse: limited time, limited options**
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19 **Abstract**
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23 Most human-caused climate change comes from fossil fuel combustion emissions. To
24 avoid the risk of serious climate change, very recent research suggests that emission
25 reductions will need to be both large and rapidly implemented. We argue that technical
26 solutions—improving energy efficiency, use of renewable and nuclear energy, and carbon
27 capture and sequestration—can only be of minor importance, mainly given the limited
28 time available to take effective climate action. Only curbing energy use, perhaps through
29 ‘social efficiency’ gains, particularly in the high-energy consumption countries, can
30 provide the rapid emissions reductions needed. The social efficiency approach requires a
31 basic rethinking in how we can satisfy our human needs with low environmental impacts.
32 Large cuts in emissions could then occur rapidly, but only if resistance to such changes can
33 be overcome. Particularly in transport, there are also serious potential conflicts between
34 the technical and the social efficiency approaches, requiring a choice to be made.
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53 Keywords: energy reductions, global climate change, social efficiency.
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4 **1. Introduction: energy and climate change**
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9 In 2005 world primary energy use was around 496 EJ (International Energy Agency
10 (IEA), Moriarty and Honnery 2007a). The UN projects the world population will grow to
11 8.32 and 9.19 billion (median values) by 2030 and 2050 respectively, compared with 6.465
12 billion at mid-2005 (UN 2006). In 2005, average per capita primary energy use globally
13 was thus about 77 GJ. However, in the US the average was 332 GJ (BP 2007), with a
14 number of countries at even higher per capita use. If by 2030 all the world's people
15 enjoyed even present US per capita energy use, total annual primary energy use would
16 then be 2762 EJ, and by 2050, 3051 EJ, over six times today's level. For comparison,
17 official estimates for global primary energy use for various scenarios in 2030 are 659-786
18 EJ (IEA 2007) and 668-816 EJ (Energy Information Administration (EIA) 2007), and for
19 2050, 800-940 EJ (European Commission 2006). Since all studies project continued
20 energy growth for the Organisation for Economic Cooperation and Development (OECD)
21 countries, they clearly expect global energy inequality to continue for many decades to
22 come.
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40 The purpose of the present research is to establish whether the threat of global warming
41 will force the world to reduce energy use, and if so, by what means. To avert dangerous
42 climatic change, the European Union (EU) proposes limiting the global temperature rise to
43 2.0 °C above pre-industrial temperatures (Bows and Anderson 2006). The
44 Intergovernmental Panel on Climate Change (IPCC) gives a 'best estimate' for climate
45 sensitivity as 3 °C with a likely range of 2-4.5 °C (Solomon et al. 2007). The IPCC survey
46 of various model results (Fisher et al. 2007) suggests that global carbon dioxide equivalent
47 (CO₂-eq) emissions by 2050 will need to be reduced by up to 85 % of their 2000 values for
48 stabilisation at 445-490 ppm—a Category 1 stabilisation target in Fisher et al. (2007)—
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4 which would give a 2.0-2.4 °C temperature rise at equilibrium above pre-industrial levels.
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6 (Following Barker et al. (2007), 'CO₂-eq' refers only to CO₂, N₂O, CH₄, and fluorinated
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8 gases.) The corresponding peaking year for CO₂ emissions alone is 2000-2015. Since CO₂
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10 levels are already 380 ppm, and non-CO₂ gases today total roughly 100 ppm CO₂-eq
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12 (Barker et al. 2007a), we are already near the upper end of this 445-490 ppm range. Even
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14 490-535 ppm CO₂-eq levels would need a 30-60 % reduction by 2050, with the CO₂
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16 peaking year 2000-2020, and the resulting equilibrium temperature rise 2.4-2.8 °C. The
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18 report also considers much higher GHG levels, but even 490-535 ppm level runs some risk
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20 of equilibrium temperature increases of 4 °C above pre-industrial, with resulting serious
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22 consequences (Parry et al. 2007).
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27 Studies of past climate have shown that abrupt climatic change can occur over the
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29 course of a decade or even a few years. Overbeck and Cole (2006) state that 'abrupt
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31 climate change in the future is inevitable', and that 'continued human forcing of climate
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33 change increases the probability of deleterious abrupt climate change'. This is important,
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35 as the IPCC (Barker et al. 2007a) note that 'if the damage cost curve increases steeply, or
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37 contains non-linearities (e.g. vulnerability thresholds or even small probabilities of
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39 catastrophic events), earlier and more stringent mitigation is economically justified.'
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41 Because of the risk of abrupt climate change, Shindell (2007) also cautions against waiting
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43 too long before acting forcefully.
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48 An important effect of increased temperatures is its effect on sea level rise. The IPCC
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50 (Solomon et al. 2007) forecast a sea level rise of between 18 and 59 cm by the year 2100.
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52 In contrast, NASA physicist James Hansen (2007) states: 'I find it almost inconceivable
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54 that "business as usual" climate change will not result in a rise in sea level measured in
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56 metres by the end of the century.' He adds that if the world warms by 2-3 °C, a rapid, non-
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58 linear and irreversible collapse of the Greenland and possibly the West Antarctic ice sheets
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4 is inevitable. His findings are supported by recent calculations suggesting that Greenland's
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6 ice sheet collapse 'could be triggered by temperatures 1 °C warmer than today's of which
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8 0.7 °C is already "in the pipeline" ' (Pearce 2007).
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11 A further uncertainty concerns the effect of any further climate change on the natural
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13 carbon cycle, specifically, the continuing ability of the oceans and the biosphere to
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15 sequester about half of CO₂ net annual emissions (Climate Institute 2007). Because of
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17 continuing climate change, some coupled carbon-climate models indicate that carbon
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19 sequestration could reverse in a warming world, with forests and soils eventually
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21 becoming an atmospheric carbon source (Jones et al. 2006). Their coupled model therefore
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23 indicates that for CO₂-only stabilisation at 450 ppm, allowable annual emissions would
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25 need to be reduced by a further 21 % compared with models that do not incorporate this
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27 feedback. Because of these carbon cycle feedbacks, the IPCC report similarly suggests that
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29 the needed reductions levels discussed above may be underestimated.
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33 It is clear that two questions are important in attempting to avert dangerous climatic
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35 change by emission reductions: by how much do we have to reduce GHG emissions, and
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37 in what time frame? Huesemann (2006) concludes that, given the high levels of
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39 uncertainty as discussed above, the precautionary principle demands that we limit
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41 atmospheric GHGs to the lowest level possible, ideally at or near their present levels i.e. at
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43 near 100 % reduction. Harvey (2007) likewise argues that we should accept only a low
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45 probability (at most 10 %) of dangerous climatic change, and consequently that
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47 atmospheric GHGs should remain near today's levels. This urgency is underlined by a
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49 recent study (Climate Institute 2007) which concluded that 'there exists evidence that the
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51 IPCC process may have led to an underestimation of the risk of greater warming and that
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53 the impacts of climate change are occurring more rapidly than previously projected.'
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4 Delaying effective response may be politically easier in the short term, but will entail
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6 higher overall costs and more eventual disruption. The more—and the longer—we
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8 overshoot, the greater the risk of irreversible adverse change, and the harder it will be to
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10 reverse emission levels. Reductions will prove progressively more difficult if the
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12 industrialising countries also get locked into high fossil fuel consumption patterns, a
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14 process well under way in China. We therefore assume here that any rise above present
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16 CO₂-eq levels carries a risk of serious adverse climate change, and that reductions in
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18 emission levels need to be made in a very few decades, not by the end of this century.
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20 Since mean temperatures have already risen 0.74 °C on pre-industrial levels, and we are
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22 already committed to about a 0.6 °C further rise from past emissions, it is likely that the 2
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24 °C EU limit is the best that can be hoped for (Riahi et al. 2006).
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29 Most of radiative forcing (about 77 %) from the emission of greenhouse gases from all
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31 sources is from CO₂, and 74 % of this CO₂ is from fossil fuel combustion and industrial
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33 processes (Barker et al. 2007a). Hence this paper will concentrate on options for CO₂
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35 reductions, particularly from fossil fuel use. We first evaluate the potential for technical
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37 measures—carbon sequestration, non-carbon energy use and improved energy
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39 efficiency—using the IPCC 2007 Mitigation report as a basis. We show that all these
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41 methods have limited mitigation potential in the time frame available. Next, we outline an
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43 alternative approach, ‘social efficiency’ improvement. Finally we argue that because of the
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45 huge unmet demand for energy in the industrialising world, any technical energy
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47 efficiency gains made would soon swamped by rising energy demand.
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2. Mitigating climate change: technical measures

Although climate change is a serious challenge that needs to be tackled without delay, a focus on mitigating climate change should not blind us to the fact that we live in a divided world, one which also faces other serious environmental, resource and political problems. All too often, researchers forget the complexity and interconnectedness of both the physical and social worlds. There are only a limited number of realistic technical approaches for mitigating the climate change effects of energy use. This section briefly examines the prospects for these mitigation options in a divided world, using the 2007 IPCC 4th Assessment Report as a basis.

The IPCC, in its Mitigation volume (Barker et al. 2007a), examined in detail the potential for carbon capture and sequestration (CCS), nuclear energy and renewable energy (RE) to reduce emissions, as well as the scope for energy efficiency in each energy-using sector. Reductions both in the short- and medium-term (to 2030) and in the longer term (up to 2100) were considered. They found that by 2030, the global economic potential for emission reductions from all sectors (including those for land use, land use change and forestry) is from 16-31 GtCO₂-eq annually, for emission taxes of up to US\$ 100/tCO₂-eq at year 2000 prices based on a 'bottom up' approach (17-26 GtCO₂-eq annually for a 'top-down' approach). This range can be compared with the estimated 2004 emissions from all sources of 49 GtCO₂-eq.

These potential reductions must also be compared with the scenario emissions in 2030 (in the absence of specific emission reduction policies) to assess the likely remaining emissions in the year 2030. The reductions above are calculated relative to the Special Report on Emission Scenarios (SRES) B2 and the similar IEA World Energy Outlook (WEO) 2004 baseline emissions. For the B2 scenario, 2030 emissions are projected at 49

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4 GtCO₂-eq/yr (Barker et al. 2007a, Table TS 15). So even in the best case, 18 GtCO₂-eq/yr
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6 would still be emitted in 2030 and in the worst case, 33 GtCO₂-eq/yr. Other SRES
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8 scenarios give even higher emissions—68 GtCO₂-eq/yr for SRES A1 B—and as the report
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10 points out, all scenarios are equally likely to occur. It is likely that reduction potentials will
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12 be higher for higher emission scenarios, but will probably be a lower proportion of
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14 projected emissions. Although the emission reduction potential for transport efficiency
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16 could be expected to be roughly proportional to total transport emissions, such is not the
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18 case for non-carbon energy sources, as many of these are resource- or cost-limited. But
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20 even if reductions are proportional, 68 GtCO₂-eq/yr would only be reduced by 22.2
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22 GtCO₂-eq/yr in the worst case.
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27 Furthermore, emissions are now rising faster than in any of the IPCC scenarios (Climate
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29 Institute 2007). The IPCC report also stresses that numerous non-economic barriers
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31 prevent the economic reduction potentials from being achieved, so actual reductions
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33 achieved for a given emissions tax will be less. Further, Hultman and Koomey (2007)
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35 point out that actual costs for new energy technologies routinely exceed estimates. Indeed,
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37 so common is this that they use the term ‘expected surprises’.
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41 How are these modelled reductions distributed globally? The IPCC Mitigation report
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43 divides the world into three categories: the OECD; the economies in transition (EIT),
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45 which include the East European countries; and the remaining countries (non-OECD/EIT).
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47 Most of the economic potential for emission reductions by 2030 with < \$US 100/tCO₂-eq
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49 emissions tax is in the non-OECD/EIT group of countries. Their overall economic
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51 reduction potential in 2030 was estimated as 8.3-16.8 for GtCO₂-eq avoided, compared
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53 with 15.8-31.1 global total. Only in the transport sector was the potential in non-
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55 OECD/EIT countries a minor part of the total (Barker et al. 2007b, Table 11.3).
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4 The only acceptable policy for very deep cuts (85 % of year 2000 emissions by 2050,
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6 for example, as discussed above) will be roughly equal emissions per capita for all
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8 countries, as advocated by the ‘contraction and convergence’ proposal (Bows and
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10 Anderson 2006). It is improbable that important industrialising countries such as China or
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12 India will permanently accept per capita emissions lower than the already-industrialised
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14 countries. It is also unlikely that these poorer countries will be prepared to accept the
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16 increased costs that reducing emissions will entail unless either OECD per capita
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18 emissions have been reduced to a level not much above their own, or the increase in costs
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20 is paid for by the OECD. OECD emissions/capita are presently much greater; in 2002, the
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22 energy-related CO₂ emissions of US/Canada, for example, were 5.3 times the world
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24 average (Sims et al. 2007, UN 2006). Industrialising countries could go even further, and
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26 demand parity in cumulative per capita emissions over the past century for CO₂ and other
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28 long-lived gases. Such an approach would require the already-industrialised countries to
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30 reduce emissions to near zero.
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36 The IPCC report projects nuclear power to increase its share of global electricity from
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38 16 % today to at best 18 % in 2030 for carbon prices up to US\$ 100/tCO₂-eq, but stresses
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40 that ‘safety, weapons proliferation and waste remain as constraints.’ Possible reductions
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42 from nuclear energy were 1.88 GtCO₂-eq. The largest RE electricity potential emission
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44 reductions in year 2030 were modelled to come from wind, hydro and bioenergy (0.93,
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46 0.87, and 1.22 GtCO₂-eq respectively). Potential CCS reductions from coal and gas
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48 electricity generation together were small at 0.81 GtCO₂-eq. All these reductions are for
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50 emission taxes of \$US 100/tCO₂-eq or less, and refer to maximum values (compared to the
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52 no-mitigation policy base scenario) for each option considered in isolation (Sims et al.
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54 2007, Table 4.19). As the IPCC report makes clear, these individual values cannot
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56 therefore be simply summed. Energy efficiency potential was seen as very large out to
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4 2030, with possible savings especially important in the buildings sector (Barker et al
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6 2007b).

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8 To be considered the solution to global warming, technology must be able to provide
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10 the reduction in GtCO₂-eq emissions needed. Assume that emissions from all sources in
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12 2030 will be 68 GtCO₂-eq, as in the SRES A1 B scenario, in the absence of climate
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14 mitigation policies. This figure seems modest, given that, as already noted, growth in CO₂
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16 emissions now outpace all SRES emission scenarios, and that the carbon intensity of the
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18 world economy has stopped decreasing (Canadell et al. 2007). From the discussion above,
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20 reductions brought about by technical means might be below 22.2 GtCO₂-eq, especially if
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22 by 2030 most reductions must come from the high-emission OECD/EIT countries. Since
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24 the residual would roughly equal present emissions in this case, it follows that the
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26 technical solutions to global warming suggested by the IPCC and others cannot deliver
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28 anywhere near the required reductions if temperature increases above pre-industrial are to
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30 be kept to around 2 °C.
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36 We have identified a large potential gap between the emissions reductions needed and
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38 what the various technology-based approaches can deliver by 2030. For example, Table
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40 4.20 (Sims et al. 2007) makes clear that potential reductions from electricity production to
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42 2030 depend not only on much replacement of old plant, but also on a large expansion of
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44 generating capacity worldwide. But if large emission reductions are required, and can only
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46 be partly met by low-carbon sources or CCS, then energy use reductions themselves, both
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48 primary and delivered, would have to produce the remaining emission reductions. This
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50 would adversely affect the introduction of low-carbon electric power, which would then
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52 only make a significant contribution in the longer term. Similarly, if few new coal- or gas-
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54 fired plants were built, any CCS would have to use mainly ‘add-on’ technology to older
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56 plants, which would both increase electricity production costs and lower efficiency
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4 (Kintisch 2007). But on the positive side, large reductions in OECD/EIT power output
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6 would enable the early closure of much carbon-intensive plant, and thus give
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8 disproportionate emission cuts.
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10 11 12 13 14 15 **3. Mitigating climate change: social efficiency** 16

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20 The preceding discussion has shown that for the crucial energy and industry sectors,
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22 emission reductions from energy efficiency, non-carbon energy and CCS will likely fall far
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24 short of that needed to avert dangerous climatic change. If so, the world will have to make
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26 do with significantly less energy use. Reductions could in principle be achieved by energy
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28 pricing, but the large cost rises necessary would be inequitable. An alternative approach
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30 would be to improve the ‘social efficiency’ of energy use, that is, the effectiveness with
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32 which a given amount of energy is used to satisfy human needs. We have appropriated the
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34 term ‘social efficiency’, because the more common term ‘energy conservation’ usually
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36 includes reductions through both technical efficiency gains as well as less use of energy-
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38 using devices. Because of the heavy emphasis on technical solutions for both our energy
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40 and climate change challenges, this approach has been seen as having only a minor role, as
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42 the IPCC report makes clear. We stress that any approach to large and rapid cuts in global
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44 energy use is likely to entail disruption—there seems no easy solution.
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50 If technical efficiency is a measure of how much output there is from a given input,
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52 social efficiency is concerned with how much social value can be derived from this output.
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54 This approach in general argues that energy demand analysis should focus on the basic
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56 needs all people have, for example for food, housing, access, sociality, exercise and new
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58 experiences, and devise new ways of meeting these demands with lowest environmental
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4 impact. Energy use is nearly always a derived demand; social efficiency shifts the focus
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6 from the energy-using equipment to the need that equipment is meant to satisfy. So first
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8 we must identify the basic human needs, then determine how the needs are to be met.
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10 Social efficiency would act directly to reduce final energy demand, and thus primary
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12 energy demand.
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15 We will illustrate how social efficiency might help by considering transport and
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17 buildings. Transport is important not only because of its high and rising share of global
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19 energy use and CO₂ emissions (IEA 2006), but also because global oil depletion could
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21 soon make big cuts in the energy derived from oil necessary. Our previous research has
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23 shown that large emission reductions for surface transport will require not only a near-total
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25 shift from the private car to public transport, but also large reductions in vehicular travel
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27 itself. To obtain the greatest benefit, expansion in public transport systems will be needed.
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29 However, emphasis must be placed on access rather than mobility, as well as policies to
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31 expand non-motorised transport, not reduce it (Moriarty and Honnery 2005, 2007b).
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33 Indeed, for deep cuts, it is likely that non-motorised transport will need to have a much
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35 larger share of total travel. In shifting to a socially efficient transport network, many of the
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37 benefits of private travel would be lost, such as privacy and the psychological benefits of
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39 driving. However, the change would bring its own benefits, including increased exercise,
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41 lower air pollution and, particularly in lower-income countries, lower traffic casualties.
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43 Drastic reductions in air travel would also be needed, and might be achieved, for example,
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45 by a shift to more local destinations for holidays.
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51 Energy use in the important buildings sector includes energy for appliances, climate
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53 control and water heating. Effecting large reductions will require less ownership and
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55 duplication of electric appliances in households, longer-lasting equipment, and, through
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57 recognition of the energy costs of absolute control of our interior environment, greatly
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4 reduced use of active cooling and heating. It will also entail a partial replacement of
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6 machine energy use by human labour—not only for non-motorised travel—which may
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8 lead to some reversal of the trend established by the Industrial Revolution. There is little
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10 scope for social efficiency improvement in industry or electricity production; energy
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12 reductions in these sectors would flow from lower industrial output (reduced
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14 manufacturing production and infrastructure) and lower power consumption of
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16 households, businesses and industry.
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24 **4. Discussion and conclusions**

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29 We have seen that deep emission reductions, if required by 2030, would require large
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31 cuts in energy use, whether by technical or social efficiency measures. This in turn would
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33 reduce the scope for low-carbon sources or CCS in the electricity generation sector,
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35 although early retirement/less use of high-emission plant would partly offset this loss of
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37 emission reduction potential. However, in the transport energy sector, technical and social
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39 efficiency approaches could themselves work at cross-purposes. If both car and air travel
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41 were greatly reduced, sales of new vehicles and planes would also decrease. Assuming
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43 world-wide reductions, not only would fleet turnover be low, but interest in, and funds for,
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45 developing radically new carbon-efficient designs would be lacking. Even if adopted for
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47 the greatly reduced fleet, the savings in CO₂-eq emissions would be minor. (On the other
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49 hand, sales of public transport vehicles would grow, allowing the share of more-energy
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51 efficient designs to rise more rapidly.) Thus, at least in transport, we may have to make a
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53 choice between social efficiency and technical efficiency.
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4 We have argued that if deep cuts are needed soon, technical solutions alone are unlikely
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6 to deliver anywhere near the reductions needed. As the IEA (2007) stresses, the primary
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8 scarcity the world faces is time. The technical energy efficiency improvements discussed
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10 in section two have a well-known ‘rebound effect’ on the resulting energy savings (Alcott
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12 2007); presumably the model results surveyed by IPCC mitigation report include this
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14 effect. But technical advances (in energy efficiency, non-carbon energy, CCS) also
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16 strengthen the belief—both in industrial and industrialising countries—that for solutions
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18 we need not look beyond technology. Since technical solutions to our problems are seen as
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20 just around the corner, presently high-consumption OECD lifestyles can be sustainably
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22 exported to the world outside the OECD. The attempt to continue present consumption
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24 patterns in the OECD sends a strong signal to all other countries with presently more
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26 modest consumption patterns to aim at OECD lifestyles.
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32 There is today a huge imbalance in energy consumption levels worldwide, itself the
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34 result of similar imbalances in per capita incomes. By OECD standards, there is thus a vast
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36 latent demand for energy-consuming goods and services. For example, most people live in
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38 countries with less than 0.02 cars/capita, compared with 0.5 or more typical of OECD
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40 countries (World Bank 2006). Air travel shows similar imbalances. An even more extreme
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42 case is annual per capita electricity consumption: in 2004 there was three orders of
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44 magnitude difference between Iceland (27.0 MWh), and Norway (24.5 MWh) on the one
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46 hand, and a dozen countries, mainly in tropical Africa, with 0.01-0.04 MWh, on the other.
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48 Even the world average is only 10 % of Norway’s per capita use (EIA 2006).
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52 Unless these inequalities continue—and the rapid growth of the Chinese and Indian
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54 economies suggest that they will not—any improvements in technical efficiency will soon
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56 be swamped by rise in the numbers and use of energy-using equipment. Indeed, this
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58 phenomenon has already being observed: between 1990 and 2004, the energy intensity of
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4 the global economy fell, but both energy use and fossil fuel CO₂ emissions continued to
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6 grow (Raupach et al. 2007). Even the modest emission reductions from energy efficiency
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8 improvements projected by the IPCC will be lost, if, as a result of the ‘demonstration
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10 effect’, world primary energy use grows faster than in the IPCC scenarios. As we have
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12 seen, the very recent global energy growth rates support this view.
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15 Our conclusion, that social efficiency must be the most important part of the solution, is
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17 based both on the limitations of available technical solutions to bring about large emission
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19 reductions in the short-term, and the recognition that energy use is a derived demand.
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21 Technical solutions have an important place—once a lower-consumption lifestyle based on
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23 social efficiency is accepted. Energy efficiency can then deliver absolute energy and
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25 emission reductions. And in the long-term the world will have to move to renewable
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27 energy sources. Whether the lifestyle changes underpinning social efficiency can be
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29 implemented in a couple of decades depends on how seriously the electorate and policy
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31 makers perceive the problem to be. Given strong political support, these changes could be
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33 rapidly implemented: Shindell (2007) has stressed that sudden climate change could help
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35 produce a more rapid positive response to the global climate challenge, as happened earlier
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37 with the discovery of the Antarctic ozone hole. Since many of the needed changes may
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39 prove unpopular with business leaders, or even the general public, there is thus no
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41 guarantee that the measures discussed here will be implemented by governments globally
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43 in a timely manner.
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49 But if they are not, we argue that effective mitigation of global climate change will not
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51 take place at all. We will be left with adapting to climate change in a world where our
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53 ability to foresee such changes will progressively diminish, along with our ability to adapt
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55 to changes, which will become more severe as the decades pass. The costs of adaptation
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4 will then fall most heavily on low-income countries least able to bear them—and who are
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6 least responsible for greenhouse emissions (Parry et al. 2007).
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