PUBLIC POLICY AND NATURAL RESOURCES MANAGEMENT

A framework for integrating concepts and methodologies for policy evaluation

David PEARCE

Economics, University College London

Contact: d.pearce@ucl.ac.uk

Draft: September 2000

1   The issue

Environmental issues are at the forefront of European Union policy. The Treaty of European Union (1992) (the Maastricht Treaty) elaborated the role of environmental goals in EU policy. It spoke of the goal of 'sustainable growth respecting the environment' rather than the Treaty of Rome's 'continuous and balanced expansion'. Second, it spoke of the need to integrate environmental issues into *all* policies, whether environmental or not. This second provision is an explicit recognition of the *pervasiveness* of environmental impacts from all economic activity The Maastricht Treaty also introduced the 'precautionary principle' (the PP). The PP effectively says that lack of scientific evidence linking cause and effect shall not be deemed sufficient reason to take no action when there are significant risks. Finally, the Treaty extended the EU's role into international and global environmental policy.

The Amsterdam Treaty of 1997 introduced the notion of the achievement of *'sustainable development'* as one of the EU's tasks, set out in Article 2. It had become clear that 'sustainable growth respecting the environment' had not raised the profile of the environment high enough, nor was it very clear what it meant. Sustainable development, which was however also not defined, took the place of sustainable growth. It was also clear that the previous attempts to get environment integrated into all policy actions had not succeeded. The Amsterdam Treaty repeats the need for this integration to take place and declares that it is one of the means of securing sustainable development.

But stating goals and adopting decision-making and decision-guiding procedures to achieve them are very different things, although the articulation of goals does have implications for the way in which they are secured. The literature on environmental policy is replete with an almost endless array of concepts, methodologies and procedures all of which are claimed to have some relevance to the overriding question:

>   ***how to take environmental issues into account in decision-making***.

This paper attempts to provide an over-arching framework that defines and organises the various concepts and methodologies and shows how this framework can be made relevant to decision-making.

The literature is often presented as if the different methodologies are competing for centre stage in decision-making: i.e. they are presented as if they are answering the central question set out above. In fact, it is far from clear what questions some of the techniques are trying to answer. In other cases it is clear that they are trying to answer different questions. Accordingly, the literature can be confusing if it is construed as having relevance to decision-making about natural resource management. We suggest that, while the entire literature is interesting, only a limited part of it is relevant to public policy.

The sections that follow are necessarily succinct given the limitation on space, and each section could be expanded considerably to allow for the various caveats and extensions.

2 Policy goals and target populations

We take it that the purpose of the resource management methodologies in question is to assist in the **evaluation of policy**. Policy evaluation[1] is the subject of a huge literature, generally known as 'public policy analysis'. Evaluation means deciding whether a given policy is good/bad, desirable/undesirable, acceptable/unacceptable. What is good or bad depends on the **viewpoint** of the decision-maker: what is good for me may not be good for you; what is good for industry may not be good for society as a whole; what is good for the EU may not be good for the world as a whole, and so on. Policy evaluation cannot be carried out unless we know what the **target population** is. EU decision-making tends to have several focuses for its policy:

1　　　The European Union population

2　　　EU plus potential accession country populations
　　　　EU plus associated nations' populations
　　　　The wider Europe (defined by UN ECE boundaries, say)

3　　　The developing countries

4　　　The world as a whole

5　　　Current generations only (in any of the regions defined above)
　　　　Current and future generations (in any of the regions defined above)
　　　　Vulnerable groups within current generations (geographically, or within a region)
　　　　Vulnerable groups across current and future generations (geographically, or within a region)

All policy evaluation must therefore define **who matters**, or, as the public policy literature puts it, who has **'standing'**.

Group 1 above defines a narrow, current-generation oriented target population. Group 2 allows for the **growth of the Union** and for **transboundary impacts** between the EU and other countries. Group 3 defines the target group for EU **development aid** policies. Group 4 defines the group for EU **global policy**, e.g. on climate change. Group 5 raises the issue of **sustainable development** in terms of targeting **vulnerable groups** within society now, and **future generations** who could be worse off as a consequence of current generation policies. These are **intra-generational equity** and **inter-generational equity** concerns.

The five groupings above assume that it is human beings who have standing. The focus is **anthropocentric**. Some people argue that all sentient beings have standing, in which case the target population has to be extended to include at least non-plant species. A 'deep ecologist' might also extend the targeted population to include plant biota and even non-sentient 'things'. It matters considerably what the target population is. In what follows, we retain the anthropocentric focus but the analysis could be extended to see what difference the appreciation of 'intrinsic' values would make.

---

[1] Also known as policy appraisal. We refer to 'policy' throughout, but all the analysis applies equally well to choosing investment projects or programmes.

The outcome of policy evaluation will be sensitive to the definition of the target population. Selecting target populations is not straightforward. It may be determined by political boundaries, by political interests, and by moral concerns. Disputes over methodologies can sometimes be traced to a failure to define the target population.

The next major issue is to what is policy trying to achieve? There has to be an agreement on the **goals of policy**. The European Union has various goals and there is no guarantee that these goals are consistent. By **consistent goals** we mean goals that, if any one of them is achieved, others are not prevented from being achieved. Consistency tends to show up in what has become known as **win-win** solutions. While it is a matter of judgement, the suggestion here is that win-win solutions are actually not common. Policies usually involve inconsistent goals in these sense that there is a **trade-off** between achieving more of one goal and more of another. Policy may therefore involve **compromise** between goals. The problem with compromise is that it leaves at least one party feeling that it could have achieved more from the policy than it did, and maybe all parties feel this. Unless they accept the compromise, they then have **incentives to disrupt** the **policy** in the hope of doing even better. The design of incentives is thus crucial to the design of policy. Essentially, policies have to be designed so as to approximate solutions in which the relevant stakeholders[2] are better off with the policy than without it.

Neglect of this simple 'game theoretic' observation - that the population must be better off with the policy than without it - is a fundamental weakness of some of the suggested policy evaluation methodologies.

The goals for policy are twofold[3]:

Improving the individual wellbeing of the determined target population
Improving the collective wellbeing of the targeted population.

The difference between the two is that the former relies on individuals to determine what their own wellbeing is- **'individual sovereignty'**- whereas the latter focuses on a concept of **society** that is not necessarily the same as the sum of individual's wellbeing. In both cases, individuals may make the decisions about what is good or desirable, but in the former case they act in their own interests, while in the latter they act as if they are citizens whose concerns extend to what is good or desirable for all individuals. This distinction is fundamental to the policy evaluation literature. Space forbids that we address it in detail. But the essence of the debate is that the former criterion appears to be based on **self-interest**, whilst the latter does not. For some, making decisions on the basis of self-interest is morally unacceptable, and hence the relevant criterion for good decision-making is that decisions be responsive to **'citizens' preferences'** rather than individuals' preferences. In turn, this raises the issue of how preferences are to be elicited. The **market place** would appear to be a medium for eliciting self-interested

---

[2] Stakeholders are those with standing. But deciding who the stakeholders are is not straightforward - see Section …

[3] It might appear that these two goals do not embrace all the goals implied in the discussion of target populations. But in general they do. For example, sustainable development says that the goal is the wellbeing of current plus future generations, or the vulnerable now and the potentially vulnerable in the future. The exceptions will be goals based on some notion of 'survivability'.

preferences. The **political arena** would appear to be a location for eliciting citizens' preferences[4].

While fundamental to an understanding of the debate about decision-making, the contrast between the two forms of decision-making is less helpful than it first appears:

- there is nothing in the notion of an individual preference that says that such preferences have to be self-interested. Preferences are motivated by a myriad concerns: self-interest, the interest of the decision-maker's household, concern for others, concern for animals, and so on. The now vast literature on expressed preferences is testimony to this[5].
- there is no guarantee that political institutions, new or old, elicit citizens' preferences since political decision-making is open to the influence of lobby groups, political self-interest etc.
- care has to be taken that rejecting individuals' preferences does not constitute a moral offence of disenfranchising individuals in the decision-making process. It is not clear, for example, who decides what is a 'legitimate' preference and what is not, opening the way for elitism at best and totalitarianism at worst.
- even if individuals' preferences are motivated by self-interest, a rule that says everyone's preferences matter would automatically detect those who suffer from the actions of others, i.e. interdependencies, or 'externalities' should automatically be recorded[6].

> *The debate over policy evaluation techniques reflects substantial differences of opinion about how far individuals make decisions, or can be trusted to make decisions, that are in the interests of society as a whole. But the contrast between elf-interested and socially-motivated preferences is almost certainly an exaggerated and unhelpful one.*

---

[4] The literature on 'deliberative and inclusionary procedures' argues that prevailing political institutions are not guaranteed to elicit citizens' preferences and that 'new' institutions such as focus groups and citizens' juries are required.
[5] The fault here probably lies with the vast number of economics textbooks that continue to portray preference-formation as if it is motivated by self-interest alone, despite frequent admonitions to the opposite effect from distinguished economists over the last fifty years or so.
[6] An externality is any adverse or beneficial effect of an action by agent A on agents B, C…such that B,C… are not compensated for any adverse effect and are not charged for the benefit of any gain.

3   The policy matrix

Policy analysts emphasise the need to establish at the outset some framework for the comparison of the criteria of a 'good' policy (project, programme etc) and the alternative options that are open. A typical example is shown in Table1, which reveals the nature of the trade-offs in all choices. We have chosen a simple speed limit example, but any other example would suffice.

The alternative **policy options** are shown at the top right of the matrix, say changes in a speed limit on major roads. The **criteria** by which the desirability of changes in the speed limits could be judged are shown to the left of the matrix. The criteria might be the number of serious accidents, travel time saved and the cost of operating vehicles. **The criteria reflect the goals of the decision-maker**. The cells of the matrix 1a then show estimates of the change in speed limits on each of the criteria used. Illustrative numbers are provided. The second matrix, Table 1b, shows the same information but this time 'normalised' on an existing reference base, e.g. the current speed limit. Since injuries and vehicle cost increase with higher speed, but time spent travelling falls, there is a **trade-off** between the criteria, reflecting the point made earlier that goals are rarely consistent.

Tables 1a and 1b make it clear that the choice of the 'right' speed limit depends on factors over and above the 'basic' information provided about the effects of speed limits. What is required is some mechanism for trading off the time, cost and injuries, i.e. we need to know at what rate the benefits of saving time can be traded for increased cost and increased injuries. Economists adopt preferences, as revealed through willingness to pay, as the means of making the trade off, but any set of weights can be used to illustrate the principles involved. To illustrate, Table 1c shows what happens if we adopted the following money valuation figures: each injury is valued at €1 million and a year of saving time is also valued at €1 million. Then the computation is simple, as Table 1c shows. The highest net benefit would be for a change in the speed limit downwards to 70 kms/hr. Again, note that the matrix in Table 1c could also be generated by *any* procedure which produces rates of trade-off.

Table 1a Criteria/Alternatives Matrix: Original Data				
	Alternative speed limit options km/h			
Criteria	70	80	90	100
Serious injuries per million vehicle kms	5.0	5.4	5.9	6.5
Time spent travelling: years per million vehicle kms	3.3	3.1	2.9	2.7
Vehicle operating costs per million vehicle kms (€ million)	12.6	12.8	13.2	13.8

Table 1b Criteria/Alternatives Matrix: Normalised on 70 kms/h				
	Alternative speed limit options			
Criteria	70	80	90	100
Serious injuries per million vehicle miles	-0.4	0	+0.5	+1.1
Time spent: years travelling per million vehicle miles	+0.2	0	- 0.2	- 0.4
Vehicle operating costs: € million per million vehicle miles	- 0.2	0	+0.4	+1.0

Table 1c	Criteria/Alternatives Matrix: Monetised Outcome				
		Alternative speed limit options			
Criteria		70	80	90	100
Money value of serious injuries: € million		+0.4	0	- 0.5	-1.1
Money value of time spent: € million		- 0.2	0	+0.2	+0.4
Money value of vehicle operating costs: € million		+0.2	0	- 0.4	-1.0
Aggregated net benefit € million		+0.4	0	- 0.7	-1.7

The policy matrix is there to remind us that with <u>any</u> form of decision-making it is essential to state the goals clearly (the criteria), the different policy options and the effects that each policy option have on the goals. The matrix also shows that, whatever decision procedure we adopt, <u>all</u> evaluative procedures involve finding weights that reflect the relative importance of goals[7]. Finally, the sensitivity of outcomes to different weights can easily be tested: a form of 'value sensitivity analysis'[8]

These reminders are necessary because the illusion is sometimes created in the literature that policy evaluation can be 'value free'. It cannot be, nor should it be. Nonetheless, the fact that it has value content means that the goal (criteria, objective function) or goals should always be stated clearly. In many cases the goals of some supposed evaluative procedures are not stated by their advocates.

---

[7] Note that treating each criterion as being equally important still involves the selection of weights, in this case unity. Note also that only if all goals are consistent in the sense defined in the text and only if changes in policy affect each of the goals in the same direction would there be no need of weights. This is so unlikely as not to be an interesting case.

[8] The phrase 'value sensitivity analysis' was introduced in Pearce et al (1975).

4   Sustainable development

We can now proceed to investigate the various decision-making procedures and the linkages between them.

4.1   Limits and sustainability

A common feature of nearly all decision-making procedures emerging from the environmental literature is that they acknowledge some form of 'bio-physical' limits to economic activity. This statement may come as a surprise, since a large literature has developed which centres on the view that some decision-making procedures, especially economics-based procedures, operate as if there were no such limits. While this characterisation is justified with reference to some of the more esoteric theoretical literature in economics, it does not describe the policy-relevant literature[9]. The debate has therefore become somewhat misguided and the real differences of view relate to the following issues:

> How are limits detected?
> How far into the future will the limits 'bind' decision-making?
> What are the policies that might accommodate limits and ameliorate them?

Space forbids a detailed discussion, but some have argued that limits, for example on physical resources, will be reflected in **resource prices**. If the limits are binding, real prices will rise. There is little evidence that, globally, real resource prices are rising, but this observation also somewhat misses the point. The resources that would appear to be binding, if ecologists and others are correct, are those *without markets* - global atmosphere, biodiversity, for example - and if there are no markets, there are no resource prices to be observed. Indeed, the implicit price is then zero and at zero prices more of the resource will be demanded than at positive prices that would rule if there was a market[10]. Anyone deriving the conclusion that non-rising real resource prices imply a world without 'limits' has therefore misunderstood the limitations of this literature.

A critical issue with respect to 'biophysical limits' is how they are to be accommodated if markets do not exist to register and adapt to scarcity. The two central notions relevant to his debate are (a) **substitution** and (b) **constraints on the overall levels of 'consumption'**. Again, much of this debate is confusing because of a failure to define concepts properly. The issues can be illustrated through an analysis of the concept of **sustainable development**.

Sustainable development is defined as rising per capita levels of human wellbeing over time. As stated, it is an anthropocentric concept designed to deal with the alleged problem of inter-generational equity. Inter-generational equity problems arise when actions by the current generation threaten the wellbeing of future generations. Hence policies aimed at sustainable development will focus on the avoidance of activities that threaten future wellbeing. Contrary to

---

[9] Space forbids a detailed discussion. Some of the economic growth models of the 1970s were certainly constructed in such a way that some form of continuous substitution between natural resources and other inputs could go on 'for ever'. Modern-day 'cornucopians' (see the writings of Julian Simon and Herman Kahn) have also tended to borrow some of the suggestions of this literature, but they tend to be more persuaded by what they see as lack of evidence of actual rather than theoretical limits.

[10] It is an irony that many environmentalists object to markets as a means of allocating scarce resources when it is the absence of markets that largely explain the degradation of those resources.

the impression given by much of the popular literature, sustainable development is easy to define, the conditions for achieving it are more interesting and complex[11]. The literature has focused on conditions defined in terms of the capacity to develop, a capacity defined by **capital stocks** and their interaction with **technological change** and **population change**. Without offering any proof here, the intuition is that future generations can only be better off[12] if they have more capital per capita than we have today. It is immediately obvious that population growth is inimical to sustainable development since it 'dissipates' the capital stock[13]. Technological change, on the other hand, enables a given capital stock to generate more wellbeing per unit of the stock. An easy way to think of it, then, is to say that future generations will be no worse off if capital stocks are 'constant' and for the rate of technological change to just offset the rate of population growth. If technological progress is faster than population change then future generations could still be as well off as we are today with a lower capital stock, and so on[14].

Capital stocks, as is now well known, involve **man-made, natural, human and social capital**. This broadening of the concept of capital is critical to an understanding of sustainable development. For it is now easy to see that the *total* capital stock could be rising while any *one form* of capital is declining. The idea that forms of capital substitute for each other is embodied in the notion of **weak sustainability**. If, on the other hand, forms of capital are *not* substitutable then the requirement that the total stock be constant (rising) has to be supplemented by the requirement than the relevant specific capital stock should also be non-declining. In the literature, this has been termed **strong sustainability**.

4.2   Weak and strong sustainability

There is, for example, a heated debate between 'weak' and 'strong' schools of sustainability which tends to neglect the following issues[15]:

- while the strong sustainability literature has focused on natural capital as a constraint, it is arguable that **social capital** is also a constraint (e.g. social organisation is threatened, with some people arguing that social breakdown may be more important that environmental breakdown. Of course it is possible to believe both threats are very important);
- **one cannot have strong sustainability without having weak sustainability**, i.e. it is pointless to set a constraint on one form of capital unless there is also an overall constraint on the total stock. Otherwise the implication is that only one form of capital generates wellbeing, which is patently untrue. Some of the literature seems not to have understood this point;

---

[11] We abstract from the issue of defining 'development'. The suggestion, not proven here, is that the conditions for achieving sustainable development will be largely invariant with the definition and measurement of development.
[12] Strictly, can only have the potential to make themselves better off since capital stocks provide potential not guaranteed wellbeing. Future generations may, after all, fail to manage the capital stocks efficiently. On the foundations of the theory of sustainable development see Pearce et al. (1989) and Pearce and Barbier (2000).
[13] Again, the issue is complex. If population growth stimulates technological change, then its benefits could exceed its costs in terms of capital dissipation.
[14] The precise relationships are more complex, but these statements capture the essence of the modern theory of sustainable development.
[15] Roughly speaking, the debate defines the difference between ecological economists (those who do not believe in substitution) and environmental economists (who probably do believe in substitution in the main). However, see the text for how confused the meaning of substitution has become.

- substitution implies **commensurability** - i.e. a common unit of measurement for aggregation;

- strong sustainability also implies commensurability since it would not otherwise be possible to know whether one was faced with constant, rising or falling natural capital, i.e. we must be able to aggregate different types of natural capital. Since one cannot have strong sustainability without weak sustainability, it is also arguable that the wider notion of commensurability applies, i.e. between different forms of capital;

- constant natural capital is still consistent with **substitution within the total stock of natural capital**: solar power substitutes for fossil fuel, groundwater for surface water etc. Strong sustainability does not therefore imply no substitution at all. Again it is unclear if the point is fully appreciated. If there is no substitution within natural capital, then natural capital cannot be aggregated and a rule of not depleting the stock of natural capital has no operational meaning (no single item of natural capital could be depleted without replacing it with exactly the same form of natural capital).

- **the domain over which substitution takes place needs careful definition**. In one sense, strong sustainability has to be true: it is self-evidently not possible to substitute for natural capital *as a whole*. To see this, consider what one would substitute for the world's oceans or for the whole ozone layer. The answer is that not that there is limited substitution but that the question is meaningless. Without natural capital as a whole, life would cease. A large part of the 'substitution' debate fails to recognise that substitution in the economic sense refers to **substitution at the margin**: i.e. a small change in damage to the ozone layer, an incremental level of damage to the oceans, etc. This failure to distinguish **total and marginal substitution** has rendered a significant amount of the debate fruitless. Equally, it can be argued that some advocates of strong sustainability are talking about total substitutability since they feel that the world is close to its physical (total) limits. Whatever is the case, economists have perhaps been less than clear in explaining the marginal concept of substitution[16];

- **the empirical evidence for and against substitution at the margin has been generally absent**, the literature tending to resort to pure assertion one way or the other;

- **if natural capital is a constraint, it suggests that it is its *per capita* quantity that matters**. If so, then unless natural capital can be augmented by technological progress, a constant level of natural capital per capita implies a rising total level of natural capital in the face of population growth. It is obvious that technological progress does augment many forms of natural capital (e.g. we are more efficient in the use of materials) but less obvious what it means for other forms of natural capital. If so, a policy of avoiding natural capital loss is not good enough, natural assets must be expanded at a rate at least equal to the rate of population growth[17];

- weak sustainability is often characterised as being consistent with a 'no limits' standpoint, whilst strong sustainability explicitly acknowledges a limit on natural capital. But there is nothing in the weak sustainability paradigm that says the cost of substituting one form of capital for the other is constant or declining. Such a view would be consistent with the declining real price of resources argument, but, as noted, this argument applies only to

---

[16] This failure is at the heart of the well-meaning but totally misguided efforts to place an economic value of world ecosystems - see Costanza et al (1997). Economic value derives from marginal changes, not from total stocks. The Costanza work is criticised in Pearce (1998).

[17] The example underlines the earlier discussion about targeted populations. It is arguable that constant natural capital per capita is an achievable goal within the EU, but far less likely if the focus is the global population.

marketed resources[18]. **Hence it is not correct to define weak sustainability as if it fails to acknowledge biophysical limits**. This justifies the point made earlier that the debate about 'limits' has tended to miss some of the central issues.

The policy evaluation implications of weak and strong sustainability are potentially very different. If natural capital is not substitutable at the margin, then aggressive policies are needed not only to maintain what natural capital there is, but to expand it, especially if the population target is developing countries or the world as a whole since population growth makes the 'constant per capita capital' rule more difficult to achieve. Since the population of the existing EU is projected to *decline* by 2050, hence both strong *and* weak sustainability arguments would then theoretically be consistent with a modest *running down* natural capital stocks[19]. One could envision a policy of just maintaining natural capital in the EU but implementing a stronger policy of augmenting natural capital in the developing world, an effective radical shift in policy for the EU if it came about. More realistically, the EU should seek to expand its natural capital base but should seek to do much more than this in developing economies.

The decision-guiding evaluation approach implied in **strong sustainability does *not* involve a weighing up of costs and benefits**: the constraint of non-declining natural capital simply has to be observed *whatever it costs in terms of forgone alternative benefits*[20]. However, this does *not* mean that the natural capital stock need not be valued in some sense, since it is not possible to know whether it is changing unless some concept of an aggregate stock is developed.

Strong sustainability also has implications for the **choice of policy instruments**. Since environmental taxes and charges cannot be guaranteed to achieve a quantity target, they will not be preferred, whereas tradable quota systems (which are quantity-based) will be preferred, as will outright bans, prohibitions, quantity-based environmental targets etc.

It is perhaps not widely recognised that **there are real-world policy parallels for strong sustainability**, an issue that is again perhaps not widely understood. In the USA, for example, the **public trust doctrine** declares that damage to a natural resource simply has to be negated by reinstating the pre-damage conditions (Pearce, 2000). This doctrine makes no reference at all to costs. The same philosophy can be detected in the US Endangered Species Act. Similarly, some countries have 'nature laws' that permits loss of, say, wetlands, on condition that some offsetting equivalent natural asset is created. Such offset policies are effectively strong sustainability policies. Such policies have been severely criticised for ignoring the opportunity cost of conservation.

> *Strong sustainability would imply the use of quantity-based policy measures at the expense of the more uncertain price-based measures, and the neglect of any evaluation procedure requiring costs to be estimated. Arguably, strong sustainability is not consistent with the environmental policy objectives of the various treaties defining the Union (e.g. Article 130R on comparing costs and benefits).*

---

[18] One helpful way of thinking about it is to say that weak sustainability is consistent with 'Ricardian scarcity', i.e. a gradual rise in the real price of natural resources, whilst strong sustainability has built into it a Malthusian concept of absolute scarcity, i.e. biophysical limits. These notions, though not in the context of sustainability, are explored in Hall and Hall (1984). The essential point is that both notions of sustainability conditions embrace concepts of 'limits'.

[19] This remark needs careful interpretation. We are not saying that natural resource *should* be run down.

[20] Effectively, at the level of the constraint, the shadow price of natural capital is infinite.

If there *is* substitution at the margin, i.e. weak sustainability applies, then what matters is the **comparative social rate of return to incremental changes in different types of capital**. It may pay society to make a marginal reduction in natural capital if the social rate of return to the use of the land supporting that natural capital is higher in some alternative use. This weak sustainability is consistent with the use of **cost-benefit analysis** because cost-benefit analysis explicitly allows for gains and losses to be weighed against each other. Weak sustainability would also be consistent with other forms of decision-making such as cost-effectiveness, risk assessment etc. where costs and outcomes are compared in some form or another. By implication, weak sustainability is consistent with EU environmental policy as currently set out in the various Articles of Union. However, it is not clear if other principles affecting environmental policy are equally consistent.

Note that the weak sustainability paradigm stresses that non-market assets be valued in monetary terms or in some terms that permit comparison.

> *It matters which version of sustainable development the European Union is committed to. Strong sustainability implies quantity-based regulations designed to protect at least what natural capital there is, and dictating a radical expansion of natural capital in the developing world. Strong sustainability is not consistent with cost-based evaluation procedures: the cost of meeting the environmental constraint is simply irrelevant. This neglect of cost raises profound issues since, clearly, other socially high priority goals could be sacrificed because of the cost of meeting a strong sustainability constraint. But some existing policy initiatives based on the public trust doctrine embrace strong sustainability. Weak sustainability is consistent with cost-benefit type appraisal in which substitution is assumed, and would be consistent with a decline, constancy or rise in natural capital, depending on comparative social rates of return.*

5 Sustainable consumption

Like sustainable development, the notion of *sustainable consumption* has created substantial confusion in the literature. This confusion derives from (a) failure to integrate the notion with the theory of sustainable development, of which it is a natural component, and (b) a failure to distinguish between 'consumption' as an economic concept and the resource inputs to consumption. **What is meant by sustainable consumption depends very much on what definition of consumption is employed**.

4.3 Sustainable consumption within the theory of weak sustainable development

Because of the development of the theory of sustainable development it is in fact possible to give the notion of sustainable consumption a rigorous meaning. To show this we require a small digression into the theory of **modified national income accounts**.

Conventional national accounts take the form:

$$NNP = GNP - dK_m = C + I - dK_m$$

Where NNP = net national product, GNP = gross national product, dKm = depreciation on man-made capital, I = gross investment.

Expanding the notion of net national product to include human and natural capital (K_h and K_n) gives:

$$gNNP = C + I - dK_m + aK_h - dK_n$$

where dK_n is depreciation on natural capital, and aK_h is *appreciation* on human capital[21]. gNNP denotes 'green' national product.

We can also write

$$S = GNP - C$$

Where S is the conventional measure of gross savings. Hence

$$S_{net} = GNP - C - dK_m$$

and

$$S_g = GNP - C - dK_m + aK_h - dK_n$$

S_g is 'genuine' or 'green' savings and is equal to the conventional notion of gross savings (GNP-C) less any depreciation on capital stocks plus an appreciation on capital stocks.

---

[21] Appreciation because human capital relates to the stock of knowledge and skills and these tend to grow through time rather than decline.

S_g is a measure of weak sustainability. As long as $S_g > 0$, a nation is saving more than the depreciation on its capital assets. If $S_g < 0$, then the nation is consuming capital and it is not sustainable over any reasonable period of time (Atkinson et al, 1997)[22].

$S_g = 0$ therefore defines 'knife edge' sustainability in the weak sense. Setting $S_g = 0$ gives us the maximum level of consumption consistent with sustainability, i.e.:

$$C_{max,ws} = GNP - dK_m + aK_h - dK_n$$

The (maximum) sustainable level of consumption is that which is consistent with genuine savings being zero[23]. In other words, sustainable consumption can be given a meaning within the context of weak sustainability. (Technology has been ignored but could be added to the right hand side. Social capital can also be allowed for)[24]. Ironically, this approach appears to be consistent with what some advocates of *strong* sustainability argue. Thus, for Costanza et al (1991) sustainable consumption is

> '..that amount of consumption that can be continued indefinitely without degrading capital stocks, including natural stocks' (Costanza et al. (1991), p.8)[25].

The formula above defines a context in which net investment is actually zero. The amount of investment taking place is just sufficient to offset depreciation. This will not guarantee non-declining per capita wellbeing if population is growing, nor would it achieve some target rate of growth of wellbeing, e.g. that people should be 'better off' as each year goes by. More generally, $C_{max,ws}$ is the maximum sustainable level of consumption but it is not necessarily the optimal level of consumption[26]. Thus, $C_{max,ws}$ is best thought of as some upper limit on optimal consumption. Indeed, $C_{max,ws}$ for the EU is likely to be *above* current levels of consumption because World Bank estimates show that EU countries have positive genuine savings (Hamilton and Clemens, 1999). Genuine savings could therefore be lower, and hence sustainable consumption could be *higher* than it is at the moment. However, we repeat that maximum sustainable consumption is not the same as optimal consumption.

What policies would follow from a focus on the genuine savings/maximum sustainable consumption notion? The genuine savings approach shows that there are a number of policies which could ensure sustainable consumption is as high as possible - investment in education , invest in technology, investment in social capital, reduction of environmental damage through decoupling of the relationship between consumption and resource inputs and, more generally, encouragement of savings via tax-breaks and interest rate changes. The lessons are not new, but they now fit together in a coherent story of sustainable consumption**.**

---

[22] Again, it is more complicated than this, but the rules as stated capture the essence of the issue.

[23] This is the 'Hartwick path'. Note that it is a sustainable but not necessarily an optimal path.

[24] As with much of the analysis in this short paper, there is a clear need for much more detailed exposition, perhaps in a future document or report.

[25] Costanza et al. may not have recognised that this is a *weak* sustainability criterion since it embraces all capital stocks, but they may have intended to imply that the overall stock of capital should not decline and, additionally, the stock of natural capital should not decline, i.e. strong sustainability.

[26] The reasons that it is not equivalent to an optimal path are complex and are not addressed here. See Hamilton (1993).

5.2 Sustainable consumption within the theory of strong sustainable development

How does the picture change if strong sustainability is assumed? The basic difference is that there is an added constraint. In addition to requiring that $Sg \geq 0$, we require that $dK_n \leq 0$. The maximum sustainable consumption level is now:

$$C_{max,ss} = C_{max,ws} - OC_{cons}$$

The expression OC_{cons} is the sacrifice of consumption that has to be made in order to conserve K_n at its existing level.. It can be thought of as a *cost of conservation* or, analogously, an *abatement* cost such that the expenditure involved conserves the stock of natural capital.

> *The maximum sustainable level of consumption is less under strong sustainability by the cost of avoiding natural capital depreciation. This is because some consumption has to be diverted to replacing natural resources in order to honour the commitment to keep natural capital at least constant*.

Annex 1 shows a diagrammatic exposition of the different consumption paths.

5.3 Optimal and sustainable consumption

In economics, it is assumed that consumption alone produces 'utility' or 'wellbeing'. In a world without population growth, then, the optimal level of consumption appears to be the highest level of consumption consistent with sustainability. That has already been defined as 'C_{max}' in the previous sections. The reality is more complex for various reasons. First, population growth rates are usually positive, so that the pursuit of C_{max} above would not guarantee non-declining *per capita* consumption, which is the requirement for sustainability. Second, technological change needs to be considered as this will augment the efficiency of resources, i.e. will raise the ability to generate consumption from given inputs. Third, optimality is usually derived from setting up the problem as one of maximising the discounted future flows of consumption, whereas sustainability might not be consistent with this formulation of the problem (see the Annex)[27]. Fourth, for complex reasons, the two maximal sustainable consumption paths ($C_{max,ws}$, and $C_{max,ss}$) are not themselves optimal. It is possible that an optimal path with rising per capital consumption exists but it will involve significant technological change.

5.4 How should 'sustainable consumption' be achieved?

We have seen that sustainable consumption has meaning in the context of the theory of sustainable development and that what constitutes the maximal sustainable level of consumption depends on whether we believe the weak or the strong view of sustainability. We have also seen that maximal sustainable consumption is not the same as optimal consumption, but technical difficulty and space forbid an elaboration of this point here.

---

[27] That optimality and sustainability need not be the same thing was originally shown by Page (1977). For a more recent statement see Pezzey (1988).

Suppose now that any of these notions of sustainable consumption is set as a policy objective.

> *The essential difference in policy is that a strong sustainability view would not allow any sacrifice in the aggregate total of natural resources unless these are compensated for by offsetting investments in the same or substitute resources, while the weak sustainability view would allow natural resources to decline provided the decline was offset by investment in some other form of capital.*

It is very important to note that weak sustainability is *not* consistent with running down resources and *consuming* the proceeds[28]. Weak sustainability does require an offsetting investment, but that investment can be in *any* form of capital. Strong sustainability limits the offset to investments in natural capital. **Weak sustainability requires that the rents from natural resources be reinvested, not consumed[29].**

On the weak sustainability approach, policy appraisal rules that compared 'true' rates of return to investments would ensure that investment is allocated across the various forms of capital in an optimal fashion. The environment would be degraded if and only if the opportunity cost of conserving natural resources was higher than the return from conservation. As noted before, this underlines the importance of 'valuing' the environment in commensurate terms that permit rates of return to be compared, and the only means of doing this is via money as a measuring rod. Full and detailed cost-benefit appraisal is thus essential to the weak sustainability approach.

On the strong sustainability approach some form of valuation is still required. Recall that the rule requires that the total stock of K_n does not decline. But K_n is made up of a myriad set of resources that cannot be measured in common units (hectares, tonnes, cubic metres etc.). Even if they had the same units, the relative importance of their loss is not the same. It matters less than one tonne of sand is used up than that one tonne of PCBs is released. Hence aggregating K_n involves a common unit that builds in some method of weighting for relative importance. Money does that because it reflects human preferences. It is possible to imagine some other index of natural resources that is weighted in some way to reflect toxicity etc.[30] Whenever the resulting index shows a decline, action would need to be taken to restore it to its initial value. In a sustainable consumption context that would imply taxing consumption and ensuring that the proceeds are reinvested in natural capital until the index resumes its initial value.

Some form of earmarked tax on consumption would therefore appear to be a policy implication of strong sustainability. On the weak sustainability paradigm, a tax might also be used to reduce consumption and increase savings, or revenues might be used to ensure that investment takes place in education, technology etc. In practice the difference between the two policies may not be that great because a strong sustainability policy has also to honour a weak sustainability constraint on the overall stock of capital, as noted earlier.

But **there are problems with any policy designed to reduce aggregate consumption**.

---

[28] This is why so many countries actually fail a weak sustainability test. See Hamilton and Clemens (1999).
[29] This is the 'Hartwick rule' again.
[30] Efforts have been made to derive a single indicator based on changes in individual indicators which are then weighted by public opinion. See Hope et al. (1991) and Hope and Parker (1995). For an approach based on trend indicators weighted by the gap between the existing state of the environment and the target to be achieved see Adriaanse (1993).

- First, it is very likely to be socially unacceptable unless it is secured through strong incentives to save. Reducing consumption is likely, for example, to reduce individual wellbeing and could have serious employment consequences if the sectors receiving earmarked funds are equally labour-intensive as the consumption sectors.

- Second, it could have consequences for nations exporting to the EU, and especially developing nations in so far as they export consumption products rather than investment products.

- Third, other than through consumption taxes and savings incentives, reducing consumption appears to involve 'lifestyle changes': somehow individuals are transformed in such a way that they decide not to consume so much and save more. Some of the literature implies a different scenario even to this, namely that people simply consume less because they work less, i.e. their consumption declines because their incomes decline[31]. But, despite the evidence to the effect that people in advanced economies have undergone 'value shifts' over time, there is little evidence that these shifts have altered consumption levels. The risk is that if lifestyle changes are not brought about spontaneously, or by encouragement and persuasion, they will be brought about by fiat. The risk here is that such measures would infringe individuals' basic rights to choose how to lead their lives.

- Fourth, changing the aggregate level of consumption appears to be a very blunt policy instrument for the objective of reducing environmental degradation. This last point is perhaps the important one, for it highlights a major confusion in the literature on sustainable consumption. **It is possible to have rising levels of consumption and falling levels of resource depreciation and environmental degradation**. What has got confused is the difference in meaning between 'consumption' and the resources going into consumption. There are many high valued consumption activities that are demanding of very little by way of resources. If consumption and resource use can be 'decoupled', then the objective of maximising sustainable consumption can be achieved without significant further degradation of the environment. It seems clear from the literature that this **decoupling** or **dematerialization** is what many people mean by sustainable consumption. But many do not mean this and this latter group is far more clearly aiming to reduce economic growth and hence consumption *levels*[32].

---

[31] This appears to be what many 'anti-growth' advocates believe.

[32] Part of the confusion stems form loose wording and vague phrases like 'consumption patterns'.

6   Decoupling/dematerialization

Section 5 showed that there were quite rigorous meanings to be attached to the phrase 'sustainable consumption'. It also suggested that, while it is theoretically possible to achieve maximum sustainable consumption through policies designed to reduce aggregate consumption (assuming that was required), this is at best an inefficient approach and at worst a socially disastrous one. A more sensible approach is to change the ratio of consumption to natural capital, i.e. to decouple the economy and natural resources. All kinds of indicators exist for checking what these ratios are (although they are usually express in terms of ratios of inputs to GNP rather than consumption). The most famous are energy/GDP ratios and, more recently, materials-intensity ratios. An example is the **total materials requirement (TMR)** approach in Adriaanse et al (1997). TMR involves what is essentially a familiar activity of constructing input-output accounts but in physical terms[33]. The TMR approach adds up all the resources used in the production of economic goods, including those resources that are discarded as waste and which have no economic value. Those entering the monetary flow are recorded in conventional national accounts but those not afforded a market price are excluded from those accounts, the so-called 'hidden flows'. The result is a set of figures of resource flows in the economy. Advocates of TMR approaches argue that these figures could be used to track whether 'decoupling' is taking place or not. Adriaanse et al (1997), for example, show time series of TMR *per capita* for several countries. These would suggest that, of the four countries they study, only the USA is experiencing 'dematerialization', with Germany, the Netherlands and Japan showing rising TMR per capita. But expressed as a ratio *to GDP*, all countries show a dematerialization trend.

The obvious problem for the issue of *policy guidance* is that, while such estimates are interesting, they have no policy meaning. The reason is actually acknowledged by the researchers. One tonne of material A is not the same as one tonne of material B in terms of environmental importance. The idea of aggregating all materials into tonnes is therefore meaningless for policy purposes. What matters is the 'impact weighted' amount of materials and one cannot know what these impacts are without knowing: the environmental toxicity of the material in question, the assimilative capacity of the receiving environments, levels of exposure and levels of human and ecosystem response to such levels of exposure. Additionally, if policy is to be sensitive to human preferences, the weights must also relate in some significant way to those preferences.**TMR totally neglects the issue of whether a given tonne of materials is important or not**. In terms of the criteria/policy matrix introduced in Section 3, tonnes have been equally weighted in the TMR approach and there is no conceivable justification for this beyond the convenience of being able to add up different tonnes.

Much the same remarks apply even to very popular indicators, such as the ratio of energy to GDP. Each energy input is not equally important because it depends on what impact the different energy inputs have on the environment. Natural gas is, for example, less damaging than, say, coal.

> *Indicators of materials intensity are interesting but their use for policy purposes is extremely limited because of a failure to define what the goal is meant to be. It appears to be that one should reduce the TMR of economic activity. But this has no necessary implication for environmental improvement since the mix of materials matters as*

---

[33] Environmental and resource input-output accounts were popular in the 1970s and derived from the early work on materials balances by Kenneth Boulding, Allen Kneese, Ralph d'Arge and Robert Ayres.

much as, if not more than, the total. What is needed then is a set of weighted materials and energy input coefficients. The weights could be based on human toxicity (dose-response coefficients), ecosystem toxicity, public opinion, and individuals' preferences expressed in monetary terms. Essentially, what appear to be 'new' indicators come full circle to indicators that have to be weighted by some set of risk factors or preferences. But the notion of dematerialization is a sound one and, indeed, has to be the basis of efforts to improve the environment and to achieve sustainable development.

7 Carrying capacity

7.1 The notion of carrying capacity

One long-standing notion of biophysical limit is that of carrying capacity. In the context of humans, carrying capacity is set by the 'binding resource', i.e. the resource that is most limited in supply. Assuming that humans have a minimum viable requirement for the resource below which they would cease to exist, then carrying capacity is given by the simple formula:

$$CC_i = MSP_i = \frac{\text{Annual resource yield(i)}}{\text{Minimum resource requirement per capita}}$$

Where i is the binding resource, and MSP is maximum sustainable population.

How useful is the notion of carrying capacity? It has some value as an **awareness raising** indicator. Beyond that its policy relevance is negligible. The reasons for this are:

- Carrying capacity indicators imply zero substitutability between assets. But resources can be substituted at least by other resources even in developing country contexts (fuelwood by kerosene for example).

- Resource yields can be increased by technological change in the case of renewable resources, and depletion profiles can be extended by technology in the case of non-renewable resources.

- Carrying capacity calculations have limited relevance when trade is possible since the scarce resource can be imported in exchange for another asset in which the exporting nation has a comparative advantage. We note below a carrying capacity concept that appears to imply that trade is not desirable, however.

- It is often possible to invest in carrying capacity even in poor country contexts, e.g. by improving water supplies through better capture of rainwater.

- CC is a limit. It tells us nothing about the desirable level of population. More than this, it is a limit determined by resource availability and by minimum input requirements. No-one would suggest that CC represents a desirable state of affairs if everyone is living at minimum requirements levels. In many respects, carrying capacity is a **survivability** concept not a **sustainability** concept. Survivability is about maximising the time available on Earth for human species, independently of the quality of that existence.

- The evidence from exercises involving crops and food, and from fuelwood availability, suggests that quite a few African countries have gone well beyond carrying capacity. But this means that they must be steadily dying or starving (independently of any crisis droughts etc), or that the numbers are wrong, or that they have found other strategies for coping with physical scarcity. There is evidence to suggest that statistical surveys tend to under-report investments in carrying capacity, e.g. woodlots and reforestation.

But there is a sense in which carrying capacity serves as a benchmark. It may help to signal that certain policies are urgent:

- raising resource productivity
- investing in carrying capacity
- encouraging trade
- limiting population
- encouraging substitutes
- changing the ratio of resource use to consumption

Note that these policies are very similar to those derived from the analysis of sustainable consumption.

7.2   Is there absolute scarcity?

One way of looking at whether absolute scarcity exists is to estimate the physical scarcity of an exhaustible resource via the 'exponential index' of stocks. This measures the number of years before stocks are exhausted given an estimate of stocks and an estimate of the rate at which consumption grows. A simple formula for estimating this index, T, which is in years, is:

$$T = \ln.(sg + 1)/g$$

Where T is time to exhaustion, ln is logarithm, $Q_0/q_0 = s$ which is the static reserve index, i.e. the total stock in the initial period (Q_0) divided by the extraction in the initial period (q_0), and g is the growth rate of extraction. Table 2 illustrates for some global resources.

Table 2   Changing values of 'resource life' 1970 to 1994

Resource	T_{1970} years	T_{1994} years	Rate of change in T % p.a.
Aluminium	31	104	5.2
Copper	21	25	0.7
Iron	93	115	0.8
Lead	21	11	- 2.3
Mercury	13	20*	1.8
Silver	13	na	na
Coal	111	139	0.9
Gas	22	42	2.7
Oil	20	35	2.3

Resource lives actually *increase* rather than decrease.

Such indicator serve to remind us that technological change improves the efficiency with which we use resources, and that discoveries often occur faster than depletion. But all the resources in Table 2 are marketed. As noted earlier, the real concern about resource exhaustion is not about

marketed resources, it is about the generally non-marketed ones, diversity, atmospheric sinks, water resources etc.

> *There is a need to develop better indicators of carrying capacity for non-marketed resources, especially biological diversity. The reality is that we do not know what a minimum viable level of diversity is. In the same way, we do not know what an 'acceptable' maximum rate of climate change is (despite the concept being embodied as a goal in the Framework Convention on Climate Change). There is a substantial research agenda in this respect.*

7.3 Carrying capacity and net primary product

Arrow *et al.* (1995) propose that a more general indicator be employed such as that set out by Vitousek *et al.* (1986). This describes pressures in terms of how much Net Primary Productivity (NPP) human beings currently appropriate as an indicator of human appropriation of ecosystems under a variety of scenarios. The starting point is photosynthesis, the process whereby energy from the sun is turned into chemical energy embodied in biomass, and which is the basis for life on earth. Ecologists tend to use energy or carbon flows as their measures so that:

GPP = gross primary production = energy or carbon fixed by green plants in photosynthesis, all measured per unit of time.

NPP = net primary production = energy or carbon fixed in photosynthesis *less* the energy (or carbon) used up by plants in respiration.

Rates of conversion of solar energy to chemical energy are very low, perhaps of the order of 1 per cent. Forest tend to be more efficient at capturing solar energy than oceans. Essentially, it is NPP which is potentially 'available' for use by non-plant species, including humankind. The concept of an 'ecological limit' can be measured by the extent to which human beings 'appropriate' the NPP. The higher the level of appropriation, the less NPP is available for all other forms of life that need to consume NPP. Thus, in forests perhaps 5-7% of NPP is consumed by animals, but in the open ocean the figure may be as high as 40%.

Estimates of human appropriation of NPP suggest that humans already dominate the consumption or use of NPP. Vitousek et al. (1986) estimated that more than 40% of the Earth's land surface has been transformed by man. NPP is like a surplus or a net investment after depreciation (what is required for maintenance of function). The standing stock of biomass today is probably around 1800×10^{15} grams (about 1800×10^9 tonnes, i.e. 1800 billion tonnes), and the NPP is about 175 billion tonnes. In turn, NPP on land is about 132 billion tonnes and of this it is thought that humans 'appropriate' about 30-40% (Vitousek *et al*, 1986). Interestingly, only a minute fraction, around 1 billion tonnes, is consumed directly for food. Most of it is appropriated in the form of wasted food, forest products, residues and pastures.

Does it matter than humans appropriate 30-40% of NPP? The problem is that this fraction will rise faster and faster as population expands and this means that there is less and less NPP left over for the other functions to be served by primary producers. Those other functions can be summed up as life-support functions. **The NPP approach is not strictly telling us anything different to the story about land conversion, deforestation, pollution etc. It is another way**

of saying that humans are displacing other species and capturing ecological functions that are also valuable as life support systems.

Vitousek et al (1997) elaborate these statistics by adding that man is responsible for 20% of CO_2 concentrations in the atmosphere, over 50% of water use and nitrogen fixation, are responsible for introducing 20% of plant species in Canada, account for over 20% of bird extinctions in the last few millennia, and have degraded or overfished some 60% of the world's fisheries. In a detailed assessment of just one region, Haberl (1997) finds that over 40% of NPP is appropriated by man in Austria. One consequence of this process of appropriation is the loss of biological diversity, essentially because man competes for available land with other species.

NPP appropriation indicators provide one interesting measure of 'biophysical limits'. It is not clear that human ingenuity could change the rate of global photosynthesis much, so that, in this sense, NPP is much more akin to an unalterable carrying capacity concept.

7.4   Carrying capacity: ecological footprints

The concept of an 'ecological footprint' (EF) was developed by Wackernagel and Rees (1996) as a measure of the extent to which the earth's carrying capacity is appropriated by human activity. The approach is essentially one based on strong sustainability in which the aim is to conserve the stock of natural capital (and ideally increase it). But whereas the economic approach to sustainability requires that natural capital (and other forms of capital) be monetised, advocates of EF reject monetisation because, reflecting as it does a statement of human preferences, those preferences may fail to recognise biophysical limits. Wackernagel and Rees object to monetisation not just on these ground: they are opposed to discounting (the monetary rate of exchange between consumption now and consumption in the future), to marginal analysis generally, and to any suggestion that natural capital has substitutes. The approach adopted by Wackernagel and Rees is therefore to find some other common unit of human impact and they choose land area.

To compute the EF the procedure is as follows:

- identify and measure the components of consumption in a given region: food, energy, transport, consumer goods and services.
- for each item of consumption, estimate the area of land that would have to exist in order to generate the resources involved in that consumption
- add the land areas to determine the complete 'footprint' of the region
- compare the footprint with the actual size of the region generating the footprint.

An example will help.

Wackernagel et al (1999) illustrate the EF approach for Italy. Each consumption commodity (e.g. cereals, fish, timber, tobacco etc.) is listed. Using internationally available statistics, the 'apparent consumption ' of commodity i ($C_{a,i}$) is computed as:

$$C_{a,i} = Q_i + M_i - X_i$$

where Q_i is domestic production of the good in question, M_i is imports, X_i is exports. The units of C_a are whatever is relevant, e.g. tonnes, cubic metres etc. C_{ai} is then divided by the average

productivity (yield) of land, y_i, in producing the commodity in question. Since the units of y are physical output per hectare, we have $y = Q_i/L$ and hence the ecological footprint is measured in per capita terms as

$$EF = (C_{a,i}.L_i)/Q_i.POP$$

Thus, Italy's apparent consumption of vegetables and fruit is 30.75 million tonnes, its population is 57 million, 'average productivity' is 18 tonnes/ha, so the EF is

$$EF \text{ vegetables/fruit}) = (30.75)(10^6)/(57.10^6.18) = 0.03 \text{ hectares per person.}$$

Extending across all consumer commodities, and with various adjustments to secure comparability, Wackernagel et al (1996) secure the result that each Italian 'commands' 4.2 hectares of land. The 'supply' of 'bio-capacity' is then estimated, i.e. the availability of land within Italy for crops, CO_2 fixation etc. This comes to 1.3 ha/cap. If a policy aim was self-sufficiency, i.e. if it is thought that Italy should meet its own ecological demands from within its borders, then, clearly, Italy is in 'national ecological deficit' of 2.9 ha/cap since domestic ecological capacity can meet only about one-third of Italy's ecological demand.

How much ecological capacity is there available globally? Wackernagel et al (1999) suggest that, globally, biologically productive 'land' is made up of:

0.25 ha/cap arable land
0.90 ha/cap forest land
0.60 ha/cap pasture land
0.50 ha/cap sea space
0.06 ha/cap built up land

2.31 ha/cap total

But this is biologically productive land and mankind is not the only 'demander' of this quantity. A rough adjustment is made for non-human biodiversity demands at 12% of the world's land area, so that the maximum available to humans is 2 ha/cap. (Note the links to the NPP approach discussed above). This is what is 'available' now. If population grows, so that a population of 10 billion would reduce the average to $2/(10/6) = 1.2$ ha/cap. If the 'norm' now is 2 ha/cap it will clearly change very quickly to 1.2 ha/cap as population grows. Wackernagel et al. declare that 'the challenge is to reduce the average footprint to at least this size' (Wackernagel et al, 1999, p.384).

Analysing 51 countries, Wackernagel et al. (1999) find that most developed countries have significant ecological deficits of around 3-4 ha/cap. The highest deficit is Singapore with 6.8 ha/cap, not dissimilar to Hong Kong's at 5.1 ha/cap. The only developed economies with ecological surpluses are the Scandinavian countries, Iceland, Canada, Australia and New Zealand. Some developing countries are in surplus, but a quite a few are in deficit: China, India, Bangladesh, Philippines, Mexico, for example. Globally, the EF exceeds the world's ecological capacity: average demand is 2.8 ha/cap compared to the notional 2.0 ha/cap available.

The notion of the EF is clearly useful for awareness raising. In terms of policy it adds little to what has been derived before from carrying capacity measures (which is what the EF is, combined with some notional 'right' to equal shares of the world's ecological capacity). Thus Wackernagel et al. (1999) derive the following policy options:

- raise productivity per unit land/sea area
- lower resource use per unit consumption
- 'reduce consumption'.

The first two amount to the need to raise resource productivity increase discussed previously. The last is problematic as was noted earlier and it is unclear that it would serve any purpose other than causing more social problems, even if it was the realistic object of policy. That it is not a realistic policy is quickly seen by just two considerations:

(a) only some form of global government could overcome the fact that no one country has an incentive to reduce consumption unless others do the same;

(b) while the 'ecological deficits' are expressed in per capita terms, their conversion to absolute terms by multiplying through by population shows that poor countries with large populations have larger ecological footprints than rich countries with smaller populations. This is shown in Table 3 below. But it is hard to imagine policies designed to reduce consumption in China and India, a logical consequence of the EF approach.

Table 3   'Deficit' ecological footprints for selected countries

Country	EF deficit/cap = ha/cap	Population = million	Total EF deficit = million ha (rounded)
USA	-3.6	270.0	-972
China	-0.4	1238.6	-495
India	-0.3	979.7	-294
UK	-3.5	59.1	-207
Germany	-3.4	82.1	-279
Denmark	-0.7	5.3	-4
Netherlands	-3.6	15.7	-57
Hong Kong	-5.1	6.8	-35
Singapore	-6.8	3.2	-22

Sources: ecological deficits from Wackernagel et al (1999). Population from World Bank data sources.

How useful is the concept of the EF for policy purposes? Van Kooten and Bulte (2000) list the following criticisms:

- a major component of the EF for developing countries relates to their carbon dioxide emissions. The EF methodology deals with this by measuring the area of land needed to grow biomes that would sequester the carbon. But there is no particular rationale for selecting sequestration as the only means of offsetting ecological demands brought about by fossil fuel burning. The optimal mix of abatement measures may well include sequestration

but will also include significant amounts of emission reduction, something the EF methodology does not address. Additionally, what constitutes an optimal mix requires that different time profiles of carbon fixing and emission reduction be compared, and this cannot be done without some form of discounting. Yet the authors of the EF approach are opposed to discounting.

- There are substantial uncertainties about how to calculate the land areas required to offset waste flows
- While EF advocates are opposed to the notion of substitution between forms of capital, the very process of aggregating different types of land assumes substitution. First, substitution between land as natural capital is assumed. Land in different uses is 'weighted' by its productivity, i.e. yield factors. This, of course, implies substitution between the land uses. Moreover, yields are simply listed without investigating whether they reflect economic distortions such as subsidies. '….solutions to environmental problems that depend on substitution cannot be studied using the EF tool' (van Kooten and Bulte, 2000, p.265).
- Substitution between natural capital and other forms of capital is denied but has actually to be assumed for the aggregation process to take place. This has to be the case because certain investment activities, e.g. housing construction, are evaluated using assumptions about how much land is needed for, say, timber. But the timber could come from land areas with very much higher yields by engaging in international trade. So, rather than one hectare of land in, say, Italy being required to produce X units of timber, Italy could secure X from another area overseas where the land required would be only some fraction of X. In this respect, trade reduces the EF. Overall, substitution is implicit in the aggregation process and different assumptions about substitution will affect the aggregate EF.
- The EF makes no distinction between land uses that are sustainable and those that are not. Land is also assumed to be 'uni-functional', i.e. serving only one use, whereas much land is multi-functional. Its productivity ('yield') has to account for these multiples uses.
- The EF is quite explicitly 'autarchic'. The more a country engages in international trade the bigger its EF is likely to be (though it is possible to have cases when this will not be the case). Hence the policy implications is that nations should minimise, not maximise trade opportunities. Apart from the implications of this for human wellbeing, if nations should be autarchic, so, presumably should regions within a nation, districts within a region, and, ultimately, persons within a district.
- As Table 3 shows, certain economies that are highly urbanised (Netherlands, Singapore, Hong Kong) can never be sustainable since they can never meet their ecological demands from their own land. Even maximising the land productivity of their imports probably cannot get them to a net positive EF (i.e. an EF of less than the nominal 2 ha/person). What are the policy implications for such nations if they can never be sustainable?

Van Kooten and Bulte (2000) conclude:

> 'in the construction of the EF metric, the very same measurement issues (aggregation, substitutability, discounting, valuation) have not been dealt with in a meaningful way. Due to this imperfection, the EF is useless for policy analysis' (p.264).

8   Environment and equity

8.1 Environmental space

A significant part of the debate about resource management is motivated by an understandable concern for equity between nations and especially equity between rich and poor nations. The ecological footprint concept has a notion of 'entitlement' to the world's carrying capacity, an entitlement that is equal to global land yield (aggregated across different land functions such as crops and carbon sequestration) divided by the world's population. As population grows, the entitlement diminishes unless global land productivity rises. This notion borrows from an earlier concept of 'environmental space' (ES) which can be defined as:

> ' the quantity of energy, water, land, non-renewable raw materials and wood that we can use in a sustainable fashion' (Hille, 1997).

Two concepts appear to be embodied in this notion: some flow rate of use that is sustainable in the sense of lasting for a very long time, and some notion of 'equity', i.e. what constitutes fair access to that flow rate of use. In some approaches there is also a minimum sustainable use rate, i.e. some use rate below which human wellbeing would be threatened (the carrying capacity concept introduced earlier).

How might an equitable share be computed? One suggestion is that a fair share is given by a country's population as a fraction of world population. Hille (1997) reports on a Dutch analysis carried out by Friends of the Earth that uses these notions. Using population shares will obviously offend another equity principle if it is not modified. The reason is that population outside any given country may grow (at say a rate ΔPOP_w) faster than the population within the given country ΔPOP_i so that the 'fair share' formula:

$$(POP_i / POP_w)_. R_w = R_i$$

(where 'i' denotes the country in question, 'w' denotes the rest of the world, R denotes sustainable resource flow, and POP is population) will result in R_i going down. Yet country 'i' is not responsible for the increased population growth so that it seems unfair that it should be penalised for population growth in the rest of the world. Moreover, if the above equation was to be used as a 'fair shares' formula, it would provide an incentive for each country to encourage population expansion in order to secure a larger share. Environmental space begins to imply unrealistic notions of institutional change - it implies a virtually dictatorial world government in order to avoid the game-theoretic context of an international agreement on such shares.

To avoid this aspect of unfairness, the Dutch study sets a limit on POP_w which could be, say, the population in a specified year. If a country's own population POP_i rises after that, its entitlement would remain the same so that its per capita entitlement would actually go down. The virtue of this approach is that it at least recognises the central role of population growth, something that often tends to be studiously avoided in discussions of 'sustainable consumption' concepts.

Now consider R_w. There are several problems of measurement, all of which were met with the EF concept as well. Some resources are tradable - e.g. timber, energy - some have limited tradability - e.g. water - and some have no tradability - e.g. land. Some resources are therefore defined within local geographical areas, others are defined globally. The equity notion in the

Dutch study is confined to inter-nation comparisons. There is no notion of equitable shares *within* a country because 'people's judgements regarding distributive justice vary as between countries' (Hille, p10). This avoids, unfortunately by sleight of hand, the problem found with EF that, if trade between nations is to be minimised, trade within nations should also be minimised, so that we each end up with 'personal' resource entitlements. In the same way, notions of distributive justice cannot be different within a country and beyond it: what is fair must be universally fair.

The next problem is to define what is sustainable use of resources. An example from the Dutch study can be given. The sustainable use of the global atmosphere is a goal embodied in the Framework Convention on Climate Change of 1992 which speaks of aiming for:

> 'stabilisation of greenhouse-gas concentrations…..at a level that would prevent dangerous anthropogenic interference with the climate system'.

The Framework Convention does not define what 'dangerous interference' means, so it offers no guide to the sustainable use of the atmosphere. The Dutch study assumes the limit on rates of warming is $0.1^{o}C$ per decade and from this deduces an 'allowable' rate of global emissions of greenhouse gases, i.e. R_w. This can in turn be converted to an energy entitlement so that R_w is expressed in units of primary energy. The result is a measure of R_i. In the Dutch study the area of focus is the European Union so, for example, the energy entitlement becomes 60 GJ per annum per person. As primary energy use in the EU is about twice that currently, the reduction required is 50% by the target date, 2050 in this case. Note that this is well within the 'Factor Four' calculations for what is achievable. The details need not detain us, although some of them are interesting - e.g. quite explicit value judgements are made to the effect that nuclear energy is 'not desirable', resulting in it being hypothetically phased out, this raising the requirement of other energy sources to meet the entitlement.

Materials are dealt with as an aggregate using the notion of 'material input'. Essentially what this is in the addition of all the tonnage of materials used. To find the total tonnage it is necessary to estimate the 'rucksack' of a given extraction of materials. Suppose one tonne of aluminium requires 4.8 tonnes of bauxite for its manufacture, but each tonne of bauxite requires the removal of 0.6 tonnes of soil. The total tonnage of materials required to produce one tonne of aluminium is thus 4.8 + 4.8(0.6) = 7.7 tonnes of materials. The total materials requirement (TMR) is then 7.7 (sometimes recorded as 6.7 which is the 'rucksack' because the tonne of aluminium is deducted).

The fallacy of this approach has already been dealt with. If TMR is an invalid construct, the alternative is to set 'entitlements' according to each individual material, and for that matter each energy source as well. Once the requirements are set individually, the implication is that there is no substitutability between then, but obviously there must be. Hence the process comes full circle to the need for some aggregation system which makes explicit allowance for substitution.

The notion of an equitable share of environmental space is also extremely suspect. The previous equations can be used to derive country i's per capita entitlement, and, obviously it is simply

$$R_w/POP_{w)} = R_i/POP_i$$

But different countries vary in the efficiency with which they use resources. Introduce a concept of wellbeing, U, then varying efficiencies mean that U_i/R_i varies from one country to the next. **Equal resource use then implies differences in the level of wellbeing from one country to the next. If developed countries are generally more efficient in their use of resources compared to developing countries, the effect of the 'fair shares' formula is to lock the developing countries into an inequitable share of the world's 'wellbeing'.**

The central fact is that an equal entitlement to resources is not at all the same thing as an equal entitlement to what is generated by those resources (wellbeing, happiness, whatever). Additionally, concepts of entitlement and space require an aggregation process and none of the procedures for aggregation, as in the case of environmental footprint, makes sense.

There is one argument that appears to favour the ES concept. Suppose, for argument's sake, that the world did 'agree' on equal entitlements to resources. What matters, as we have seen, is not resources but what they produce. The focus on resources comes about because of the notion of biophysical constraints. Given equal entitlements of resources, then each country would have a massive incentive to raise the resource productivity of its entitlement. It would do this by developing technology to raise resource productivity. But unless there is also 'equal allocation' of technology, those with better technology endowments would generate more wellbeing from their entitlements than those without the technology. It is easy to see that countries would have a strong incentive to 'ring-fence' technological developments for their own purposes, unless such technologies are truly public goods. Existing inequity in the distribution of income per capita would simply be perpetuated.

A final observation is in order. Some of the sustainable consumption literature reads as if reducing resource consumption in the North will somehow raise resource consumption in the South, improving the South's wellbeing. But not consuming a tonne of material in the North does not make that tonne available in the South unless it is freely donated by the North to the South. Resource availability is not the same thing as being able to use the resource since that ability depends on having income and wealth. The relevant policy is to raise the South's per capita income, rather than to assume that reduced resource consumption in the north will somehow magically reappear as resource consumption in the South.

> ***It is easy to be sympathetic to the concerns that have produced notions like environmental space and ecological footprints. They quite rightly emanate from concerns about equity. In so far as they remind us yet again that raising resource efficiency is paramount, they are helpful. Unfortunately, beyond this they little or no relevance for policy.***

8.2 Equity and efficiency

How should equity be ensured in natural resource decision-making? There are several ways in which decision-making can be made sensitive to efficiency *and* equity concerns. What needs to be avoided is the idea that equity is some overriding goal. The reason for this is that, without efficiency, it is less likely that equity goals can be served. The converse does not follow: it is possible to be efficient without being equitable. The essence of the notion of efficiency is that resources are not wasted and that maximum aggregate wellbeing is derived from a given stock of resources. In simple terms, the 'pie' of wellbeing is maximised. Once efficiency is secured, a separate decision can be made about how to distribute the pie, the equity decision. Clearly, if

efficiency is ignored the pie will be smaller and there will be less available to distribute according to some equity criterion. It is in this sense that efficiency is a 'higher order' goal and great caution should be exercised when devising policy to ensure that efficiency is secured.

How might decisions be made so as to reflect equity concerns? Cost-benefit analysis has traditionally sought to integrate equity with efficiency by adopting an 'equity weighted' approach to costs and benefits. This has largely gone out of fashion but was widely used in the 1970s and early 1980s. For any set of individuals 1,2… with net benefits B1, B2 etc, the goal to be maximised is not B1+B2 etc, but aB1 + bB2 + cB3 etc, where a,b,c are the weights. More vulnerable groups would have higher weights determined by equity considerations[34]. **While it is common to see the criticism that cost-benefit 'ignores equity', the statement is false**.

---

[34] See Pearce (1986). The weights might be some ratio of marginal utilities of income, or they might be weights derived from marginal tax schedules.

8.3 Towards a rational resource management policy for the European Union[35]

The previous sections have set out the kinds of considerations that are relevant to a rational resource management policy in the EU, and has sought to evaluate various 'candidate' methodologies for implementing such a rational policy. We now try to bring the various arguments together.

The EU is committed to sustainable development. This involves raising the per capita wellbeing of the EU population, and other target populations and especially those in the potential Accession countries and in the developing world. Sustainable development can only be achieved if capital stocks are raised in per capita terms over time, and if technological progress exceeds the rate at which population grows.

The theory of sustainable development permits a rigorous concept of sustainable consumption to be defined and measured. In general, a policy of strong sustainability does imply a lower aggregate consumption level than a policy of weak sustainability. The former differs from the latter by the amount of consumption that has to be displaced in order to generate funds which can be used to hold the stock of natural capital constant in per capita terms. But it cannot be assumed that, in real world terms, either notion of sustainable consumption entails reducing actual levels of aggregate consumption in the EU. The relationship between actual consumption, maximum sustainable consumption and optimal consumption is very complex. *It would be sensible to commission research to establish what the links are between these concepts, in so far as they can be quantified.*

Policies aimed at *weak sustainability* require that the EU should have a clear idea of the comparative rates of return to different capital assets - man-made, human, social and environmental. The need for comparison arises because of the assumption that these forms of capital are substitutable *at the margin* and hence that choices can and should be made between them. Those rates of return must account for the full impacts - marketed and non-marketed - of resource use. Economic valuation and cost-benefit analysis provide one coherent set of procedures for determining these comparative rates of return. It is possible that alternative procedures could secure similar comparisons - e.g. health or risk indicators, but the advantage of money measures is that they encompass many different dimensions of human concern - health, amenity, resource depletion etc. It is also possible to integrate concerns about *equity* into cost-benefit analysis (see Section 8.2).

Policies aimed at strong sustainability would require that the EU take a far stronger stance towards restoration of natural resource damage and investment in 'new' resources such as renewable energy. But the foundations of strong sustainability are not themselves very secure: it is not clear that resources have no substitutes at the margin, nor is it easy to countenance a context in which restoration of natural resource damage should take place regardless of the opportunity cost in terms of forgone benefits from the alternative use of conservation funds. This said, public trust doctrine has already produced some instances in which resource damage has to be offset regardless of cost. Cost-benefit considerations cease to be relevant with strong

---

[35] Space limitations have prevented us from addressing the issue of uncertainty and risk management, but this is not likely to change the conclusions offered in this section.

sustainability, but it is still necessary to 'value' resources in order to know whether the index of natural capital is rising or falling.

There is one common feature to all the policy guidance approaches considered in the previous sections: they all conclude that **improving resource efficiency** is important in varying degrees. This is true whether the issue is 'sustainable consumption' , materials intensity, ecological footprints or environmental space. In theory the whole array of policy instruments is relevant to achieving resource efficiency: command and control measures, economic instruments, voluntary and negotiated agreements, public information, liability regulations etc. In practice, the weaker the sustainability goal the more likely it is that this wide array would be used. The close the goal is to strong sustainability, the more likely it is that regulation would approximate quantity-based approaches such as tradable quotas and traditional regulation. Price-based measures such as charges and taxes might be considered to uncertain in their effects for strong sustainability to be guaranteed. This is not a very firm conclusion but is perhaps an issue of emphasis rather than rigid dividing line.

The relative merits of different policy instruments have been widely debated and space forbids a discussion here, but a few remarks are in order. There is a strong resistance to all regulatory measures and a number of EU governments have 'de-regulation' high on their political agendas. The basic rationale is that regulation imposes costs on business that impair competitiveness. The evidence that this is so is in fact rather scant, but at the very least the perception that a connection exists is a strong one. Choosing policy instruments must therefore take account of the costs of regulation and minimum compliance cost instruments should be chosen wherever possible. This in turn suggests a much stronger bias towards economic instruments than is currently the case in the EU. It is known that such instruments generally (but not always) keep compliance costs down. In so doing they minimise the incentive to industry to lobby against regulations. They also maximise the chances that further environmental regulations will be accepted. Adopting high cost regulation is therefore counterproductive in environmental terms, let alone economic ones. Other incentive mechanisms such as recycling tax revenues so as to reduce labour taxes are welcome initiatives practised in a number of EU countries. Less popular and deserving of more attention are incentive systems such as accelerated depreciation on clean technology and abatement technology. Such subsidies have a number of beneficial effects. They are paid 'up front' and hence avoid industry's legitimate concern that policy measures will be changed during the life-cycle of the capital equipment of the firm. They can also induce technological change with substantial savings in future costs as industry is stimulated to move down the 'learning curve' of new technology. While it is not conventional to argue for these subsidies, there is a growing body of thought that suggests that they are just as important as environmental taxes[36].

In short, the means for stimulating resource efficiency are known and there is little by way of 'new' policy to be devised. But instruments aimed at stimulating technological change that raises resource efficiency do need far more rigorous development.

How might global equity best be served? It is tempting to think that reducing resource consumption in rich countries will serve an equity goal, but there is little to suggest that it would help. The solution to the equity problem is not novel and remains that of investing in the capital

---

[36] Other subsidies should, however, generally be rejected and it remains the case that massive environmental gains could be secured by changing subsidy regimes in the EU, especially in agriculture and fishing, and redirecting at least part of the savings towards encouraging sustainable resource management.

and technology base of poor countries and encouraging the demographic transition. What the literature on sustainable development indicates is that capital-based policies remain important but that the composition of those policies might be oriented far more to enhancing human capital and natural capital, at the cost of some less emphasis on traditional policies aimed at man-made capital.

Table 4 summarises some of the conclusions from the previous sections.

Table 4   **Implications of resource models for natural resource management**

Model	Implication for the EU
Weak sustainability	- Encourage savings - Invest in human capital (education) - Stimulate technology (accelerated depreciation etc.) - Encourage economy-resource decoupling by market based approaches; renewable energy - Population policies in LDCs - Cost benefit appraisal - Modified national product accounts - Invest 'resource rents'
Strong sustainability	As for weak sustainability but - More emphasis on quantity-based controls - Indices of natural capital - Less emphasis on cost-benefit but need to develop notion of acceptable cost
Materials intensity	- Awareness raising - Encourage resource efficiency
Ecological footprints	- Awareness raising - Encourage resource efficiency
Environmental space	- Awareness raising - Encourage resource efficiency
Equity	- Integrate with cost-benefit - Ensure efficiency goal is honoured

8.4 Future work

What future study work does the European Commission need to consider? The suggestion here is that the theory of sustainable development illuminates the contributions that various 'resource management methodologies' can make. The central messages for policy do not really differ much from those that have been widely discussed in policy circles, but sustainability and optimal consumption make it clear that resource management policies cannot be practised in isolation of all other economic policy. The need to maintain a healthy savings ratio is at the core of macroeconomic policy, but it is also essential for sustainable development. Some of the suggestions made by the approaches considered here are misdirected - they are more likely to divert attention away from what is needed. This is especially the case with notions of environmental space, ecological footprints and 'reducing aggregate consumption'.

But there is a need for well-targeted future study in some areas. Some suggestions would be:

1   Clarifying the relationships between (maximal) sustainable consumption under different assumptions about sustainability, and the notion of optimal consumption. While this would be a theoretical exercise to some extent, an attempt should be made to secure rough rules of thumb that could be applied to actual magnitudes in the EU.

2   Securing a far better idea about the relevant parameters that determine whether consumption paths are optimal or not. The most important are elasticities of substitution between resources and other forms of capital, and the social discount rate. The latter needs appraising in the context of recent work which suggests very low discount rates for long-term considerations, plus the notion that rates vary with time.

3   Determining the equity weights that might be used in formal appraisals, allowing for income differences within the EU and between the EU and Accession countries.

4   Developing 'genuine savings' accounts for the EU, hopefully building upon existing work on national accounts modification.

5   Securing a far better understanding of causal processes at work in environmental degradation. What are the relative contributions of market failures, government policies (such as subsidies), information deficiencies and institutional weakness? Recent focus on 'pressure- state- response' approaches to causal analysis has not addressed these issues adequately, perhaps because modelling them is complex and uncertain;

6   While the 'menu' of policy instruments is well understood, and is not likely to change much, the relative efficiencies of those policies in delivering environmental goals is still imperfectly understood. Despite the large number of policy innovations in the EU, it is hard to discover material that determines conclusively whether policy A is 'better' than policy B. The general absence of 'ex post' policy appraisals in the EU partly explains this state of ignorance.
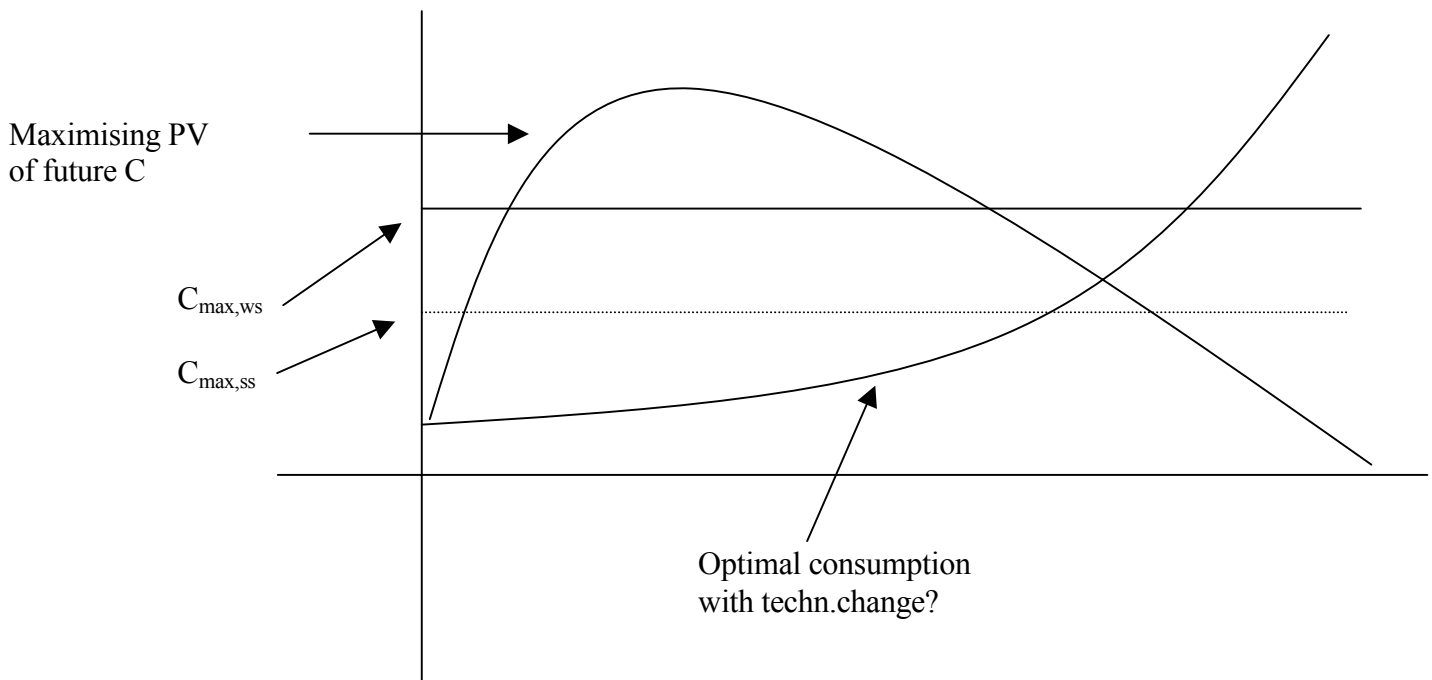
7   Whether one believes in strong or weak sustainability, a common issue is the cost of regulation and conservation. While much of the debate that takes place is about measuring the benefits of environmental improvement, there is in fact still very little understanding of the economy-wide costs of regulation.

8   In the context of development aid, it is not clear that the comparative rates of return to developing counties of different forms of capital enhancement are understood. Some clearer idea of what investment in natural resources would bring relative to say, human capital enhancement, is required. This requires a 'cross sectoral' look that is often missing.

9 References

Adriaanse,A. 1993. Environmental Policy Performance Indicators, The Hague: Sdu Uitgeverij Konninginnegracht.

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

Atkinson, G., Dubourg, R., Hamilton, K., Munasinghe, M., Pearce, D.W amd Young, C. 1997. *Measuring Sustainable Development: Macroeconomics and the Environment*, Cheltenham: Edward Elgar.

Costanza, R., Daly, H and Bartholomew, J. 1991. Goals, agenda and policy recommendations for ecological economics, in Costanza R (ed), *Ecological Ecpnomics: the Science and Management of Sustainability*, New York: Columbia University Press

R.Costanza, R.D'Arge, R de Groot, S.Farber, M.Grasso, B.Hannon, K.Limburg, S.Naeem, R.O'Neill, J.Paruelo, R.Raskin, P.Sutton and M van den Belt, The Value of the World's Ecosystem Services and Natural Capital, *Nature*, **387**, May 15 1997, 253-260.

Haberl, H. 1997. Human appropriation of net primary production as an environmental indicator: implications for sustainable development, *Ambio*, **26**, 3, 143-146

Hall, D and Hall, J.1984. Concepts and meausres of natural resource scarcity with a summary of recent trends, *Journal of Environmental Economics and Management*, **11**, 363-379

Hille, J. 1997. *The Concept of Environmental Space*, Copenhagen: European Environment Agency

Hamilton, K. 1993. *Sustainable Development, the Hartwick Rule and Optimal Growth*, Department of Economics, University College London, mimeo.

Hamilton, K and Clemens,M. 1999. Genuine savings rates in developing countries, *World Bank Economic Review*, **13**, 2, 333-356

Hope, C., Parker, J and Peake, S. 1991. A pilot environmental index for the United Kingdom: results for the last decade, *Statistical Journal of the United Nations*, **ECE 8**, 85-107

Hope, C and Parker, J. 1995. Environmental indices for France, Italy and the UK, *European Environment*, **5**, 13-19.

Page, T. 1977. *Conservation and Economic Efficiency*. Johns Hopkins University Press: Baltimore.

Pearce, D.W. 1986. *Cost-benefit Analysis*. Basingstoke: Macmillan

Pearce, D.W. 1998. Auditing the Earth: The value of the world's ecosystem services and natural capital, *Environment*, **40**, 2, 23-28

Pearce, D.W.2000. *Economic Valuation Techniques for the Assessment of Environmental Damage and Natural Resource Depletion*, Report to the United Nations Compensation Commission, Geneva.

Pearce, D.W., Nash, C.A and Stanley, J. 1975. Evaluating project evaluation criteria, J*ournal of the American Institute of Planners*, March.

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

Pearce, D.W. and Barbier, E. 2000. *Blueprint for a Sustainable Economy*, London: Earthscan.

Pezzey, J. 1989. *Economic Analysis of Sustainable Growth and Sustainable Development*, Environment Department Working Paper No. 15, Washington DC: World Bank.

Van Kooten, G.C and Bulte, E. 2000. *The Economics of Nature: Managing Biological Assets*, Oxford, Blackwell.

Vitousek, P., Ehrlich, P., Ehrlich, A and Matson, P. 1986. Human appropriation of the products of photosynthesis, *BioScience*, **36**, 368-73

Vitousek, P., Mooney, H., Lubchenco, J and Melillo, J. 1997. Human domination of Earth's ecosystems, *Science*, **277**, 485-499

Wackernagel, M and Rees, W, 1996. *Our Ecological Imprint: Reducing Human Impact on the Earth*, Gabriola Island BC: New Society Publishers

Wackernagel, M., Onisto, L., Bello, P., Linares, A., Falfan, I., Garcia, J., Guerrero, A and Guerrero, G. 2000. Natural capital accounting with the ecological footprint concept, *Ecological Economics*, 29, 375-390.

10 Annex: diagrammatic exposition of consumption paths

Maximising PV
of future C

$C_{max,ws}$

$C_{max,ss}$

Optimal consumption
with techn.change?

The traditional optimal consumption path is given by the inverted 'U' curve and results from maximising the present value of future consumption. Whilst optimal the path is not sustainable: consumption eventually goes to zero, a result that is mainly driven by the existence of positive discount rates (for utility). The two straight lines show the *maximal constant consumption levels* that are also sustainable. The upper line shows sustainable consumption under a weak sustainability approach and the lower shows maximal consumption under strong sustainability[37]. Neither path is optimal, for complex reasons. The final upward sloping curve combines sustainability and optimality. To achieve such a path requires technological change to accommodate population change and increasing depreciation on capital stocks.

---

[37] The two straight line C_{max} lines are actually constant consumption and hence constant utility lines. Hamilton (1993) refers to these as 'minimal sustainability' paths because utility is not rising. We have chosen to illustrate constant consumption, i.e. constant utility, paths. The problem can be formally stated as being one of achieving maximal consumption (utility) with minimum sustainability, i.e. it is a 'maximin' problem.