measuring resource productivity

a background paper by David Pearce

for the Department of Trade and Industry & Green Alliance conference:
Revolutionising resource use: measuring radical improvements in resource productivity
London, 14 February 2001

dti
Department of Trade and Industry

"green alliance...

This paper is intended as a brief background 'benchmark' paper to assist with discussion of the notion of resource productivity. A far more detailed paper, prepared for DG Environment of the European Commission, and titled Public Policy and Natural Resources Management: a Framework for Integrating Concepts and Methodologies for Policy Evaluation, is available on the Commission's web site at www.europa.eu.int/comm/environment/enveco/studies2.htm, or by contacting the author at d.pearce@ucl.ac.uk. The extended paper deals with related notions such as 'sustainable consumption', 'sustainable development', 'ecological footprints', 'environmental space', 'genuine savings' etc. which are not addressed here.

David Pearce

David Pearce, Department of Economics,
University College London and OXERA Ltd,
Oxford.

Department of Trade and Industry

Department of Trade and Industry
Environment Directorate
151 Buckingham Palace Road
London SW1W 9SS
tel: 020 7215 1975 fax: 020 7215 1621
e-mail: sustainability@dti.gov.uk
web: www.dti.gov.uk/sustainability/

Green Alliance

Green Alliance
40 Buckingham Palace Road
London SW1W 0RE
tel: 020 7233 7433 fax: 020 7233 9033
e-mail: ga@green-alliance.org.uk
web: www.green-alliance.org.uk

Green Alliance is a registered charity number 1045395. Company limited by guarantee, registered number 3037633.

'Measuring Resource Productivity - A background paper' by David Pearce for the Department of Trade and Industry and Green Alliance conference, 14 February 2001

Design by Sarah Flood

Published February 2001

contents

preface

This paper has been drafted to inform debate at the joint Department of Trade and Industry & Green Alliance conference - Revolutionising resource use: measuring radical improvements in resource productivity on 14 February 2001.

The Prime Minister and Trade and Industry Secretary, Stephen Byers, recently set out the Government's vision of an innovative, highly competitive and resource efficient economy that delivers continually improving quality of life and prosperity for everyone. A central aim of DTI's Sustainable Development Strategy is to identify ways of radically improving resource productivity so that rising economic prosperity is increasingly de-coupled from environmental impacts.

In taking forward this agenda, a key challenge is to establish meaningful goals and metrics that are both effective national policy tools and genuine corporate management aids. The conference's aim is to take forward collective thinking on how such a resource productivity goal might be expressed and progress measured at both the national, economy-wide level as well as within individual companies. This paper briefly outlines some of the issues that arise in relation to developing indicators.

summary of key issues and options

This paper identifies the following key issues and options for measuring resource productivity:

- Should resource productivity indicators be replaced with environmental productivity indicators? The former seem intuitively straightforward, but have a number of problems. The latter are more directly related to the focus of interest - pollution - and are capable of being combined with a wider array of weighting systems, but may be less attractive to those who think in terms of materials and energy efficiency.

- Should simple indices based on individually defined materials and energy sources, or specified pollutants, be used? Or should some attempt be made to weight them for relative ecological and health toxicities?

- Is there a need for aggregation, or could there be a consensus on what a few of the most important materials, energy sources or pollutants are?

- Can money values of damage be used to obtain weights? If not, what other weighting system can be used?

- How important are location effects?

- How important is it to account for supply chain effects?

- How can recycling be included in the Resource Productivity indicator?

1 defining resource productivity

An obvious way in which traditional goals of securing economic growth (increases in per capita GNP) and more recent goals of improving the environment is to raise resource productivity. Resource productivity means raising the ratio of 'output' to natural resource 'inputs'. The less natural resources used per £1 of output, the less potential waste there will be. The First Law of Thermodynamics dictates that every tonne of materials or energy taken from the environment must eventually return to it: matter and energy cannot be created or destroyed. Hence raising resource productivity both saves resources and helps improve the environment.

2 is the notion of resource productivity new?

The importance of resource productivity has been known for a long time,[1] for example in the discussions surrounding the energy 'crises' of the 1970s when there was a substantial focus on the 'energy ratio', the ratio of energy use to GNP. In advanced economies this ratio has systematically declined over the past 100 years or so: more GNP is secured each year per unit of energy input. Nearly all of this change has been due to changes in economic structure, changes in types of fuel, and technological change. Only a small part has been due to conscious effort to save energy. In the 1970s, the ratio also changed because of high oil prices. But policy measures can be effective. Hence mechanisms to accelerate the rate at which this ratio would increase (if measured as GNP/energy), or decrease (energy/GNP), were high on the political agenda in an effort to prevent future crises arising from artificially induced energy shortages. Recent rediscoveries of the importance of resource productivity include Pearce et al. (1989), Hawken (1994), von Weiszäcker et al. (1997) and those advocating 'material input per unit of service' (MIPs) - see Hinterberger et al. (1997).

3 why raise resource productivity?

The motivations for raising resource productivity are:

(a) to conserve 'scarce' energy and materials resources
(b) to conserve the natural environments which act as the receiving 'sinks' for resources when they are converted to wastes
(c) to increase profitability in firms - provided the costs of improving resource productivity are not greater than the cost savings, profits will rise
(d) to increase the net disposable income of households - provided the costs of improving households' use of resources does not exceed the cost savings, households will be better off (even if they convert some of the savings to other goods, e.g. saved energy costs may reappear as increased warmth).

1 Indeed, all the way back to the great economist William Stanley Jevons whose *The Coal Question* of 1865 raised the spectre of a rapidly rising cost of British coal in the face of growing demand, with the prospects of Britain's industrial supremacy being threatened. Interestingly, Jevons rejected 'resource productivity' as a solution, arguing that it would reduce costs, which would stimulate industrial growth, which would raise the demand for coal, making the situation worse.

The most important of these reasons is probably the second. The reason is that the receiving environments are often 'unpriced': a price is not paid for emitting wastes into the environment or, if it is (e.g. via the costs of regulation or through environmental taxes etc.), the price appears to be too low for environmental 'sustainability'. In economic terms, conserving resources as inputs will tend already to be allowed for through the fact that raw materials and energy are priced goods - they have a market. Hence their cost will appear in company profit and loss accounts. It could be argued that current energy and materials prices do not reflect future scarcity, i.e. do not allow for the fact that each tonne used today cannot be used tomorrow.[2] But markets are generally aware of future scarcity, so the argument is not a strong one.[3] On the grounds that the 'saving resources' argument is not strong, and because problems associated with emissions are very much at the centre of environmental policy, the benefits of reducing emissions by reducing resource use are stressed here.

The final two reasons raise the attractive possibility that raising resource productivity is a 'win-win' or 'double dividend' situation: no-one loses since profits go up and the environment improves. Like most popular notions, care needs to taken into assuming this is the outcome. It will not be true if more is spent on raising resource productivity than the cost reduction secured, a situation that would mean profits fall rather than rise. If increases in demand outstrip efficiency gains it will also not be true, the environment suffers and Jevons (see footnote one) was right, unless 'new' resources come to light, e.g. energy from hydrogen cells. There are also effects on the profitability of resource suppliers who may face falling demand as a result of the conservation measures.

4 how far can resource productivity be raised?

The literature tends to confuse two issues. Technologically, what are the limits to raising resource productivity? At least by a 'factor 4' according to many and even a 'factor 10' according to others. The correct answer depends on detailed technological knowledge of existing and new technologies, now and in the future. For example, advocates of hydrogen power would point to enormous potential in reducing fossil fuel use per unit of GNP if we switched to a 'hydrogen economy'. What is technologically possible, however, depends on what is economically and politically feasible. Some new technologies will not just 'come about' (if they did there would be little point in discussing resource productivity - they will happen anyway). They will need substantial incentives. The shift away from old technologies will mean displacing those who rely on those technologies (e.g. for employment) and redirecting them to the new technologies. All in all, there will be costs of dislocation and these are often politically sensitive. What is technologically feasible may therefore be thought of as an 'envelope' within what is practically achievable is defined.

2 In the economist's jargon this is 'user cost'.

3 If there are monopoly elements in the supply of natural resources (e.g. OPEC) then prices will more than reflect future scarcity. In any event, whether future scarcity is fully accounted for in the market place is something that can be tested.

5 will increasing resource productivity always improve the environment?

Yes, always, provided the situation with improved resource productivity is compared to what would have happened without it, the 'counterfactual'. But the absolute burden on the environment will only be reduced if the rate of growth of resource productivity exceeds the rate of growth of output (GNP, say). More strictly, the rate of growth of resource productivity must exceed the rate of growth of GNP per capita plus the rate of growth of population. Unless this condition is met, the total emissions to the environment could increase even with resource productivity gains.[4] Annex 1 provides a 'thought experiment' to show what is involved in real-world terms.

6 instruments for raising resource productivity

The means of making natural resource use more efficient are:

- Reducing the wasteful use of resources.
- Adopting technological change which raises the efficiency of a given unit of resource.
- Substituting other inputs, such as labour, for natural resources, so that output stays the same but resource use is reduced.
- Recycling materials (note that energy cannot be recycled) so that the 'same' unit of resource is used several times.
- Substituting one resource for another. If the focus is on environmental pollution, one tonne of one material may be less polluting than one tonne of another.

Pure self-interest should reduce waste, but there is often a lack of information about the costs of materials and energy use, and there is a substantial literature that tries to explain why people (including firms) do not minimise energy and materials costs. Technological change may occur 'naturally' but it can be induced by incentives such as accelerated depreciation allowances. Substitution of other inputs for natural resources is often overlooked as a means of improving the environment: taxes on natural resources and emissions help to induce such substitution, and the effect can be enhanced by using tax revenues to reduce national insurance contributions.[5] Recycling of materials also reduces environmental impacts by (a) reducing the amount of 'virgin' materials extracted and (b) preventing much of the material reappearing as waste. The same principle applies, however: nothing is gained if it costs more to recycle the resource than the benefits secured.

4 Which is why some people argue that one has to surrender the idea of an increasing level of 'output'. But there are formidable problems with this view as well - see Pearce (2000).
5 Also widely regarded as a 'double dividend': the environment improves and the cost of labour is reduced, thereby reducing unemployment. UK taxes that do this include the Landfill Tax and the Climate Change Levy.

7 indicators of resource productivity

The choice of an indicator depends on:

- The goal that is being sought.
- The importance attached to simplicity of indicator construction.
- In the case of indicators for corporations, whether the corporation wishes to assume responsibility for supply chain and even downstream environmental effects.

The problem is easily illustrated by taking the simplest form of indicator. For a company it is Gross Revenue divided by Materials or Energy Input, and for a nation it would be GNP divided by Materials or Energy Input. To focus discussion we work only with materials. The analysis holds for energy as well. The indicator is then:

$$RP = Y/m \qquad \ldots\ldots[1]$$

Where Y is the output measure and m is the (materials) input measure. The measure is attractive because of its simplicity, but it conceals quite a few problems discussed below.

8 problems with simple indicators

- Is the measure of 'm' the materials purchased by the firm, or all the materials that have been used to bring about that supply of materials to the firm? An example would be whether it is the tonne of aluminium used, or the tonne of aluminium plus all the spoil and waste associated with getting that one tonne of aluminium to the factory gate (popularly known as the 'rucksack') (see also the annex on input-output analysis).
- Since there are many different materials, do we have to construct indicators of Y/m for each material, or can we aggregate in some way?
- If the focus of concern (the dominant goal) is reducing environmental pollution, will any given increase in Y/m have the same effect regardless of location?
- How can recycling be accounted for?

These are issues for discussion and some suggested answers are provided in the table overleaf.

The 'rucksack' question is, by and large, not relevant, although some corporations may feel a 'supply chain responsibility' and hence may wish to adopt a 'life cycle' approach in which they count as part of their materials input the materials that have been used in producing the materials they purchase. But if everyone accounts for supply chain effects there will be substantial double (and triple etc.) counting. But for one corporation the life cycle approach is meaningful, although it adds to complexity.

Problems with simple indicators

Question	Focus: the corporation	Focus: the nation
Is 'm' what is delivered to the factory gate or should it include 'the rucksack'?	If RP measures are applied to all corporations, then there is no need to include the 'rucksack' because it will be accounted for in the supplying industry's RP calculation.	The process of aggregation should automatically account for all materials flows, but it is useful to be reminded that all inputs, including associated waste, must be accounted for.
Can we aggregate the different 'm's?	No. Adding up tonnes of different materials or joules of different energy sources is meaningless, even though it is the subject of some approaches. An aggregation rule is needed. See text.	No. Adding up tonnes of different materials or joules of different energy sources is meaningless, even though it is the subject of some approaches. An aggregation rule is needed. See text.
Is a unit increase in Y/m of the same 'value' regardless of where it occurs?	No. Location matters. A reduction in 'm' in one location may be environmentally highly beneficial but less beneficial in another location.	Since the 'location' is the whole nation, location is not strictly relevant in this case.
How can recycling be accounted for?	There is a need for 'materials accounting' - see text.	There is a need for 'materials accounting' - see text.

The most important issue is how to aggregate materials.[6] One tonne of aluminium is clearly not the same as one tonne of sand. Aggregating them as 'two tonnes of materials' or a 'total materials requirement' (TMR) is meaningless, although widely used in some of the literature (e.g. Adriaanse et al. 1997). If, as suggested, the focus should be on the environmental impact of the materials when converted to waste, then each tonne needs to be weighted by some 'toxicity' factor representing the damage it does to the environment. The resulting indicator now looks more complicated:

$$\text{'Toxicity weighted RP'} = Y / \sum_i w_i . m_i \qquad \ldots\ldots[2]$$

where 'i' refers to the number of materials (aluminium, sand etc) and w to the 'toxicity weight' of the ith material and Σ notation indicates the sum of 'w.m' for all the different materials. The obvious problem is how to choose the weights, w.

6 Exactly the same problem occurs for energy: energy sources differ considerably in environmental impact, so the 'joules' are not equal in importance. This is, incidentally, one reason why 'energy accounting' in which all energy sources are aggregated in terms of joules or barrels of oil equivalent etc. is not a valid approach. It also means that the popular 'energy ratio' is also somewhat misleading.

There are numerous options for choosing toxicity weights. If the focus is on human health or on ecological toxicity (ecotoxicity) there are tables of toxicity weights produced by the US Environmental Protection Agency. These tend to relate to chemicals rather than materials but could be used for those cases. If the inputs are energy sources, perhaps emission coefficients could be used - grams of NO_2, CO_2 etc, per kWh of energy. These coefficients vary by energy sources. The problem here is that the aggregation difficulty has now been transferred to the pollutants themselves: how can NO_2 be added to CO_2? If we knew the relationship between the pollutants and, say, lives foreshortened (an epidemiological dose-response coefficient) then the pollutants could be aggregated. The units of measurement would actually be lives foreshortened, or some indicator of morbidity. The problem still remains, for now health effects need to be compared to other effects: is a kilogram of deposited NO_2 on an ecosystem more or less important than the health effects of a kilogram of ambient NO_2?

The complexities of choosing toxicity weights largely explains why the resource productivity literature does not pursue the issue and settles for easier, but unfortunately not very meaningful, indicators such as 'tonnes of material'.

There are potential solutions to the aggregation problem. People could 'vote' on the weights. One way of doing this is to find what they are willing to pay to avoid the effects of pollutants. By tracing the damage done back to the ambient concentrations of the pollutant and from there to the level of emissions, the '£ value' of damage can be estimated. This is what environmental economists do. One problem is that the £ value is different in different locations, but that is as it should be since toxicity varies with location, i.e. it depends on what is in the ecosystem that is affected, and what kind of ecosystem it is. But making adjustments for location specific effects is hugely complex and not conducive to finding widely usable indicators. Hence the 'purity' of the indicator probably has to be sacrificed for something that is usable. One tempting way of modifying the simple indicator would be to deduct the monetary value of the damage (D) done by the material from the output measure to give

$$RP^* = (Y - D)/m \qquad \ldots\ldots[3]$$

The attraction of this index is that it reminds us that the materials input, m, produces two effects: the effect on output (Y) and the effect on damage (D). Y-D can be thought of as the 'true' output of the material, i.e. the financial output minus the environmental damage done.

While it may be possible to estimate the value of the damage done by the production of the good (the output) to which m is an input, it may be difficult to allocate this damage to individual inputs. The process will work for, say, energy. One kWh of energy produced by gas has known, representative, emissions. So an emission factor will translate the energy used into tonnes of CO_2, NO_x etc. The impacts of these pollutants can be measured (ignoring the 'location' issue discussed above) and valued. In other cases it will not be so simple. Monetary values relate to impacts and while it is routine to translate these impacts into money values of emissions, the next step - going from emissions to materials inputs - can be very difficult.

Finally, consider recycling. Taking a simple example, suppose a corporation or nation uses ten tonnes of a single material to produce £1 million of output. Assume there is only one input. The simple RP index is £100,000 per tonne. If two of the tonnes of input are from recycled material, the net 'claim' on virgin natural resources is eight tonnes. Hence the RP index based on virgin materials only is £125,000 per tonne. This is the simplest form of adjustment for recycling, but is also has fairly obvious problems. Recycling itself consumes materials and energy so this would need accounting for.

9 resource productivity or environmental productivity?

Note that many, but not all, of the problems of resource productivity indicators are overcome if the focus is moved away from resources towards environmental impact, i.e. to environmental productivity indicators. Instead of Y/m type indicators we would have Y/e type indicators where e would be emissions. Then it would be a measure such as 'revenue or GNP per tonne of CO_2'. Such indicators have the attraction of focusing on the issue that really matters - environmental quality. They can also be aggregated if the 'money value of damage' approach is used, and possibly could be aggregated by some toxicity weights. They suffer the same problem as the resource productivity indicators in that environmental impact is location specific (though not for the greenhouse gases where one tonne of CO_2, for example, does the same damage regardless of its source[7]).

Note that quite a few corporations already report environmental productivity indicators.

7 It is said to be a 'uniformly mixed pollutant'.

10 the options

Based on this very brief discussion the options and issues appear to be:

- Should resource productivity indicators be replaced with environmental productivity indicators? The former seem intuitively straightforward, but have a number of problems. The latter are more directly related to the focus of interest - pollution - and are capable of being combined with a wider array of weighting systems, but may be less attractive to those who think in terms of materials and energy efficiency.
- Should simple indices based on individually defined materials and energy sources, or specified pollutants, be used? Or should some attempt be made to weight them for relative ecological and health toxicities?
- Is there a need for aggregation, or could there be a consensus on what a few of the most important materials, energy sources or pollutants are?
- Can money values of damage be used to obtain weights? If not, what other weighting system can be used?
- How important are location effects?
- How important is it to account for supply chain effects?
- How can recycling be included in the resource productivity indicator?

annex 1: a thought experiment

Even if resource productivity can be raised, will it be enough to offset the extra demands on the environment arising from (a) economic growth and (b) population growth. To get some 'feel' for what is required we conduct a thought experiment at the global level.

As a rough indicator, consider the equation:

$$-\Delta t/t = \Delta p/p + \Delta y/y$$

where t is the inverse of resource productivity, p is population, y is per capita GNP and the Δ notation simply means 'change in'. The equation says that resource use per unit output must decrease at a rate equal to the rate of growth of population plus the rate of growth of GNP per capita.

In 1998 world population was 5.90 billion people and in 2050 the UN's population projections suggest it will be 8.91 billion. This is a growth rate of 0.8 per cent per annum. The rate of growth in income per capita over the next 50 years or so is obviously more difficult to estimate. Available data suggest that the rate of change in world per capita GNP was around 1 per cent per annum from 1975-1998. If this rate was to continue, then the equation suggests that $\Delta p/p + \Delta y/y = 0.8 + 1.0 = 1.8$ per cent per annum. Thus resource productivity must improve by at least 1.8 per cent per annum to offset this potential rising impact from economic growth and population change.

Table A1.1 provides some estimates of efficiency changes in energy use 1950 to 1999. The main focus of interest is on the period from 1970. Energy efficiency improves from 0.37 kilograms of oil equivalent to 0.26 kilograms per $ of GNP, a rate of improvement of 1.2 per cent per annum. This is reasonably close to the 'break even target' of 1.8 per cent for $\Delta t/t$ above. The United Nations suggests that materials intensity has declined at about 2 per cent per annum since 1971.

Table A1.1 World energy efficiency improvement

Year	World GNP (GWP) 10^{12} $ (1990)	Total primary energy (TPE) 10^{9} toe	TPE/ GWP kgoe/$
1950	5.37		
1966	11.38	4.16	0.366
1970	13.81	5.17	0.374
1980	20.01	6.91	0.345
1992	27.99	7.85	0.280
1999	33.27	8.53	0.256

Source: author's computations using GNP data from Maddison (1995) Appendix G to 1992 and BP's *Statistical Review of World Energy* (various issues). For GNP in 1999 average world growth of GDP of 2.5 per cent is taken from World Bank, World Development Report 2000, so that GWP in 1999 = $(1.025)^7$.GWP in 1992. This results in a higher estimate of GWP in 1999 than that recorded in the *World Development Report* but is consistent with the Maddison (1995) procedure.

Catalogues of technological potential abound, probably one of the more famous being 'Factor Four' which argues that resource efficiency can be improved fourfold. Assuming this occurs over 50 years, the rate of change in efficiency would be 2.7 per cent per annum, more than adequate to meet the $\Delta t/t$ target of 1.8 per cent per annum.

The thought experiments suggests that the total burdens on the environment from materials and energy use could be about the same in 50 years time, or even less than they are now provided resource productivity aspires to the 'Factor Four' targets. If, on the other hand, past trends only in resource productivity occur, the world will be worse off environmentally in 50 years time. Note that the experiment relates to energy and materials only. Probably far more serious are the effects of population change, and economic growth, on land use.

annex 2: input-output analysis

From a national standpoint, resource and environmental productivity measures can be described using input-output (I-O) analysis. I-O tables show the purchases made by any given sector, say agriculture, from all other sectors. They also show the sales made by agriculture to all other sectors. Suitably extended, they can show what natural resources go into each sector and what wastes are produced by each sector. Manipulation of the tables can then estimate what the total resource input is to agriculture allowing for (a) the natural resources bought directly by agriculture, and (b) the natural resources that have gone into other sectors the output of which is then purchased by agriculture. Similarly for waste. The waste 'caused' by agriculture is the waste directly from agriculture, plus the wastes generated by the inputs into agriculture. If we now hypothetically change the level of demand in the economy, it is possible to see how that demand results in changes in outputs in each of the economic sectors. In turn, those changes in output (measured in money terms) result in changes in the natural resource inputs and waste outputs (measured in physical terms) associated with each of the changes in output.

I-O tables could therefore be used to provide resource and environmental productivity indicators. The assumption of I-O tables is that the various inputs are used in fixed proportions to produce a given output. They cannot therefore be used to simulate the effects of price changes since price changes are assumed to have no effect on the relative proportions of inputs, although some very advanced I-O analysis does try to show how the I-O coefficients change with changing prices. But I-O tables are useful in showing the full effects of a change in any one sector or in 'final demand' (household demand, exports, investment and government expenditure).

references

Adriaanse, A., Brigenzu, S., Hammond, A.S., Moriguchi, Y., Rodenburg, E., Rogich, D and Schütz, H. 1997. *Resource Flows: The Material Basis of Industrial Economies*, Washington DC: World Resources Institute.

Hawken, P., 1994. *The Ecology of Commerce: How Business can Save the Planet*, New York: Harper Business.

Hinterberger, F., Luks, F and Schmidt-Bleek, F. 1997. *Material flows vs 'natural capital'. What makes an economy sustainable?* Ecological Economics, 23, 1-14.

Pearce, D.W., Barbier, E and Markandya, A .1989. *Blueprint for a Green Economy*, London: Earthscan.

Pearce, D.W. 2000. *Public Policy and Natural Resources Management: a Framework for Integrating Concepts and Methodologies for Policy Evaluation*, at:
www.europa.eu.int/comm/environment/enveco/studies2.htm

Von Weizsäcker, E., Lovins, A and Lovins, L. 1997. *Factor Four: Doubling Wealth, Halving Resource Use*, London: Earthscan.

Printed on paper made from 100% recycled post consumer waste with soya based inks.