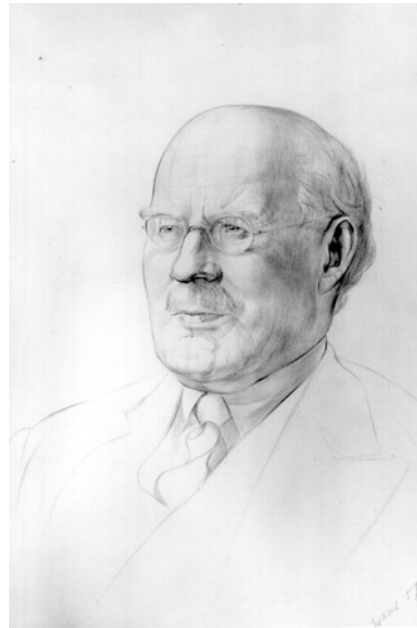


**Measuring our Future – the Role of Sustainability Metrics**  
**The 11<sup>th</sup> Hartley Lecture**  
**delivered at the Royal Society on 10<sup>th</sup> November 2005**  
**by**  
**Professor Richard Darton FREng**  
**Department of Engineering Science**  
**University of Oxford**

**Introduction**

It is an honour and a pleasure to be invited to give this lecture, named after the late Sir Harold Hartley. The subject I have chosen, Sustainable Development, is one that would have interested Hartley, a scientist who went into the world of commerce, and who worked hard to see science and technology contribute to wealth creation and development.

Harold Brewer Hartley was born in 1878, and graduated in 1900 at Oxford in Chemistry and Mineralogy. He immediately took up a Fellowship at his College, Balliol, and set about developing a new course in Physical Chemistry. He was one of those enlightened supporters who voted in favour of the Statute establishing a Chair of Engineering Science at Oxford, which led to the appointment of Frewen Jenkin as first Professor. Oxford had long hesitated about Engineering – whether it was a respectable subject for study at a University – and it was something of a landmark when Jenkin gave the first official lectures in 1908. Very much later, Hartley persuaded his friend Sir Donald Pollock to endow a Readership in Engineering Science, which, just five years ago, we converted into the Donald Pollock Chair in Chemical Engineering. Thus Hartley's good offices have led, many years later, to the growth of a chemical engineering school at Oxford – a circumstance that would have pleased him greatly.



Sir Harold Brewer Hartley  
(1878-1972)  
by Merlyn Oliver Evans  
Copyright: Balliol College, Oxford

Hartley resigned from Balliol in 1930 to pursue a career in industry, and he later featured as one of that small band of Oxford men and women who have been

President of the Institution of Chemical Engineers. In Hartley's case he had the rare privilege of serving twice – in 1951-2 and 1954-5.

Although twice president of an Engineering Institution, Hartley's academic qualifications as an engineer were non-existent, by modern standards. Indeed the Dictionary of National Biography records of him, that he was keen on technique and precision of measurement, but "mathematical treatments of any complexity were a closed subject". It was perhaps of Hartley that Professor PV Danckwerts was thinking when he wrote that "if an Oxford chemist sees a differential sign he turns the page; if he sees an integral sign he closes the book". Danckwerts was of course also an Oxford chemist, was also at Balliol and also a President of the Institution of Chemical Engineers, and was famously undeterred by integral signs.

Hartley's experience of life was broad. A volunteer in 1914, by 1918 he had risen to the rank of brigadier general. He was a director of many companies including two airlines and a railway. He was knowledgeable about raw materials and their conversion, and chaired the Electricity Supply Council. He was one of the first to spot the industrial importance of applied microbiology, or biochemical engineering as he called it. He also believed in the need for a more scientific approach to process control. In his 1955 Presidential address to the Institution of Chemical Engineers, Hartley pleaded for more measurements to be made on full-scale chemical plant, so that better control strategies could be developed to improve the efficiency of production.

His interest in measurement resulted in his accepting the presidency of the Society of Instrument Technology in 1957, and led ultimately to the sponsoring and naming of the Hartley lecture series. He was a firm believer in Lord Kelvin's dictum, expressed by Kelvin in a lecture to the Institution of Civil Engineers in 1883

*"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."*

This brings me to the real subject of this lecture – sustainable development and its measurement. Are we able to measure it, and thus say with Kelvin, that we know something about it, or does it remain such a vague and qualitative concept that our knowledge must be termed meagre and unsatisfactory? So what are sustainability and sustainable development?

### **Sustainability – definition and potential**

There are very many different definitions of sustainable development, but that given in the Brundtland report is good for most purposes:

*"Sustainable Development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs." Our Common Future, World Commission on environment and development, 1987*

This is a very carefully crafted short definition, which is deceptively simple in its language, but which includes the two main features. First that the needs of the present

are met, and second, that we must not make it more difficult for future generations to meet their needs. This concern for the needs of future generations is termed “inter-generational equity” – being fair to those who will come after us.

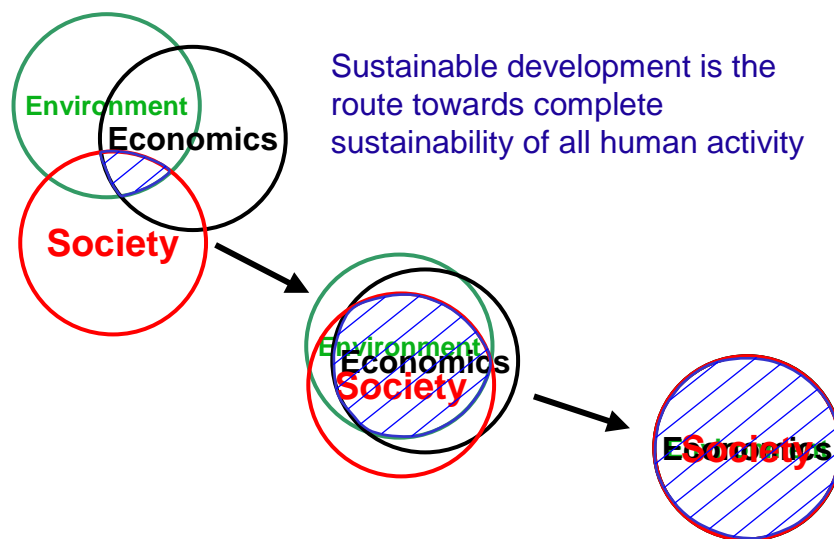
The Brundtland Report records the realisation that much material development is not only not meeting the current needs of huge sections of the world’s population, it is leaving a legacy of consumed resources and scattered pollution, that will make it harder for future generations to meet their needs. Partly this is a question of scale. With a human population of around 6 billion people, perhaps rising to 10 billion later this century, the very small quantity of consumption and pollution that we are each responsible for individually soon adds up.

Brundtland’s report, though published in 1987, is still very well worth reading; although many details have changed since then, the broad thrust of the argument remains as compelling as when it was first published. The appearance of this little book was a watershed, for the ideas in it had a huge influence on the UN Conference on Environment and Development in 1992 (the Rio summit), and on much that has happened since then.

Note that *Sustainable Development* does NOT mean *No Development*: the report itself made it clear that much of the world’s population lives with an unacceptably poor quality of life, and this has to change. The average income of the world’s richest billion people is about 50 times that of the poorest billion. The poorest billion lives on an income of around 1\$ per day, and whilst the World Bank tells us that the number living at this level has halved since 1981, this still represents grinding poverty for a billion people.

The urgent need for economic development, that enables people to break out of the bleakness of poverty, has to be balanced with the need for social development and social justice. And satisfying both these basic human needs has to be balanced with the finite resources of the environment which must supply our wants and absorb our waste products. This balance is conveniently illustrated as a Venn diagram in which economics, society and environment, the three major needs, are shown as adjacent circles. That zone where the three needs are properly accounted for, represented in the Venn diagram by the area of overlap, marks human activity which is sustainable. This “sustainable” zone does not represent stasis – everything remaining the same for ever, nor does it require some reversion to a primitive life-style – living in caves for example.

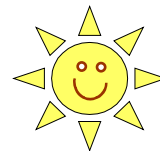
The objective is to develop a sustainable world in which human needs are met, not in the same way for everybody, because, as Brundtland was careful to point out, there will always be cultural diversity; but in this idealised sustainable state, human society is in equilibrium with a natural world that is passed, undamaged, from one generation to the next. We cannot be sure that this idealised state is obtainable, but we can be sure that our present situation can and must be significantly improved.



To illustrate the potential for more sustainable living, just consider the current debate about energy supply and global warming. We are concerned both that our supplies of fossil fuel, particularly oil, may become in short supply in the next few decades, and that the carbon dioxide we are putting into the atmosphere will cause global temperatures to rise by several degrees this century. And yet we rely on fossil fuel to drive the economy and create the wealth that is so desperately needed. What is to be done?

## Solar energy – the potential

*Why not use the nuclear reactor in the sky?*



- World primary energy demand ~12.5 TW  
(~176 mln bdoe)
- Total solar radiation
 

intercepted	~ 170,000 TW
reaching surface	~ 120,000 TW
falling on land	~ 20,000 TW
- Land area needed at 15% (PV) 0.4% of land area
- Deserts are about 10%
- Use roofs, walls etc for distributed generation

Well, we should note that the current world primary energy demand of about 13 TW is tiny compared with the 120 000 TW of solar energy reaching the earth's surface. If we converted solar radiation to electricity at 15% efficiency, we would still only need

to cover 0.4% of the earth's land area with photovoltaic cells to supply all our present energy needs. I am not at all suggesting that we should do this; I am only pointing out that we have not been set a question to which there is no conceivable answer. There are many answers, probably involving wind power, nuclear and a lot of other options that produce much less carbon dioxide. It is a question of developing new technology and probably different ways of living: there is no energy shortage, just an energy distribution problem, and a failure as yet, in imagination – the world can, and will, be different, when fossil fuels no longer dominate the energy supply scene.

### **Sustainable Development – critics, and the need for measurement**

It must be admitted that the concept of Sustainable Development has its critics, from the senior industrialist who told me that the whole idea is a confidence trick, to others who simply have difficulty understanding it. Journalist Ross Clark recently wrote in the London Times,

*In the absence of any precise meaning, the concept of sustainability is pointless. It could mean virtually anything, and therefore means absolutely nothing. It has become merely a marketing slogan. If you buy a “sustainable” hardwood floor does it mean that the factory could theoretically carry on sawing up trees ad infinitum, or that the floor will sustain your weight? I couldn't argue with a consumer who was more interested in the latter assurance: at least it can be proven. (The Times, 29 October 2005)*

Such criticisms are familiar to all of us working in the field, but do seem to me to be nonsense. It has been pointed out that many useful concepts such as “justice” also defy precise definition, but should we, for lack of an agreed definition, consider justice to be meaningless and allow criminals to go free? Neither should we accept the lazy conclusion that because it is difficult to understand, we should not be bothered with it.

Of course the concept and terminology of Sustainable Development will be misused, as an advertising gimmick, as a political slogan, and for much else. Its real meaning is not made less relevant and important by this misuse.

The need to have quantitative measurements of sustainability is crucial, since they focus attention on the precise issues. In particular, we really need to be aware of how sustainability is changing at all levels, local, national and global, and measurement is essential in order to chart these changes. If we can measure it, we can take planned and coherent action to change it in a desired direction. The measures of sustainability that provide this guidance are called “metrics” or “indicators”.

Since sustainability has many aspects, its measurement will involve the gathering together, and perhaps the weighting in a single composite number, of many individual measurements. Choosing a group of metrics for a complex situation is not straightforward. It is rather like choosing the instrumentation scheme for a complex industrial process like a catalytic cracker. Thousands of different measurements are possible, but a safe and efficient control scheme can probably be arranged with some hundred separate instruments (measuring temperature, pressure, flow rate etc). Each of these hundred measurements is important in determining how the process is working, and in enabling the control system. But overall performance can most

usefully be presented in terms of a few key indicators like yield of gasoline per tonne of feedstock, or the profit (\$/day).

Whether we are choosing the hundred metrics for detailed control, or choosing the few important indicators to monitor overall performance, detailed knowledge of the process, together with experience and judgement are needed to make a good choice.

When choosing metrics we must be clear for what purpose they are intended. The requirements are then

1. Relevance to the defined purpose
2. Available data – quantifiable empirical data, not qualitative judgements
3. Coverage – key aspects must be included
4. Avoid duplication and needless complexity
5. Use composites if appropriate (recognise weighting problem)

Defining the purpose and choosing the metrics with care is essential. If this is not done, then we simply have a collection of statistics.

Composite indicators which combine two or more aspects can be very powerful. They do introduce the problem of weighting the different aspects, though this can be overcome when a common measure is available, such as monetary value, or an environmental impact like *global warming potential*. Otherwise a view has to be taken on the relative importance of the factors combined in the composite.

Perhaps the best way to show what sustainability indicators can do for us is to consider some examples.

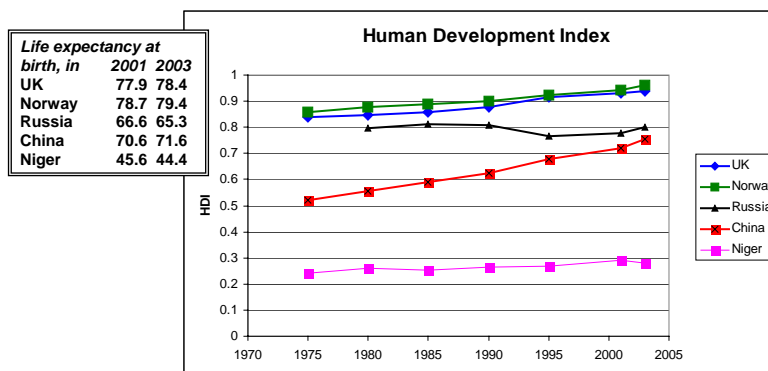
### **Example of Indicators – Human Development**

The United Nations Development Programme (UNDP) reports on the progress of human development in every part of the world. Its latest Human Development Report, for 2005, discusses the Millennium Development Goals, a set of quantified targets for reducing extreme poverty and extending universal rights by 2015. Over the years, the UNDP has been publishing a series of metrics that has recorded the ups and downs of development in the world: the Human Development Index (HDI). This Index is an average of three normalised indices covering

1. Life expectancy at birth
2. Education (adult literacy, and school enrolment)
3. Gross domestic product (GDP) per head, on a purchasing power parity (PPP) basis.

The three attributes, life expectancy, education and GDP per head, have been carefully chosen by the UNDP as main indicators of human development. Interestingly, the calculation of the GDP indicator involves taking the logarithm of GDP per head, because “a respectable level of human development does not require unlimited income” according to the authors of the Report. This method assigns greater importance to changes at the poorest end of the economy.

## Metrics – used by the UN



The HDI is a composite metric used by the UNDP, based on statistics for life expectancy, education and income.

Data from [hdr.undp.org/reports/global/2005/](http://hdr.undp.org/reports/global/2005/)

Movements in the HDI record events and trends, the triumphs and tragedies of human experience on a large scale over many years - the rise of China, whose HDI is now not far behind what it was for Russia 30 years ago; the march of HIV-AIDS through sub-Saharan Africa where life expectancy in some countries is now less than 40 years, and falling; the recent widening gap between countries of the former Soviet Union, and Western Europe.

The HDI, though useful, cannot possibly represent the entire state of development in a particular country, and various other indicators are also used by the UNDP, such as the Human Poverty Index, and the Gender Empowerment Measure. These illustrate particular aspects of development in more detail. All these indicators are used by international bodies such as the UNDP and the World Bank to inform development advice and aid.

### Example of Indicators – a Sustainable Development project

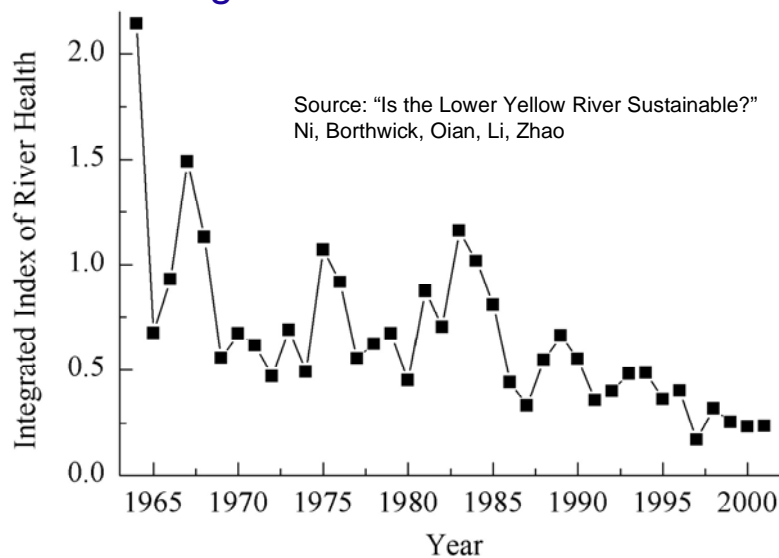
The Human Development Index is a composite indicator for human development, but it is not in itself an indicator for Sustainable Development, because it does not account for changes in the environment. We recall the Venn diagram that showed the three major aspects of Sustainable Development: economic, societal and environmental. A composite indicator that does not relate to all three, may be measuring something, but it isn't sustainability. To give an example of how indicators can be used in the context of Sustainable Development, I would like to use a case study kindly supplied to me by my colleague Professor Alistair Borthwick.

This study relates to the Yellow River in China. This river is vitally important to about 100 million Chinese people who depend on the Yellow River's resources for agriculture, industry and domestic consumption. The river transports an astonishing 1.6 billion tonnes of yellow sediment every year, which not only gives the river its name, but also causes silting up, and severe flooding when the river bursts its banks. At the same time, a variety of factors including increased rates of extraction for human usage, and climate change, are causing flow rates in the river to decline. This

is a familiar story in many parts of the world where scarcity of water resources is a real problem. To date, the worst year for no-flow events was 1997, during which no water flowed into the sea for 330 days. At Lijin Hydrological Station no measurable discharge occurred on 226 days. That year, the maximum no-flow river length during the year was 700 km, almost equal to the entire length of the Lower Yellow River.

It is important for the state of the river to be monitored and assessed, and for this purpose Alistair Borthwick and Professor Ni at the University of Beijing have defined a River Health Index, which takes into account the length of river over which there is no-flow, the amount of sediment, the severity of no-flow events which upset the river's ecosystem, and the availability of water for socio-economic development.

### Lower Yellow River Integrated River Health Index

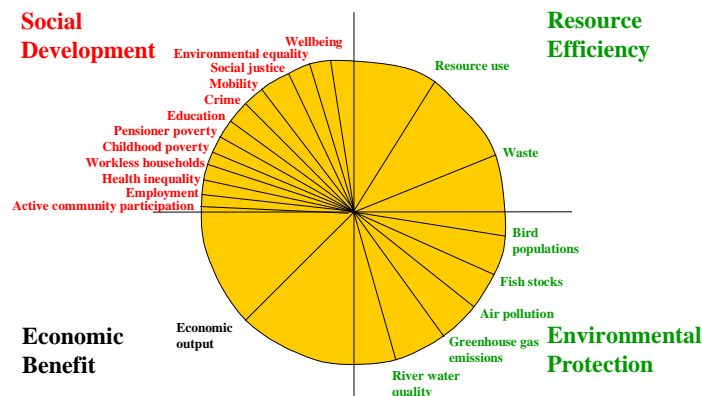


The trend of this River Health Index over the years shows that the Lower Yellow River is dying. This can be seen from this one simple picture in which we have rolled up together both the environmental health and the socio-economic benefit. That is the strength of the composite indicator – the key data are monitored and the situation is presented clearly and understandably. To meet the challenge, the Chinese government has decided to divert 55 billion m<sup>3</sup> per annum of water from South China to the Yellow River by constructing three canals. By these means it is hoped to return the river to better health.

#### **Example of Indicators – a Sustainable Development overview**

In my next example, I am not sure whether the use of sustainability indicators has been well-grasped, though it is a difficult and rather large problem. The challenge is to monitor and report the performance of the UK government's policy to promote Sustainable Development. For some time the government has used a set of 68 indicators for this purpose. Initially 15 of these were termed "headline" indicators, but this sub-set of 15 has now been superseded by a sub-set of 20, in which aspects of social development have a much more significant weighting.

## Metrics – used by the UK Government



The twenty “framework” indicators used by the UK government are more closely aligned to a social agenda than the previous fifteen “headline” indicators. This is a subset of the UK government’s 68 indicators. ([www.sustainable-development.gov.uk/indicators/index.htm](http://www.sustainable-development.gov.uk/indicators/index.htm))

Although the government is publishing this helpful data freely, it is not easy to place in context. For some indicators, such as material consumption, a relation is made with GDP, so that one can judge the change in consumption per unit of economic output, which is useful. But for many indicators there is no comparison or normalising factor, and no international comparison either, so one really cannot judge how the UK is doing without gathering further data oneself.

The Government’s thinking is indicated by its recent decision to create a framework indicator “wellbeing” for which scores will be obtained by satisfaction surveys. I am doubtful of the wisdom of this. In the early 1990s the UNDP reported “Human Freedom Indicators” and the “Political Freedom Index”, both based on the judgements of experts. This honest attempt to chart these important freedoms nevertheless had to be abandoned: lack of objective data undermined the indicators as drivers for policy change, since it was not clear which issues in particular were influencing the scores, and they were easily disputed. You will recall that I suggested the availability of quantifiable empirical data to be an important prerequisite for a sustainability indicator.

But we should even be careful with quantitative data in the public domain, if they are being used to drive policy. Economists are familiar with Goodhart’s Law, stating that “*When a measure becomes a target, it ceases to be a good measure*”. The explanation is that people can take steps to optimise performance according to the measure, thereby altering the process which we are attempting to monitor. Just think of hospital targets for waiting times, which, we now know, can be shortened by administrative policies which do not involve treating patients.

We do need to worry about Goodhart’s law operating on sustainability indicators. For example the UK Government is committed to reducing CO<sub>2</sub> emissions to 40% of 1990 levels by 2050. Meeting this target is going to mean considerable changes in the energy supply mix; we will have to be careful that the policies driving us to meet our CO<sub>2</sub> target do not make some other aspect of sustainability worse. This is a general

concern, and it implies the need for composite targets as well as composite indicators – which simply means we should keep many criteria in mind at once.

### Example of Indicators – industrial operations

My final example of indicators at work concerns the assessment of industrial activity. Several years ago the Institution of Chemical Engineers published a set of 50 metrics for assessing the sustainability of process plant operations. They present a balanced coverage of environmental, economic and social aspects of sustainable of chemical manufacturing operations, and with some adjustments they could be used as a model for other industries.

**Sustainability Indicators for Industry**  
Institution of Chemical Engineers, [www.icheme.org/sustainability/](http://www.icheme.org/sustainability/)

**Environmental indicators**

- Resource usage
- Emissions, effluents and waste

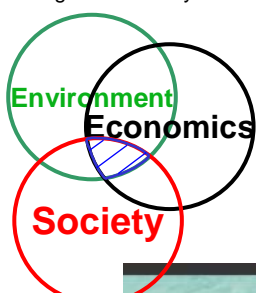

**Economic indicators**

- Profit, value and tax
- Investments

**Social indicators**

- Workplace
- Society

50 indicators in total, but under each heading there is scope for additional items.  
Example: R&D expenditure as % sales - an economic indicator for investment.

We have used them at Oxford as a guide for student design work, and I believe that other Universities have also used them in this way. We can normalise the metrics by comparing them with company targets or industry best practice, which will yield a “footprint” of plant behaviour. Alternatively the metrics could be combined in one or more composites. The Chemical Industries Association collaborated with us in drawing up this list of metrics, and it is interesting to see that this trade organisation has now published its own list of guiding sustainability principles and quantitative targets.

### Conclusions - The future

We began this lecture with the birth of Harold Hartley in 1878, and remarked how, as complex industrial processes developed in the 20<sup>th</sup> Century, Hartley saw the need for better measurement and control of such systems if they were to fulfil their potential. We have seen how indicators can be used to monitor the progress of quite complex things, such as the state of human development in a country – and that these indicators can then be used to inform policy. Of course it is still early days: we are still developing our ideas about sets of metrics, how to put them together and how to use them. We can expect the technique to improve considerably as more case studies become available and good practice is shared.

In its consultation document *Fuelling the Future*, published by the DTI in 2000 the Foresight Energy and Environment panel commented that “...the provision of energy supplies, and the environmental consequences of energy use involve large-scale and long-term investment over [a 40-year] timescale.” The same large-scale and long-term thought must be given to the use of land and water resources, and as the panel also pointed out, new technology is only one aspect of the changes expected – we also have to cope with changes in lifestyles and working patterns. Aligning decisions about development with the priorities of sustainability, or at least encouraging this alignment, will take us towards a more sustainable world. Not doing so, will store up more difficulties for future generations to sort out.

What sort of world will Brundtland’s “future generations” actually see? Whether it will be ecological disaster, technological dreamworld, green Utopia, or something else quite different, time will tell, but we do have the ability to influence this outcome. Sustainability Metrics will present the information we need to monitor our progress. They will help us to maintain a consistent approach over longer periods of time than we normally consider when planning development projects, as we take decisions that will take us into one future rather than another. Our future will be a highly sustainable one, we have every reason to hope.

#### **Acknowledgement**

I am grateful to many colleagues and students who have helped to develop these ideas, but in particular I would like to record my thanks to Professors Al Borthwick and Roger Booth of the University of Oxford, and Professors Roland Clift and Adisa Azapagic of the University of Surrey.