



Open Research Online

Citation

Ekins, Paul and Simon, Sandrine (2001). Estimating sustainability gaps: methods and preliminary applications for the UK and the Netherlands. *Ecological Economics*, 37(1) pp. 5–22.

URL

<https://oro.open.ac.uk/39/>

License

None Specified

Policy

This document has been downloaded from Open Research Online, The Open University's repository of research publications. This version is being made available in accordance with Open Research Online policies available from [Open Research Online \(ORO\) Policies](#)

Versions

If this document is identified as the Author Accepted Manuscript it is the version after peer review but before type setting, copy editing or publisher branding

Estimating sustainability gaps: methods and preliminary applications for the UK and the Netherlands

Paul Ekins, Sandrine Simon

School of Politics, International Relations and the Environment (SPIRE), Keele University of Kee/e Staffs. ST5 5BG, UK

Abstract

Received 7 February 2000; received in revised form 13 November 2000; accepted 15 November 2000

This paper sets out and applies a new methodology for determining whether or not economic activity is environmentally sustainable. By comparing current environmental impacts with standards of environmental sustainability, it calculates the ‘sustainability gaps’ (SGAPs) with respect to different environmental impacts. For the UK, SGAPs are computed for CO₂, SO₂ and other air pollutants. Across none of these environmental themes can current UK use of the environment be said to be sustainable. The SGAP indicators can be combined with current trends to show how long it would take, on continuation of the trends, for the sustainability standard to be attained. The paper calls this indicator the ‘Years to Sustainability’ (YS) measure. For the policy objective of sustainable development to be made fully operational, it is necessary for the concept of environmental sustainability to be clearly defined by quantitative indicators. On the basis of the indicators set out in this paper it can be judged whether economic activity is moving towards or away from environmental sustainability, and at what speed.

Keywords: Environmental sustainability; Sustainability indicators; Sustainability gap
© 2001 Elsevier Science B.V. All rights reserved.

1. Introduction

Sustainable development has become one of the core organising concepts of environmental policy. One element of this concept is environmental sustainability, which has been defined as the maintenance of important environmental functions into the indefinite future (Ekins, 1997, p. 39). Ekins and Simon (1998, pp. 54ff.) have shown how, from this definition of environmental sustainability, sustainability principles can be formulated and how, from them in turn, sustainability standards for each individual environmental impact may be derived. This paper seeks to develop this work further to demonstrate how the standards may be used to generate indicators that show in an easily comprehensible way the extent to which current development patterns are environmentally sustainable.

For the concept of environmental sustainability to be used in this way, it is necessary for the sustainability standards to be derived as far as possible on the basis of objective considerations deriving from environmental science concerning the maintenance of important environmental functions, rather than being influenced by considerations of cost or political feasibility. There are a number of criteria which determine the levels at which the environmental sustainability standards should be set. In general, the level should be such that anthropogenic impacts on the environment:

- Do not threaten critical ecosystems (e.g. pollution is kept below the ecosystems' critical loads, biodiversity is conserved)
- Do not threaten biogeochemical systems (e.g. anthropogenic emissions do not destabilise the climate or destroy the ozone layer)
- Do not have a detrimental effect on human health
- Do not harvest renewable resources faster than their rate of regeneration
- Do not deplete non-renewable resources faster than the rate of development of substitutes for them.

In cases where there is uncertainty over which ecosystems or environmental functions qualify as important, or critical, or over the appropriate standard to be applied, an approach based on the idea of 'safe minimum standards' or the Precautionary Principle would seek to avoid situations where there was a risk of irreversible changes or of immoderate costs in the future. The difference between the current level of environmental impact from a particular source, and the sustainable level of impact according to the sustainability standard, may be termed the 'sustainability gap' (SGAP). Two earlier papers (Ekins and Simon, 1998, 1999) have discussed the sustainability gap idea in general terms. This paper presents some results for the UK and the Netherlands of applying the SGAP idea to various environmental themes. Government environmental policy is often associated with targets, which may or may not be aligned with the sustainability standards. If the sustainability standard is considered too expensive or demanding politically, then perhaps a less demanding target will be set, or the timescale for achieving the sustainability standard will be lengthened, with interim targets being adopted. This seems a preferable way for political considerations to enter into sustainability policy, rather than such considerations leading to the adjustment of the sustainability standards themselves, because the trade-off between achieving environmental sustainability and other political objectives is then apparent. Where government targets are aligned with sustainability standards, these targets become 'sustainability targets'. Where they are not, they are just 'policy targets', and the gaps between current environmental impacts and the policy targets are 'policy gaps'.

This paper derives sustainability standards, policy and sustainability targets, and SGAPs for carbon emissions, and various other air emissions which degrade air quality. The criteria for sustainability set out above are discussed further in Ekins, 2000 (pp. 92ff.), but here there is only space to note a few general points. First, it can be seen that for a given environmental impact (e.g. a polluting emission) there may be different sustainability standards with respect to different criteria (e.g. a critical load for an ecosystem may be above the level that causes a detrimental effect on human health, or vice versa). For environmental sustainability overall, it is the most stringent standard that is binding. Second, environmental effects may be local, regional or global. For example, the effects of sulphur deposition, or of air quality, are local (although the emissions that give rise to them may be very non-local, and may even have come from another country), while those of carbon emissions are global. In the local case, local environmental unsustainability in some places may be compatible with local sustainability elsewhere (although care should always be taken to take into account ecosystem connections and interactions). In the global case, a particular impact can only be pronounced sustainable in the context of the aggregate impacts from everywhere else. It has not been possible to explore all these complexities in this paper. Their implications will, however, be noted where appropriate.

Section 2 looks at a number of sources of local (or regional) air pollution in the UK. Particular instances of environmental unsustainability are identified in relation to the relevant sustainability standards. However, there has been no attempt either to combine the sustainability standards across the different criteria (e.g. to compare the standards for impacts on ecosystems with those for human health), or to estimate whether synergies between impacts (e.g. different air pollutants), or the possible effects of accumulation of pollutants, imply different sustainability standards to those given. The results in Section 2 should therefore be interpreted with caution. They certainly suggest widespread unsustainability across the issues studied, but they should be regarded as indicative of unsustainability, rather than definitive as to its absolute extent. In particular the actual SGAPs quoted should be

treated as minima, and might turn out to be greater if all relevant considerations were to be taken into account.

The overall sustainability standards for environmental themes, which are not available for the UK, have been estimated in official sources for the Netherlands for a number of themes. Section 3 uses this data for the Netherlands to carry out the next stage in the development of sustainability indicators, for which the UK data are inadequate. The indicators that are derived show the extent to which development patterns in the Netherlands from 1980-1991 were environmentally unsustainable, the improvements in environmental sustainability which were achieved over this period, and the length of time, on trends then pertaining, before environmental sustainability would be reached.

Section 2 looks only at local environmental impacts. Section 3 does not make explicit the kind of approach that is necessary to derive a sustainability standard for a global impact. This is the subject matter of Section 4, with regard to carbon emissions and global climate change. Sections 2, 3 and 4 are concerned only with physical environmental impacts and SGAPs expressed in physical terms. Section 5 outlines a methodology for converting these SGAPs into monetary units. The paper does not apply this methodology in practice, which remains a task for future research, but the indicators which could emerge from such an application could give useful insights into the economic implications of seeking to achieve environmental sustainability, as well as into the sustainability performance of the economy as a whole. Section 6 concludes.

2. Various sustainability gaps for local air pollution in the UK

2.1. SO₂ emissions

Emissions of SO₂ cause important problems of air pollution and acidification. In the UK the effects on human health are now confined to some urban areas. Those on ecosystems may be local or regional. The emission reduction targets that have been agreed internationally have been driven mainly by ecosystem (critical load) considerations, but they do not yet represent sustainability standards, in that they do not yet envisage the reduction of anthropogenic sulphur depositions to levels below all ecosystems' critical loads.

The sustainability standards for SO₂ are related to both ecosystem and health effects. Table 1 includes standards for both ecosystem and health effects, but no attempt is made to compare them in order to derive an overall sustainability standard. In general, it is clearly possible for emissions overall to fall within standards of ecosystem sustainability, but for instances of unsustainable impacts on human health to remain, or for there to be no unsustainable impacts on human health, but for emissions (and subsequent deposition) to be too great for some ecosystems. Full environmental sustainability would require both sets of standards to be met. The main sources of SO₂ pollution are the power generation and industrial sectors, which in 1995 contributed 67% and 22%, respectively (DETR, 1997, Table 2.3, p. 32).

The use of coal as a fuel in the generation of electricity is a major cause of SO₂ pollution. Power generation using natural gas is sulphur-free. Various studies have focused on the cost of SO₂ abatement techniques. The costs of the main abatement techniques (not including fuel-switching) are presented in Table 1. Table 1 also presents summary results concerning the sustainability and policy gaps for SO₂ emissions. The current situation is compared with the level of the targets, and the gaps are deduced from the comparison.

The 1993 and 1998 targets of the EC Large Combustion Plant (LCP) Directive (Council Directive 88/609/EEC, as amended by Council Directive 94/66/EC) have already been reached.

It seems very likely that the 2003 target will also be reached on current policy. The year 2000 target of the UNECE Convention for Europe (UNECE) Sulphur Protocol (SSP) has already been reached. The July 2000 forecast of Cambridge metrics (CE, 2000, Table 5.3, p. 37) that 2010 UK SO₂ emissions will be 732 thousands tonnes (kt), so easily achieving the 2010 target of 983 kt.

Table 1
Sustainability standards, policy targets, gaps and abatement costs for UK SO₂ emissions^a

Current situation	Standards and targets	Policy/sustainability gaps	Information on costs ^d
1995: total UK SO ₂ emissions: 2365 kt	UNECE SSP: 80% reduction from 1980 level by 2010 (2010 target: 983 kt) <i>Intermediate targets:</i> 50% reduction by 2000 (2000 target: 2457 kt) 70% reduction by 2005 (2005 target: 1474 kt) 1999 UNECE Protocol: 2010 target: 625kt	CE forecast for 2010: 732 kt implying no policy gap Policy target for 2000 already achieved	* <i>Flue gas desulphurisation</i> sulphur removal: 85-100% cost effectiveness: (\$ t ⁻¹ S removed): 950-1100
1993: LCP SO ₂ emissions: 2329 kt 1995:LCP SO ₂ emissions: 1756 kt	LCP Directive: Emission reduction from 1980 level * by 20% by 1993 (level: 3104 kt) * by 40% by end of 1998 (level: 2328 kt) * by 60% by 2003 (level: 1552 kt)	20% reduction target achieved in 1993 40% reduction target achieved in 1998	* <i>Physical coal clean</i> sulphur removal: 25 effectiveness: (\$ t ⁻¹ S removed): 1350
Power sector forecast emissions: 2005: 363 kt 2010: 339 kt	HMIP target for 2005: 365 kt EA sustainability standard: 200-300 kt (take as 250 kt)	Policy gap for 2005: 0 kt Sustainability gap for 2005: 113 kt for 2010: 89 kt	* <i>Heavy fuel oil</i> desulphurisation sulphur removal: 80-90%; Cost effectiveness: (\$ t ⁻¹ S removed): 2500-2800
15 min mean: maximum emissions detected in the UK: Bexley: 481 ppb Belfast, E.: 569 ppb Leeds: 513 ppb Newcastle, C.: 322 ppb	EPAQS limit value: 100 ppb for SO ₂ emissions (15 min mean). To be achieved by 2005, 99.99% achieved	Exceedance of limit in: Bexley: 381 (481-100) Belfast: 469 (569-100) Leeds: 413 (513-100) Newcastle: 222 (322-100)	* <i>Gas oil desulphurisation</i> sulphur removal: 80-90%; Cost effectiveness: (\$ t ⁻¹ S removed): 2570-3100
Annual mean in UK Maximum emissions detected in the UK: Barnsley: 24 ppb Belfast: 23 ppb Grimethorpe: 23 ppb	WHO annual mean concentration: 17 ppb	Exceedance of limit in: Barnsley: 7 (24-17) Belfast: 6 (23-17) Grimethorpe: 6 (23-17)	

^a Sources: DETR, 1997, Table 2.3, p. 32; CE, 2000, Table 5.3, p. 37; HMG 1997 Table II 10.2, p. 166; DOE, 1996b, p. 172.

^b Source: Haikos, 1993, p. 25.

In December 1999 the UK Government signed a new UNECE agreement limiting UK SO₂ emissions in 2010 to 625 kt. The CE projections for 2010 indicate a gap of 107 kt with respect to this target. It is likely that even this new UNECE target will not give full protection to UK ecosystems (or those outside the UK) from UK sulphur pollution, so that further SO₂ reductions from this level are likely to be necessary if no ecosystem critical loads in the UK are to be exceeded (the sustainability standard).

- In 1996 Her Majesty's Inspectorate of Pollution (HMIP, now absorbed into the Environment Agency, EA) set a limit for the power sector of 365 kt, to be achieved by 2005 (DOE, 1996a, pp. 8-9). In 1998, having estimated that, to bring depositions of SO₂ within critical loads, power stations would have to reduce their emissions to 200-300 kt (EA, 1998, p. 11); the Environment Agency proposed bringing the achievement date forward to 2001, but this has yet to be agreed. Cambridge Econometrics' (CE) forecast in July 2000 estimated that the power sector's emissions in 2005 with current policy would be 363 kt (CE, 2000, Table 5.3, p. 37), implying a sustainability gap, but no policy gap. By 2010, when SO₂ emissions are forecast (by CE) to have fallen further, there will be a sustainability gap for the sector of 89 kt.
- With regard to human health and the sustainability standards prescribed by the UK Government's Expert Panel on Air Quality Standards (EPAQS), the UK Government admitted in its National Air Quality Strategy that 'peak concentrations are such that the level recommended by EPAQS is widely exceeded' (HMG, 1997, p. 167). The same is true for the guidelines issued by the World Health Organisation

(WHO). The exceedances are observed locally. In the case of the EPAQS limit value, only the two most remote continuous SO₂ monitoring sites in the UK recorded no exceedances in 1993-94, while the highest exceedances were recorded in Bexley, Belfast, Leeds, and Newcastle (HMG, 1997 Table II 10.2, p. 166). The WHO limit values were most exceeded in 1993-94 in Belfast, Barnsley and Grimethorpe (DOE, 1996b Table II 10.3, p. 172).

2.2. Air quality (apart from SO₂)

The UK National Air Quality Strategy has emphasised that air quality is an issue that is clearly related to sustainable development. The strategy attempts to set standards and help provide adequate measures in line with the objective in Agenda 21 to 'minimise hazards and maintain the environment to a degree that human health and safety is not impaired or endangered, and yet encourages development to proceed' (HMG, 1997, p. 4).

The substantially lower levels of some forms of airborne pollution that are experienced today in the UK, compared to earlier decades, still generate, directly or indirectly, premature mortality and chronic illness. Although much attention has focused on human health, the issue of ecosystem health, particularly related to the issue of acidification, is also of importance for sustainability. As a consequence, as noted earlier with regard to SO₂, policies related to air pollution in the UK have focused both on urban air pollution, most recently in relation to transport, and on trans-boundary pollution such as pollution by acidifying substances.

Table 2 provides a summary concerning the sustainability gaps expressed in physical units for the main air pollutants in the UK, apart from SO₂, which has already been considered. In the first column, Table 2 gives the current situation concerning air pollutants. It shows that certain towns or areas experience serious problems of air pollution. In the second column, sustainability standards are presented; they deal with levels, as defined by competent scientific bodies, that are acceptable for human health. The targets given in column 3 are the policy targets set by the government. In some cases, they correspond to the sustainability standards; in other cases, the sustainability standards, as scientifically defined, are more stringent than the targets. The sustainability gap and the policy gap (the physical difference between the current situation and the sustainability standard and policy target, respectively) are calculated in the last two columns. Clearly the significance to be attached to these gaps depends on the accuracy with which the air quality has been measured and the representativeness of the site where the monitoring station is located.

It should be noted that ecosystem sustainability standards are not considered in Table 2. Nor are possible synergistic effects between different pollutants, or the possible implications of the accumulation of pollutants. These issues would, of course, need to be taken into account in any overall sustainability assessment. DETR, 1998, discusses the complexities involved in the development of an overall indicator of air pollution concentrations. This looks forward to the kinds of aggregate indicators used in Section 3 to derive more complete SGAPs for environmental themes in the Netherlands, but which are not yet available for the UK.

Table 2 shows that:

- For carbon monoxide: the EPAQS target of 10 ppm as a rolling 8 h average corresponds to a sustainability standard. The biggest exceedance of this limit is observed in Belfast (HMG, 1997, Table II 5.2, p. 102).
- In 1995, the UK had made some progress in reducing the emissions of VOCs, although further reductions had to be made if the 1999 limit of the UNECE VOCs protocol was to be achieved. In the specific case of benzene, the highest SGAP in 1995 was in Southampton (DETR, 1997, Table 2.24b, p. 52). For butadiene 1,3, on the other hand, no SGAP is observed.
- For O₃, the highest 8 h mean concentration (in Lullington Heath) exceeds the target/standard of EPAQS (HMG, 1997, Table II.8.3, p. 141) and the WHO standard; a 66% reduction is still needed to meet the EPAQS standard.

Table 2
Sustainability standards, targets and gaps for air quality^a

Air quality	1995 situation (or date given)	Sustainability standard	Policy target	Sustainability gap (SGAP)	Policy gap (PGAP)
CO	CO total emissions: 5478 kt Highest maximum 8 h rolling average: Belfast centre: 14 ppm	<i>EPAQS</i> : 10 ppm as a rolling 8 h average concentration	In 1997, <i>EPAQS</i> standard adopted as an objective to be achieved in 2005	Belfast: SGAP 4 ppm in 1995 (three periods when the 8 h concentration of 10 ppm were exceeded)	Belfast: PGAP 4 ppm in 1995 (three periods when the 8 h concentration of 10 ppm were exceeded)
VOCs general	VOCs emissions: 2634 kt in 1988; 2201 kt in 1995. Forecast for 2010: 1320 kt	See specific cases benzene and 1,3-butadiene	<i>UNECE VOCs protocol</i> , reduce by 30% from 1988 to 1999; reduce to 1200 kt by 2010		16% reduction by 1995 PGAP of 120 kt forecast for 2010
VOCs: benzene	Highest concentration: Southampton: 2.4 ppb	<i>EPAQS</i> : standard of 1 ppb, as a rolling annual mean	<i>EPAQS</i> standard adopted; objective to achieve it by 2005	Southampton: SGAP 1.4 ppb	For no PGAP, reduce SGAP to 0 by 2005
VOCs:1,3-butadiene	Highest concentration: Southampton: 0.5 ppb	<i>EPAQS</i> : standard of 1 ppb, as a rolling annual mean	<i>EPAQS</i> standard adopted; objective to achieve it by 2005	No SGAP	No PGAP
O ₃	Highest 8 h mean concentration: Lullington Heath: 126 ppb	<i>EPAQS</i> : standard of 50 ppb, as a rolling 8 h mean. <i>WHO</i> : ground levels: 60 ppb 8 h mean	<i>EPAQS</i> standard adopted; objective to achieve it by 2005. <i>Ozone EC Directive</i> . One hour mean concentration: 90 ppb	50 and 60 ppb (8 h mean) widely exceeded in every year in which monitoring has taken place. 66% reduction needed to meet <i>EPAQS</i> standard	50 ppb (8 h mean) and 90 ppb (1 h mean) exceeded in every year in which monitoring has taken place. 66% reduction needed to meet <i>EPAQS</i> standard
Lead	Highest concentration (ng/m ³): Imperial Metal Industries 2: 1020	<i>WHO</i> 's guideline: 500 ng/m ³ (annual average)	<i>WHO</i> guideline adopted; objective to achieve it by 2005	Highest SGAPs (ng/m ³): Imperial Metal Industries 1:200 Imperial Metal Industries 2: 520	For no PGAP, reduce SGAP to 0 by 2005
PM ₁₀	Highest concentrations 24 h: Belfast: 395 µg/m ³	<i>EPAQS</i> limit: standard of 50 µg/m ³ as a rolling 24 h mean	<i>EPAQS</i> standard adopted; objective to achieve it by 2005	Highest SGAP: Belfast: 345 µg/m ³	For no PGAP, reduce SGAP to 0 by 2005
NO ₂	Highest hourly mean concentrations: Central London: 101 ppb (98th% ile) and 44 ppb (50th% ile); annual mean 47 ppb	<i>EC Guide</i> values for hourly mean: 70.6 ppb (98th% ile); 26.2 ppb (50th% ile) <i>WHO</i> guide: 21–26 ppb an mean <i>EPAQS</i> : 21ppb annual mean	The <i>EC directive 85/203</i> : limit for hourly mean concentrations of 104.6 ppb (98th% ile). <i>EPAQS</i> : 21 ppb annual mean. Both to be achieved by 2005	SGAP of 30.4 ppb (98th% ile) and 17.8 ppb (50th% ile) in Central London	There are currently wide exceedances of the 2005 policy targets

- The WHO standard for lead has been adopted as a target. Some SGAPs can still be observed. The highest located at a measurement site (Imperial Metal Industries/site 2) exceeds the standard by 520 ng/m³ (DETR, 1997, Table 2.18, P- 45).
- The highest exceedance of the sustainability standard (and policy target) for PM₁₀ is observed in Belfast (DETR, 1997, Table 2.10, p. 37).
- The sustainability standards for NO₂ emissions are more stringent than the targets adopted. The highest hourly concentrations (98th per-centile) are observed in London (HMG, 1997, Table II.7.2, p. 115), where both the sustainability standard and the policy targets are most often exceeded.

3. From 'sustainability gaps' to 'years to sustainability'

Adriaanse (1993, p. 75) defines sustainability as either a 'no-effect level' or a 'no-major-effect level' of environmental impact. His approach involves aggregating measures of environmental stress into 'theme equivalent units' for different environmental themes, and normalising these units of stress in terms of a sustainability standard. Space precludes detailed examination of the approach here, but it has been used by the Netherlands Government in its National Environmental Policy Plans. Some of Adriaanse's results are laid out in Table 3. Columns 1 and 2 of Table 3 show Adriaanse's calculations of various stresses across seven environmental themes in the Netherlands for 2 years, 1980 and 1991, measured in various 'theme equivalent' units. Column 3 (ibid., p. 76) gives the sustainability standards he derived according to the definition above (ibid., pp. 78ff). Column 4 gives the 'normalised' stress according to the methodology advocated by Adriaanse, whereby the individual environmental stresses are weighted by the sustainability standards, converting the different environmental theme units (Ceq etc.) into a common unit, here called Environmental Pressure equivalent units (EPEq) (ibid., Table 603, p. 146). Column 6 gives the implied normalised sustainability standards. Because of the way the weighting has been carried out this standard is 100 for each theme, so that the total normalised sustainability standard across the six themes is 600 EPEq.

Table 3
Various sustainability measures for the Netherlands^a

	Environmental stress, (ES) various units		Sustainability standard (SS)	Normalised environmental stress, EPegs (100*ES/SS)		Implied normalised SS, EPeg	Years to sustainability (YS)
	1980	1991		1980	1991		
Climate change, Ceq	286	239	10	2390	100	54	
Ozone depletion, Oeq	20000	8721	0	na	na	8.5	
Acidification, Aeq	6700	4100	400	1025	100	16	
Eutrophication, Eeq	302	273	86	317	100	71	
Dispersion, Deq	251	222	12	1850	100	80	
Waste disposal, Weq	15.3	14.1	3	470	100	102	
Disturbance, Neq	46	57	9	633	100	Never	
Total	Na	Na	Na	7999	600	51	
				7488 ^b	500	43	

^a Source: Own calculations from Adriaanse, 1993.

^b This total line has had the figures for disturbance removed to show the effect of an increasing time trend on the total YS figure.

The final column computes the number of years before sustainability will be reached if the trend established in 1980-91 is extrapolated linearly, both for the individual environmental themes and for all the themes together. It can be seen that the overall sustainability standard of 600 EPeg will be reached after 51 years, although individually climate change, eutrophication, dispersion and waste disposal will still not have reached their sustainability level by then.

Finally it can be seen from Table 3 that the various measures cannot all be derived for all the environmental themes. For ozone depletion, the sustainability standard of 0 means that no figure for normalised stress can be derived, although there is no problem computing the Years to Sustainability. For disturbance the increasing trend from 1980-91 means that no figure for YS can be given. However, in this case there is no problem with normalising the stress, and the increasing trend is factored into the total normalised figures, increasing the length of time before sustainability overall will be reached (removing disturbance from the total actually reduces the time before sustainability is reached to 43 years).

In Table 4 the first three columns are repeated from the previous table, but the next two columns go beyond Adriaanse to calculate the 'sustainability gap' (SGAP) for each theme for each year, where SGAP is the distance in theme equivalent units between current conditions and the sustainability standard. Thus in the SGAP columns the standard is subtracted from the

stress for each year. The next two columns normalise this SGAP as shown, in the manner suggested by Adriaanse but not actually calculated by him. It can be seen that the NSGAP for climate change, for example, was reduced by 17% from 1980-91, while that for disturbance increased by 30%. The total NSGAP was reduced by 18% over this period. The final column again gives the years required to reach the sustainability standard (to reduce SGAP and NSGAP to zero) given the trend established from 1980-91. The YS is the same irrespective of whether individual or normalised units are used.

Both the normalised SGAP (NSGAP) and Years-to-Sustainability (YS) indicators give useful information on the achievement of sustainable development. Normalising the SGAP figures into the arbitrary units of 'environmental pressure equivalents' of NSGAP permits them to be aggregated across themes into a total NSGAP. As shown in the tables, this then enables an index number to be derived showing overall progress towards sustainability and a Years-to-Sustainability indicator to show how long it will be on current trends before overall sustainability (though not sustainability for each theme, which can only be derived from the individual theme indicators) will be achieved.

4. UK sustainability in terms of carbon emissions

4.1. Introduction

Section 2 calculated UK SGAPs for individual air pollutants with a local and regional impact. This section now explores the concept of the SGAP for the UK in respect of a global pollutant, CO₂. CO₂ is only one of a number of greenhouse gases (GGs), although it is the most important, and is estimated by the IPCC to be responsible for 70% of projected global warming (Houghton et al., 1996, p. 40). In the UK its share has been calculated to be even higher: 79% in 1990, and projected to rise to 85% by 2010 (DETR, 2000, Table 1, p. 46), so there is some justification in only focusing on CO₂ in the first instance, as is done here.

However, it may be noted that in the sustainability analysis that follows what is identified as a sustainable trajectory for UK carbon emissions will only be so if other greenhouse gas emissions are being abated to a similar extent.

One of the core requirements of environmental sustainability is the prevention of the disruption of climate stability by human activities. Such stability depends on the atmospheric concentration of greenhouse gases (GGs), which is affected by the total global emissions of these gases.

Maintaining climate stability is the fundamental objective of the Framework Convention on Climate Change (FCCC), which set aspirational CO₂ emissions targets for 2000 and, with the Kyoto Protocol, targets for a basket of six GGs (expressed as CO₂-equivalents) by 2010. These targets are less stringent than potential sustainability standards for CO₂ emissions, as will be seen below.

4.2. UK policy targets

Much effort has been put into finding measures to reduce CO₂ emissions, as well as calculating the cost of reducing the gap between the projected emissions for 2010 and the target. The second column of Table 5 summarises a range of CO₂ reduction measures which have been put forward, as well as estimates of costs associated with the implementation of these abatement methods and technologies. It will be noted that a number of the abatement options have negative marginal costs, implying that reducing carbon emissions through these options will increase economic efficiency as well as reduce environmental impacts.

Table 4
Various sustainability measures for the Netherlands^a

	Environmental stress (ES)		Sustainability standard (SS)	Sustainability Gap (SGAP)		Normalised SGAP (100*SGAP/SS), Epeq	Years to sustainability
	1980	1991		ES-SS	1980		
Climate change, Ceq	286	239	10	276	229	2760	54
Ozone depletion, Oeq	20 000	8721	0	20 000	8721	100 ^b	8.5
Acidification, Aeq	6700	4100	400	6300	3700	1575	16
Eutrophication, Eeq	302	273	86	216	187	100	71
Dispersion, Deq	251	222	12	239	210	1992	80
Waste disposal, Weq	15.3	14.1	3	12.3	11.1	100	102
Disturbance, Neq	46	57	9	37	48	100	Never
Total	na	na	na	na	na	7399	51
						100	82

^a Source: Own calculations from Adriaanse, 1993.

^b The second entry in this column has converted the NSGAP to index numbers, with 1980 = 100.

The first column of Table 5 presents information about the atmospheric concentration of CO₂, and UK CO₂ emissions in relation to various possible sustainability standards and policy targets.

- The fundamental standard for environmental sustainability with respect to the climate is the highest level of atmospheric concentration of CO₂ that is compatible with climate stability. There is considerable uncertainty about this level. It would be safest to set a sustainability standard of the pre-industrial CO₂ concentration (280 ppm). If the calculation of the gap is based on the sustainability standard of returning to this level of concentration, which would require immediate and very great reductions in global CO₂ emissions, the sustainability gap would be 78 ppm CO₂ (Houghton et al, 1996, Table 1, p. 15, gives the 1994 atmospheric concentration of CO as 358 ppm.)
- The first target of FCCC was to return CO₂ emissions to their 1990 level by the year 2000. Recent projections (DETR, 2000, Table 1, p. 46) suggest that this will be achieved, so that the gap against this target is 0 mtC. The Kyoto Protocol to FCCC, agreed in December 1997, has committed the UK to a reduction of 12% in the six scheduled GGs, one of which is CO₂, by 2010. Again, recent projections (DETR, 2000, Table 1, p. 46) suggest that this will be achieved.

- The UK government has set an aspirational policy target of reducing CO₂ emissions by 20% from 1990 levels by the year 2010. Comparing this target with the level of emissions projected by the UK government for that year (DETR, 2000, Table 1, p. 46), the policy gap is 22 mtC.

4.3. Global CO₂ considerations

The UK government's 20% CO₂ reduction target is motivated by a perception that CO₂ emissions will be constrained beyond the 2008-2012 commitment period of the Kyoto Protocol, and a desire to be prepared for these constraints. It is not, and does not pretend to be, a sustainability target.

Because GGs have a global environmental effect, to be sustainable UK GG emissions must be compatible with a sustainable overall global emissions level. Calculating UK sustainability in terms of carbon emissions therefore entails the calculation of the sustainable global level of emissions and the UK share of this level.

The objective of the Framework Convention on Climate Change (FCCC) is "the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system ... within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (quoted in Vellinga and Grubb, 1993). Precisely what this means in terms of the atmospheric concentration of GGs like CO₂ and methane is not spelt out. The most that could be done to meet the objective would be to return GG concentrations to their pre-industrial levels before significant climate change gets under way. Given that global CO₂ emissions would immediately have to fall very sharply to achieve this, and in fact are still rising, this is not generally to be a feasible objective.

However, it may be possible to satisfy the sustainability requirement of climate stability by limiting both the absolute global temperature increase (affected by the cumulative total of emissions) and the rate of warming (affected by the rate of emissions). The global temperature appears not to have varied by more than 1°C in a century during the last 10 000 years, and the average global temperature during the last ice age was only 5°C below pre-industrial levels. The IPCC has concluded that a rate of warming of 0.1 °C per decade (about half current rates) is probably the maximum over time that many ecosystems could tolerate (IPCC, 1990, quoted in Hadley Centre, 1995, p. 11). In the absence of any more definitive information, these may be taken as the sustainability standards for the rate and level of global temperature increase to 2100.

Table 6 shows that a 'sustainable' level of cumulative carbon emissions (one that is consistent a 1°C warming limit) is 295 GtC (assuming anti-deforestation measures). This should be put in a context of already identified, economically recoverable fossil fuel reserves of over 1000 GtC and carbon emissions to 2100 that, without CO₂ reduction policies, are likely to be 1500 GtC (Hare, 1997, Table 5, p. 10, and Table 8, p. 13, derived from Houghton et al., 1996). Clearly, climate stability will require much fossil fuel that has already been discovered not to be burned over the next 100 years, as a result of very substantial efforts at carbon reduction.

The conversion of a 100-year carbon budget to interim targets requires modelling using another whole range of assumptions about economic and population growth, and technical change.

Table 5
Targets, standards, gaps and abatement costs for atmospheric concentrations of carbon and UK carbon emissions^a

Atmospheric concentration of CO ₂		UK GG/CO ₂ emissions		Costs/CO ₂ saving ^b		
Pre-industrial:	280 ppm	GG in 1990:	212 mtC	Abatement option	CO ₂ savings (mt)	Marginal cost (£/t)
In 1994:	358 ppm	CO ₂ in 1990:	168 mtC	Fuel switching	8.07	-19.87
Target/standard:		Target/standard (FCCC)		Appliances	25.97	-14.89
Return to pre-industrial concentration	78 ppm	Return CO ₂ emissions to 1990 level by 2000	152 mtC	Industrial CHP	20.80	-13.02
Gap with respect to target:		Projection for 2000	0 mtC	Lighting	32.72	-12.38
		Gap with respect to target:		Small-scale CHP	6.89	-8.43
		Target/standard (Kyoto)		Cooking	4.05	-8.18
		Reduce GG emissions by 12 $\frac{2}{3}$ % from 1990 by 2010	186 mtC	Gas turbines	35.28	-7.08
		Corresponding 2010 emissions	183 mtC	Space heating (service sector)	31.63	-8.02
		Projection for 2010	0 mtC	Water heating	8.63	0.08
		Gap with respect to target:		Industrial motive power	22.92	4.07
		Target/standard (UK domestic)		Domestic space heating	34.69	4.18
		Reduce CO ₂ emissions by 20% from 1990 by 2010	134 mtC	City-wide CHP	12.17	14.49
		Corresponding 2010 emissions:	156 mtC	Renewables	17.29	17.21
		Projection for 2010	22 mtC	Process heat	15.44	19.68
		Gap with respect to target:		Industrial space heating	7.77	27.79
				Nuclear	33.24	30.0
				Advanced coal technology	3.19	36.73

^a Sources: Houghton et al., 1996, Table 1, p. 15; DETR, 2000, Table 1, p. 46.

^b Source: Jackson, 1991.

Table 6
CO₂ concentrations, cumulative emissions, global temperature increase^a

Atmospheric CO ₂ concentrations (ppm)	327	335	350	384	411	436	450	464	550
Temperature increase (°C)	0.7	0.8	1.0	1.4	1.7	2.0	2.1	2.5	3.0
Estimated cumulative emissions (GtC) to 2100	225	250	295	410	500	585	630	720	870

^a Source: Hare, 1997, Table 15, p. 55.

The most detailed modelling exercise of this sort, which envisages a carbon budget in the above range is the Fossil Free Energy Scenario (FFES), elaborated in 1993 by the Stockholm Environment Institute, on commission from Greenpeace International, and reported in a study entitled *Towards a Fossil-Free Energy Future* (SEI, 1993). The commission stipulated that scenarios had to be consistent with a range of 'acceptable' emission trajectories on CO₂, based on Greenpeace's earlier work, all of which

entailed zero use of fossil fuels by 2100. Some climate modelling suggested that these trajectories would restrict global mean temperature rise to a maximum of 1.7°C above 1990 levels, with temperatures falling from 2070, and that the decadal rate of temperature increase would fall below 0.1 °C by 2040 (SEI, 1993, Figure 3.5, p. 17). The trajectories are therefore somewhat less demanding than the physical targets in the previous paragraph, but they will be used here to illustrate how an SGAP for UK carbon emissions may be calculated.

4.4. A sustainable CO₂ emissions trajectory for the UK

Table 7 shows CO₂ emissions from fossil fuel use for the world and the UK for various years. The columns for 1980, 1990 and 1995 for rows 1 and 2 are actual emissions. For the 2010, 2030 and 2100 columns, the first row gives the projected global emissions from the FFES study for those years. As noted above, this trajectory is identified for the purposes of this paper as one that is compatible with long-term environmental sustainability. The Trend entries in Row 2 for these columns gives UK emissions that will result if the trend that prevailed from 1980 to 1995 continues in a linear manner, entailing a reduction of 1.13 mtC per year. On this trend UK carbon emissions in 2100 will be 29 mtC, when the FFES (sustainable) level is 0. Extrapolating Trend beyond 2100, UK carbon emissions will fall to 0 in the year 2126.

The STrend entries indicate the linear trend that would be necessary for 1995 emissions to fall to 0 by 2100. The FTrend entries indicate what UK emissions would have to be to follow the trend of the FFES trajectory. This is the average trend that all countries would need to follow if the global FFES projections were to be realised. It may be noted that the UK government's current aspirational target of reducing carbon emissions to less than their 1990 level by 2010 implies a 2010 target of 127 mtC, which is in line with both the S and FTrend figures for that year.

However, be seen that between the years 2010 and 2020 (least UK emissions on the current Trend) is substantially in excess of these 'sustainability' trends. Finally for Row 2 the DETR entry 2010 column, taken from the UK government Draft Climate Change Programme, indicate 2010 emissions are actually forecast to be substantially (25 mtC) above even the Trend figure for that year. It seems unlikely that the trend of the past will be followed, let alone greater carbon reductions be achieved, without substantial policy measures.

Of the figures given, only FTrend relates UK emissions to the globally sustainable trajectory of FFES. This relation is such that countries, developed and developing, will be required to reduce their emissions at least according to this

trend for the FFES trajectory to be realised. This is highly unrealistic, not least because the FCCC is based explicitly on the understanding that industrial countries will start to reduce their emissions while those from developing countries continue to grow. For the FFES trajectory to be attained with developing country emissions growing, perhaps until 2010, industrial countries will have to reduce their emissions significantly faster than the FFES trend. To decide how much industrial countries should reduce their emissions, and how much those from developing countries can grow, some explicit mechanism is required to share out global carbon emissions.

Any formula for sharing the world's carbon emissions is likely to be disputed. Some will argue that it should be on the basis of current shares. Some will argue that it should be related to a country's share of world GDP. Others still will want it related to a country's share of world population. The 'environmental space' methodology (see Opschoor and Weterings, 1994, 1995, for a theoretical discussion), which has been widely used to calculate global environmental entitlements and limits (e.g. Buitenkamp et al., 1993; FOE, 1995; McLaren et al., 1998; Sachs et al., 1998), normally calls for world carbon emission rights to be allocated on an equal per capita basis.

Table 7
UK and global carbon emissions for various years

	1980	1990	1995	2010	2030	2100
1. Global, GtC ^a	5.2	5.9	6.1	FFES: 5.26	2.55	0
2. UK, mtC ^b	165	159	148	Trend: 131 Strend: 127 Ftrend: 128 DETR: 156	108 99 62	29 0 0
3. UK share of population, %	na	1.1	na	0.89	0.77	0.6
4. UK share of world CO ₂ , mtC (1.1%) ^c	na	65	na	58	28	0
5. UK share of world CO ₂ , mtC (share of world population) ^d	na	65	na	47	20	0
6. Various SGAPs, mtC				SGAP1: 3 (DETR: 28) SGAP2: 73 SGAP3: 84	46 80 88	29 29 29
7. Various SGAPs, %				SGAP1: 2.3 (DETR: 22) SGAP2: 57 SGAP3: 67	74 129 144	na

^a Sources: 1980, 1990-WRI 1994, Table 23.4, p. 366; 1995-Brown et al., 1996, p. 65; FFES-SEI 1993, Table 4.3, p. 25. Un Giga (10⁹) tonnes of carbon.

^b Sources: 1980, 1990, 1995-DETR 1997, Table 1.2, p. 9; 2010 DETR — DETR 2000, Table 1, p. 46. Units are million of carbon.

^c Calculated on the basis of the UK's 1990 share of world population.

^d Calculated on the basis of the UK's share of world population at the date given, assuming linear growth of world pop from 5.3 in 1990 to 8.9 billion in 2050, and of UK population from 57 in 1990 to 60 million in 2050.

In 1990 the UK population was about 57 million out of a world population of 5.3 billion (WRI, 1994, Table 16.1 p. 268). The UK therefore had about 1.1% of the world's population. However, Table 7 shows that in that year its carbon emissions were 2.7% of the world total. This means that UK carbon emissions per head were nearly 2.5 times the world average. The world population is currently expected to reach 8.9 billion in 2050 and 9.5 billion by 2100 (UNPD, 1999), but that in the UK is expected to stay relatively constant. Row 3 of Table 7 shows how the UK's share of world population will decline, from 1.1 to 0.63% from 1990 to 2100, if its population stabilises at 60 million by 2050, but that of the world grows according to the UN's medium projection.

Considerations of fairness seem to argue for relating CO₂ emission rights in some way to population. So do considerations of political pragmatism. As developing country emissions increase, it will be imperative, if global emissions are to be constrained, that they accept emission limits under the FCCC. It seems most unlikely that they will be prepared to do so under any formula that is not related to population. Their preferred formula would probably be globally equal per capita emissions.

On the other hand, it hardly seems desirable for a carbon reduction formula to be such as to enable countries to increase their share of carbon emissions by increasing their share of the global population. Given that population growth is an important driver of carbon emissions, it would be better for the formula to give incentives for the restraint of population growth.

For these reasons it seems desirable to relate a country's share of world carbon emission rights to its share of world population in a certain year. This establishes the principle of equal per capita emissions rights for that year. Thereafter, countries whose populations grow more slowly than the world average will have higher per capita emission rights than countries with higher than average population growth. With regard to which year should be chosen, there seems some logic in choosing 1990, which is the FCCC reference year for carbon emissions. For the UK, which formula is chosen makes a substantial difference to its sustainable emissions trajectory, as a share of the FFES global trajectory. Row 4 gives its sustainable emissions with the UK share calculated as 1.1% of the global total, where 1.1% was its population share in 1990. Row 5 gives its sustainable emissions with the UK share calculated according to its current share of world population, which falls to 0.77% in 2030 and 0.63% in 2100. Its 2030 'sustainable emissions' fall to 20 mtC under this formula, from 28 mtC under the constant 1990 share formula.

Rows 1-5 enable various 'sustainability gaps' (SGAPs) to be calculated for the UK, where SGAP is the distance from the current situation, or from the projected outcome in the future according to the current trend (Trend in Table 7), and the relevant sustainability standard.

SGAP1 takes the sustainability standard to be FTrend. SGAP2 takes the sustainability standard to be the result of giving the UK 1.1% of sustainable global emissions (Row 4). SGAP3 takes the sustainability standard to be the -result of allocating the UK a share corresponding to its share of the global population (Row 5).

It can be seen that the current Trend gives an SGAP in 2030 of 46 mtC related to FTrend (SGAP1), 80 mtC related to a 1.1% share of global emissions (SGAP2) and 88 mtC relating the UK share to its share of world population in the year in question (SGAP3). The SGAPs in 2010 are smaller but still substantial, apart from SGAP1, but this small gap depends on the 1980-95 trend being maintained. If the DETR forecast of 2010 emissions on current policies is correct, even SGAP1 in 2010 rises to 28 mtC. Projecting the Trend beyond 2100 shows that it will be 126 years from 2000 before the UK reaches a zero emissions level, which for sustainability will need to remain 0 until carbon sequestration from the atmosphere has reduced atmospheric CO₂ concentrations to the 350 ppm that corresponds to the upper warming limit of 1°C. Unless and until the science of global warming and its possible impacts starts to rule out some of the potentially disastrous outcomes that can currently be envisaged, this would appear to be the kind of long-term sustainability goal that is in accordance with a precautionary approach to environmental policy.

5. The sustainability gap in monetary terms

While the calculation of the SGAP, NSGAP and YS indicators relate the environmental indicators to the concept of sustainability and, therefore, to sustainable development, none of the physical SGAP indicators give any idea of the economic implications of a sustainability gap or of attempts to reduce it. They give no insights into the scale of the economic resources that might be required, relative to the overall scale of the economy, to bring environmental performance close to the defined sustainability standards.

In order to generate these economic insights, detailed microeconomic analysis is required of the technologies that could be employed to reduce environmental pressures. In general, a number of different technologies are available to reduce environmental impacts, with different levels of potential impact reduction at different costs. Table 1 and Table 5 gave some information on costs for some of these technologies for SO₂ and CO₂. Putting the microeconomic analyses of these technologies together, it is possible to build up a marginal cost curve of pressure reduction (e.g. emission abatement) on the assumption that the cheapest technologies are implemented first. These marginal cost curves are, of course, affected by technical change, and they can be used to gain insights into the economic implications of such change by projecting their future development.

Marginal cost curves have been derived for carbon dioxide, sulphur dioxide and nitrogen oxides (Simon, 1998). In principle these cost curves could be applied to the physical SGAPs estimated for the different pollutants in order to derive a monetary equivalent for the physical SGAP indicators. These monetary SGAPs (MSGAPs) could then be aggregated across different physical indicators within the same environmental theme (e.g. the different greenhouse gases that contribute to global warming) to arrive at an MSGAP for the environmental theme as a whole. The environmental theme SGAPs could then be aggregated together to derive an overall monetary SGAP (OMSGAP) for economic activity as a whole. As is made clear in Ekins, 2000 (p. 146), it is important to note that the OMSGAP figure thus derived is not commensurable with GNP or the other national accounting product aggregates, and could not therefore be subtracted from, say, NNP, in order to produce a 'sustainable income', or 'Green GNP' figure. It is also important to note that OMSGAP does not represent the amount of money that would have to be spent to achieve sustainability. The OMSGAP is very much a static, partial equilibrium calculation, representing at a moment in time the aggregation of expenditures that would need to be made to reduce the various dimensions of the physical sustainability gap to zero.

The OMSGAP would be an expressive indicator of the potential of an economy, at a certain moment in time, to achieve environmental sustainability. It would reflect both the physical distances from environmental sustainability and the economic possibilities of reducing those

distances. Over time, OMSGAP would decrease if either the physical sustainability gaps decreased, or new technologies, processes or materials were developed which enabled those gaps to be reduced at lower cost in the future. OMSGAP/GNP, either in aggregate or for each environmental theme, would also be an interesting indicator with which to make inter-country comparisons of environmental efficiency, in much the same way as energy intensity (Energy Use/GNP) is currently used.

6. Conclusion

This paper has developed a number of new indicators of environmental sustainability which may be used to assess whether the development process of an economy is sustainable or not. The indicators are based on a perception that objective standards of environmental sustainability, within acceptable margins of error and uncertainty, may be derived from considerations of ecology, environmental science and environmental impacts on human health. Comparisons of current states of and pressures on the environment with these standards may then be made, leading to the derivation of physical 'sustainability gaps' (SGAPs) for the environmental issues in question. Development can only be said to be sustainable when the SGAPs, across all environmental themes of concern, are either zero, or may be projected to fall to zero within an acceptable time scale.

For the UK, the paper has shown that SGAPs currently exist with regard to CO₂, SO₂ and other air pollutants. None of these emissions in the UK can be said to be sustainable. However, for the local air pollutants the situation is improving, albeit in some cases only slowly. While currently UK CO₂ emissions are also decreasing, projections indicate that they may not continue to do so. Even so, on the current trend there is a substantial CO₂ SGAP until the third decade of the next century. Given the climate change that is already apparent, it may well be that climatic conditions will have changed drastically and irreversibly before the SGAP has been closed.

By combining the physical SGAP indicators with figures for the marginal cost of abatement, avoidance or environmental restoration, a monetary indicator of the overall distance to sustainability (OMSGAP) may be derived. Expressed as a ratio with respect to GDP, OMSGAP would give a meaningful indication of the relative environmental sustainability of economic performance.

The indicators SGAP, YS and OMSGAP are potentially useful new indicators of environmental sustainability. Until these, or similar, indicators, come to be employed, it will not be possible to judge whether development is in fact becoming environmentally sustainable and how far current performance is from environmental sustainability. While much of the data to compute the indicators already exists, a considerable statistical effort is still needed in the UK and elsewhere to address the complexities identified in the paper, so that they may be derived across all relevant environmental themes.

Acknowledgements

The research reported in this paper received financial support from WWF-UK and the Environmental Research Trust, to whom gratitude is warmly expressed.

References

- Adriaanse, A., 1993. Environmental Policy Performance Indicators, SDU, The Hague.
- Brown, L. et al., 1996. Vital Signs 1996-1997, Earthscan, London.
- Buitenkamp, M., Venner, H. and Warns, T., 1993. Action Plan Sustainable Netherlands, Vereniging Milieudefensie (Friends of the Earth Netherlands), Amsterdam.
- CE (Cambridge Econometrics), 2000. UK Energy and the Environment: Analysis and Forecasts to 2010, July, Cambridge Econometrics, Cambridge.
- DETR (Department of the Environment, Transport and the Regions), 1997. Digest of Environmental Statistics, No.19, The Stationery Office, London.

DETR (Department of the Environment, Transport and the Regions), 1998. 'Development of an Overall Indicator of Air Pollution Concentrations', November, DETR, London (<http://www.environment.detr.gov.uk/airq/airpollconc/index.htm>).

DETR (Department of the Environment, Transport and the Regions), 2000. Climate Change: The Draft UK Programme, The Stationery Office, London.

DOE (Department of the Environment), 1996a. Reducing National Emissions of Sulphur Dioxide: A Strategy for the United Kingdom, DOE, London.

DOE (Department of the Environment), 1996b. The United Kingdom National Air Quality Strategy: Consultation Draft, August, DOE, London.

EA (Environment Agency), 1998. 'Proposals for Reducing Emissions of Polluting Substances from Existing Coal- and Oil-Fired Power Stations', Consultation Paper, EA, London.

Ekins, P., 1997. Sustainability as the basis of environmental policy. In: Dragun, A., Jakobsson, K. (Eds.), 1997 Sustainability and Global Environmental Policy. Edward Elgar, Cheltenham, pp. 33-61.

Ekins, P., 2000. Economic Growth and Environmental Sustainability: The Prospects for Green Growth. Routledge, London, New York.

Ekins, P., Simon, S., 1998. 'Determining the sustainability gap: national accounting for environmental sustainability', In: Vaze, P. (Ed.), 1998 UK Environmental Accounts: Theory, Data and Application, Office for National Statistics, London, pp. 147-167.

Ekins, P., Simon, S., 1999. The sustainability gap: a practical indicator of sustainability in the framework of the national accounts. *International Journal of Sustainable Development* 2 (No.1), 32-58.

FOE (Friends of the Earth), 1995. Towards Sustainable Europe, FOE, London.

Hadley Centre, 1995. Modelling Climate Change: 1860-2050, February, Meteorological Office, Bracknell.

Halkos, G., 1993. 'An evaluation of the direct cost of abatement under the main desulphurisation technologies', Discussion Paper Number 9305, University of York.

Hare, B., 1997. Fossil Fuels and Climate Protection: The Carbon Logic, Greenpeace International, Amsterdam.

HMG (Her Majesty's Government), 1997. The United Kingdom National Air Quality Strategy, Cm 3587, March, The Stationery Office, London.

Houghton, J., Meira Filho, L., Callander, B., Harris, N., Kattenburg, A., Maskell, K., 1996. Climate Change 1995: The Science of Climate Change, Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel on Climate Change), 1990. Climate Change, The IPCC Impacts Assessment, Report prepared for IPCC Working Group II, In: W. J. McG. Tegart, G.W. Sheldon and D.C. Griffiths (Eds.), Australian Government Publishing Service.

Jackson, T., 1991. 'Least-Cost Greenhouse Planning: Supply Curves for Global Warming Abatement', *Energy Policy*, January, pp. 35-46.

McLaren, D., Bullock, S., Yousuf, N., 1998. Tomorrow's World: Britain's Share in a Sustainable Future, Earthscan, London.

NETCEN, 2000. The UK National Air Quality Information Archive, <http://www.aeat.co.uk/netcen/airqual/welcome.html>.

Opschoor, J.B., Weterings, R., 1994, 1995. Special Issue on Environmental Utilisation Space, Milieu, Netherlands Journal of Environmental Sciences, Vol. 9, Stichting Bevordering Milieukunde, Nijmegen.

Sachs, W., Loske, R., Linz, M., et al., 1998. Greening the North: A Post-Industrial Blueprint for Ecology and Equity. Zed Books, London.

SEI (Stockholm Environment Institute), 1993. Towards a Fossil-Free Energy Future: The Next Energy Transition, SEI, Boston/Greenpeace International, Amsterdam.

Simon, S., 1998. 'The Sustainability Gap in Monetary Terms for SO₂, NO_x and CO₂', mimeo, Department of Environmental Social Sciences, Keele University, Staffs.

UNPD (United Nations Population Division), 1999. Long-Range World Population Projections: Based on The 1998 Revision (ESA/P/WP.153), United Nations, New York (www.popin.org/longrange/tab1.htm).

Vellinga, P., Grubb, M., 1993. Climate Change Policy in the European Community, Royal Institute of International Affairs, London.

WRI (World Resources Institute) (with UNDP and UNEP), 1994. World Resources, 1994-95, Oxford University Press, Oxford/New York.