TREASURY WORKING PAPER

01/27

Sustainable Development: Environment and Economic Framework Integration

Basil M. H. Sharp

Abstract

Sustainable development is a multifaceted concept that has drawn on a number of disciplines including economics, ecology, ethics, sociology and political science. Sustainable development links the welfare of generations with the capacity of the biosphere to sustain life and has a policy focus. Sustainable development is not a fixed state but rather a process of change in which resource exploitation, the direction of investment, the orientation of technological development and institutional change are made consistent with the future as well as present needs.

Practical policy analysis needs to be guided by specific objectives analysed within a consistent and coherent framework. In the absence of an operational framework the policy analyst is left with an indeterminate model to work with. This vacuum can lower the quality of advice, increase reliance on *ad hoc* decision-making and potentially impact economic growth and the welfare of current and future New Zealanders. This report does not consider the range of policy instruments that could be used in achieving sustainable development outcomes.

A framework for economic-environment integration is proposed. The specific framework is shown to depend on "the problem". It is not a mechanistic process and careful attention has to be given to grafting a rigorous model for analysis. Three case studies illustrate how economic-environment integration can be achieved. Specific frameworks can be developed for the purpose of empirical analysis and hypothesis testing.

Three themes for future research are described. One theme is empirical and suggests a study of existing rules and mechanisms *vis-à-vis* sustainable development. Another broad theme is directed at obtaining a better understanding of sustainable development within the context of an open-economy dependent on key natural resources for economic growth. Finally, there is a need to develop a range of indicators for policy analysis.

JEL classification: P28 Economic Systems, Natural Resources and Environment; Q01 Sustainable Development.

Keywords: Sustainable Development; Framework Integration; Environment and Economic Framework.

Basil M H Sharp: Department of Economics, University of Auckland, Private Bag 92019, Auckland Central, Email: b.sharp@auckland.ac.nz, Tel: 64-9-3737599

Contents

SUSTAINABLE DEVELOPMENT: ENVIRONMENT AND ECONOMIC FRAMEWORK INTEGRATION*

Summary

Sustainable development is a multifaceted concept that has drawn on a number of disciplines including economics, ecology, ethics, sociology and political science. Sustainable development links the welfare of generations with the capacity of the biosphere to sustain life and has a policy focus because it is about the "design" of policy that ensures delivery of a set of quantitative and qualitative outcomes.

Project Aims

The primary purpose of this project is to:

- Inform the thinking of officials within Treasury, enabling them to provide high quality economic policy taking into account insights from other disciplines where this is both useful and appropriate.
- Explore whether it is possible, and if so, develop a framework to integrate economic advice provided by Treasury on environmental issues with insights from other disciplines in a way that is helpful to Ministers for decision-making purposes.

The secondary purpose is to ensure officials within Treasury and key Government Departments are aware of the key relevant frameworks, the need for integration and a possible approach they could apply in the course of their work.

The report focuses on economic and environment framework integration. Linkages with the "social" component of sustainable development are identified but not developed. Economic and social integration has been dealt with through the study on the Inclusive Economy undertaken by the Social Policy Branch of The Treasury. The report does not discuss or assess the range of policy instruments that might be used to achieve sustainable development outcomes.

Ethical Underpinnings

It must be recognised that most views on sustainable development are based on a particular ethical stance. At the level of applied policy analysis, discourse will be based on ethical values embedded in the analytical framework. These values must be made transparent. For example, the issue of substituting manufactured and natural capital can be viewed as having economic, ethical and technical dimensions. The capacity of technology to provide likely substitutes for natural capital is an empirical issue that is unlikely to be resolved *ex ante*. Whether or not substitution is acceptable is an ethical issue.

Approaches

Economics as a discipline has a long tradition of using mathematical models to analyse issues related to sustainable development. Neoclassical economic theory brings an understanding of important elements in growth and sustainable development. Theory provides a way of organising one's thoughts and assists us to pin point critical policy issues.

---

* The paper was commissioned by the Environment Cluster within Treasury. I am particularly grateful for the guidance and advice offered by Linda Cameron, Alistair Dixon, Mark Sowden, Catherine Adams, Jonas Tornquist, Mary-Ellen Fogarty and Sarah Box. Eithne Barry was a great help with the literature survey. I would also like to thank Ralph Chapman (MfE) for his comments on an earlier draft.

The paper was presented at an external seminar to representatives from key Government departments in July 2001 and the feedback received contributed to the development of the paper.

The introduction of ecology and physical laws poses no special problems provided they could be represented in an analytically rigorous way. Environmental economists have long attempted to incorporate renewable resources and the ecology of life supporting systems into their models.

Methods used in ecological economics tend to be more pluralistic, look more to biological and physical sciences, and often adopt different ethical positions. A great deal of the ecological economics literature is based on traditional economic theory. However distinctive lines of research are evident when dealing with ecology and ethics. It is simply not possible to resolve different high-level propositions for sustainable development based on different ethical principles. Modelling the different positions in a rigorous and transparent way will at least enable the implications of alternative courses of action to be drawn out and discussed.

Frameworks

Sustainable development is not a fixed state but rather a process of change in which exploitation of resources, the direction of investments, the orientation of technological development and institutional change are made consistent with the future as well as present needs.

There is little prospect for developing a mechanistic rule, economic, scientific or otherwise, to provide definitive and reliable answers about sustainable policies or conduct. However there is greater optimism when it comes to identifying processes and procedures that can guide decision-making.

Frameworks offered by two Ministries include the features of natural capital and emphasise the role of government in sustainable development. This emphasis on public policy is reinforced in the OECD framework. The OECD framework offers considerable detail on the techniques that can be used to guide collective decision-making – such as total economic value – and the policy instruments that are available to achieve sustainable development outcomes.

Towards an integrated framework

Three case studies were used to illustrate how economic-environment integration can be achieved for the purposes of public policy analysis. The aim was simply to demonstrate an approach, not to analyse the specific content of each policy proposal. Two of the three case studies were framed within the context of economic growth; the other incorporated the notion of total economic value. This is particularly encouraging for three reasons. First, by explicitly stating an economic objective, analysts can trace out the opportunity costs of pursuing other, possibly, competing objectives. Second, the values attached to the flow of environmental services, although unpriced in the market, are made transparent and correctly located within the policy objective. Third, the economic impact of specific policy instruments – such as regulations – can be rigorously analysed.

The case study documents were strategic in nature and did not advance into the analytical phase of evaluating public policy alternatives. The conceptual apparatus and tools for detailed analysis are laid out in the body of this report. In particular, the integrated framework must explicitly link policy objectives with the policy instruments aimed at promoting sustainable development. Assessment of policy instruments is not discussed in this report.

Clearly, it is not possible to design an optimal set of instruments if the policy objective(s) is (are) not specified. This view leaves the policy analyst with an indeterminate model to work with. More significantly, it lowers the quality of advice and increases reliance on *ad hoc* decision-making. The potential impact of this approach on economic growth and the welfare of current and future New Zealanders should not be underestimated. A set of guidelines for sustainable decision-making includes:

- Prior assessment of what criteria and evaluation tools should apply to the issue.
- Assessment of physical impacts across time and space.
- Assessment of economic benefits and costs.
- Identification of whether and how social values and norms may be affected.
- Engagement in public discourse about the consequences of different actions.
- Pluralistic decision-making.
- Using the results of the decision process to incorporate new information.

A more detailed list of potential components of an integrated environment-economic framework include:

- The scale/scope of the particular issue.
- Ecological, industrial, organisational, policy linkages.
- Manufactured, natural, human and social capital.
- Total economic value.
- Institutions and governance.
- Participation.
- Intragenerational and intergenerational equity.
- Risk, uncertainty, technology.
- Time and the dynamics of economic-ecological phenomena.

Economic and environmental framework integration can be achieved at a high level by mapping the above components into a framework that addresses the policy issue at hand. Three case studies illustrated how the integrated framework can be applied. The approach emphasised five steps:

- Problem identification.
- Specific statements of objectives and constraints.
- Policy focus that linked objectives with institutions.
- Transparent application of concepts.
- Rigorous analysis.

The specific framework to emerge from this process depends on "the problem" and the result of careful synthesis. No mechanistic rule is proposed.

Specific frameworks can be developed for the purpose of empirical analysis and hypothesis testing. For example, it is possible to estimate elasticities of substitution, indices of sustainable development, total economic value, the distribution of risk for specific policy actions, and so on. Contemporary advances in institutional economics provide a basis for assessing the quality of property rights and systems of governance.

Recommendations for future research

This report has not considered the range of policy instruments that could be used in achieving sustainable development outcomes. The set of instruments is largely known but we have little have less knowledge of their application in practice. This important topic can be addressed in two ways:

(a) Survey the existing mechanisms and processes, across government departments, to see how they are being applied in practice and to what benefit.

(b) Analyse the quality of institutional arrangements using the theory and frameworks provided by the institutional economics and property rights literature. In some cases it might be possible to assess the quality of operating institutional structures, such as those that govern access to scarce natural resources. For example, the work of Oliver Williamson (1985) provides a basis for the analysis of the institutional underpinnings of sustainable development. Ragnor Arnason (2000) provides a specific example of how to analyse property rights in the context of fisheries management.

Sustainable development is critical to the welfare of New Zealand's population. The economy is relatively open and depends to a large degree – *viz.* the primary industries - on the functioning and integrity of its unique ecosystems. Global economic activity is dynamic and increasingly interdependent. International influences on sustainable development – especially from a small country perspective - are not well canvassed in the literature. For example, the dairy industry is a major exporter and makes a significant contribution to the New Zealand economy. The expansion of dairy farming is becoming increasingly dependent on access to water resources. It is perhaps appropriate that the sustainability of this expansion and, especially, the institutions that govern water allocation should be analysed. The integrated framework provides a basis for future research.

There are few, if any, sustainable development indicators in use. If we are serious about achieving sustainable outcomes then indicators are needed to inform policy makers. Future work could be directed at developing a range of indicators, for use at the macro and micro levels, and for *ex ante* policy analysis.

1. Introduction

Sustainable development is a multifaceted concept that has drawn on a number of disciplines including economics, ecology and ethics. Recent contributions from sociology and political science have expanded the domain of sustainable development. Particular mappings of these disciplines into a definition of sustainable development often reflect disciplinary backgrounds. Thus a definition provided by an economist is likely to differ from an ecologist. Differences also occur within broad disciplinary groupings.

It should be of little surprise that the term "sustainable development", as interpreted and used by policy advisors, is open to wide interpretation. There is increasing recognition of the need for a multi-disciplinary and integrated approach to inform decision-making on sustainability issues at the political level.

Today, most views of sustainable development include economic, environment and social dimensions. The report focuses on economic and environment framework integration. Linkages with the "social" component of sustainable development are identified but not developed. Economic and social integration has been dealt with through the study on the Inclusive Economy undertaken by the Social Policy Branch of The Treasury.

The primary purpose of this project is to:

- Inform the thinking of officials within Treasury, enabling them to provide high quality economic policy taking into account insights from other disciplines where this is both useful and appropriate.

- Explore whether it is possible, and if so, develop a framework to integrate economic advice provided by Treasury on environmental issues with insights from other disciplines in a way that is helpful to Ministers for decision-making purposes.

The secondary purpose is to:

- Ensure officials within Treasury and key Government Departments are aware of the key relevant frameworks, the need for integration and a possible approach they could apply in the course of their work.

This report addresses the issue of sustainable development in the five sections that follow this introduction.

Section 2 describes the evolution of the term sustainable development and provides a limited sample of definitions from the range available.

Section 3 provides an overview of the basic elements of sustainable development.

Section 4 illustrates a number of sustainable development frameworks.

Section 5 illustrates how the frameworks could be integrated and how the approach could be applied in practice. A limited number of "case studies" are used to illustrate application of the framework.

Section 6 provides a conclusion and a list of recommendations for future work.

2 Background

The goal of achieving sustainable development was given international prominence by the United Nations Conference held in Stockholm in 1972. This sparked a great deal of debate and research on the need to conserve natural resources and the environment in order to achieve sustainable development.

It should not be surprising that the original work of the Club of Rome can be directly linked with the burgeoning literature on sustainable development. Work reported by the Club of Rome (Meadows *et al.*, 1972) emphasised the need to conserve stock resources such as fossil fuel and minerals, and to control pollution such as acid rain and CO_2 concentrations. Simulations undertaken by Forrester (1971) highlighted four forces that limited economic growth *viz.* depletion of natural resources, risk of pollution, increased population and decline in food availability.

Dynamic models belonging to the Club of Rome *genre* attracted strong criticism from system theorists and economists. The absence of mechanisms for signalling relative scarcity, no technological progress, and limited substitution across natural resources and capital were considered serious shortcomings. For example, Nordhaus (1973) suggested that a pricing mechanism would reflect increasing scarcity and provide incentives for the search for substitutes and more efficient production techniques. Berlinski (1976) was particularly critical of the theoretical underpinnings of systems analysis in general and the "limits-to-growth" models in particular.

Although the Club of Rome acknowledges the indispensable role of the market for allocating resources, stimulating innovation and competition, it now sees an irreplaceable role for the state in correcting and utilising market forces (Colombo, 2001). Recently, the Club of Rome has been prominent in the debate on climate change by emphasising the significance of governance in sustainable development. It believes that the goal of international politics should be expanded to include the development and dissemination of more efficient technologies and organisational structures to achieve sustainable development.

Beginning in the early 1980s focus shifted from the conservation of stock resources to the need to conserve living resources in order to obtain sustainable development. This view was given some impetus by the World Conservation Strategy (IUCN, 1980). By the end of the 1980s the significance of sustaining the functioning of natural ecosystems was well recognised and had been incorporated into notions of sustainable development. Ecologically sustainable development reinforces the concept because it too favours the preservation of ecosystems and biodiversity.

The concept of sustainable development has thus evolved out of a concern that existing socio-economic systems may lead to economic growth or production that is not sustainable and consequently lower the well-being of future generations.

There is a huge range of definitions of sustainable development. The following definitions listed below provide a limited sample from the range.

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (WCED, 1987, p. 43)

The definition proposed in *Our Common Future* emphasises both needs (especially the world's poor) and limitations imposed by technology and social organisations on the capacity of the environment to meet present and future needs. There are at least four strands to this definition. First, interpretation of need clearly depends on how we define needs. Second, the concept implies limits. Limits on the use of renewable resources are defined with respect to regeneration and natural growth (e.g. fishery) within a broader context of "system wide" effects (e.g. unintended bycatch). In contrast, the rate of stock resource depletion should depend on the "criticality" of the resource, availability of technology to reduce depletion rates, and the likelihood of substitutes becoming available. Third, sustainable development requires the conservation of plant and animal species. Finally, adverse impacts on the environment should be minimised.

Although the concept of sustainable development used in *Our Common Future* implies limits it does not suggest absolute limits. In particular, the limits are seen to be contingent on the state of technology, social organisation, and the ability of the biosphere to absorb the effects of human activity. Therefore sustainable development is not a fixed state but rather a process of change in which exploitation of resources, the direction of investments, the orientation of technological development and institutional change are made consistent with the future as well as present needs.

***Key elements**:*
- *Development is seen as a process of change*
- *Introduces the idea of balancing future needs with present needs*
- *Limits to development are conditioned on technology, social organisation and the biosphere*

Sustainable development involves devising a social and economic system which ensures that a set of desirable goals or objectives for society are sustained (Pearce et al. 1989)

In *Blueprint for a Green Economy* Pearce *et al.* (1989) suggest that a set of desirable goals for society would include rising real incomes, increasing educational standards, improved health of the nation, and that the general quality of life is advanced. They see three concepts of environment, futurity and equity being integrated in sustainable development. Furthermore, future generations should be compensated for reductions in the endowments of resources brought about by the actions of present generations. In their view, compensation should come about by passing on endowments of capital. The economic notion of capital is expanded to include human capital, manufactured capital and natural capital.

Key elements:
- *Greater specificity of goals e.g. income, education and quality of life*
- *Emphasis placed on devising social and economic systems that can deliver goals*
- *Intertemporal compensation through adjustments to capital (natural and manufactured) stocks*

Development ensuring non-declining per capita utility (Pezzey, 1992).

Conventional models of economic growth express instantaneous utility as a function of consumption $U_t = U(C_t)$. The analytical problem is to find a consumption path $\{C_t^*\}$ that maximises the present value of utility over (typically) an infinite time horizon subject to a set of constraints. The constraint set could include equations that describe the depletion of resources, production relationships, and the impact of pollution on the environment.

$$\underset{\{C_t\}}{Max} \int_0^\infty U(C_t)\, e^{-\delta t}\, dt \qquad (1)$$

subject to:
set of constraints

where δ is the social rate of time preference. The above model can be modified to include a variable discount rate. Discounting is discussed in more detail later. This formulation assumes that intertemporal preferences are well known and are consistent over time. Each generation passes on to the succeeding generation exactly what is required (e.g. resource endowments) to maximise the present value of utility. Typically, the economy is assumed to be closed and production is set equal to consumption plus investment.

Pezzey (1992) suggests that sustainable development be interpreted as non-declining per capita utility. Utility is defined as a function of consumption (*C*), natural resource stocks (*S*) and pollution stock (*P*) – that is, *U(C,S,P)*. Thus the instantaneous change in utility should be non-negative ($\dot{U}_t \geq 0$) over time. This of course incorporates the notion of intergenerational equity *viz.* the per capita utility we enjoy today should be strictly no more than the per capita utility enjoyed by any generation in the future.

Key elements:
- *Formal analytical model of intertemporal choice*
- *Notion of intergenerational equity included in objective function*
- *Explicit treatment of sustainable development variables, such as consumption, resources and pollution*

Sustainable development requires natural capital be kept intact (Daly, 1991).

Daly (1991) distinguishes between growth, as a quantitative increase, and development as a qualitative improvement or unfolding of potential. Two principles are advanced for the management of renewable resources. First, harvest rates should not exceed natural regeneration rates. Second, waste emissions should not exceed the assimilative capacity of the receiving ecosystem.

Non-renewable resource use poses something of a problem for this approach to sustainable development because it is not possible to keep them "intact". The laws of physics see to it that the energy services embodied in fossil fuels can only be used once. This problem is resolved by requiring investment in the exploitation of non-renewable resources to be paired with a compensating investment in non-renewable substitutes.

Key elements:
- *Conservation of natural capital over time*
- *Natural and manufactured capital are treated as complements*
- *Pairing of non-renewable resource depletion with investment in renewable substitutes*
- *Intergenerational criterion is implicit in the constraint set*

The Australian National Strategy for Ecologically Sustainable Development aims "to meet the needs of Australians today, while conserving our ecosystems for the benefit of future generations" (Productivity Commisssion, 1999, p. 2).

In 1992 all Australian governments endorsed the goal of ecologically sustainable development (Productivity Commission, 1999). The emphasis placed on "ecological" created implementation problems for the Australian Strategy. An inquiry into the implementation of the Strategy by Commonwealth departments and agencies found that many had used a narrow interpretation of "environment" and had not undertaken sustainable development activities. Three dimensions – economic, environmental and social - are immediately apparent in the Australian definition of ecologically sustainable development. Moreover, the Strategy acknowledges the potential for tradeoffs to occur, for example between present and future consumption, and between economic, environmental and social objectives.

Key elements:

- *Enhance individual and community welfare by following a path of economic development that safeguards the welfare of future generations*
- *Provides for equity within, and between, generations*
- *Protect biological diversity, maintain essential processes and life support systems*

Ecological economics

Ecological economics is a transdisciplinary field with a domain that spans the entire set of interactions between ecosystems and economics systems, including the co-evolutionary relationships (Costanza, 1991). Three disciplinary pillars support ecological economics: ecology, economics, and ethics. While ecological economics acknowledges the utility of economic instruments as a means for achieving an efficient allocation of scarce resources it is quick to point out the shortcomings of allocative efficiency *viz.* efficiency does not guarantee ecological sustainability or distributional equity.

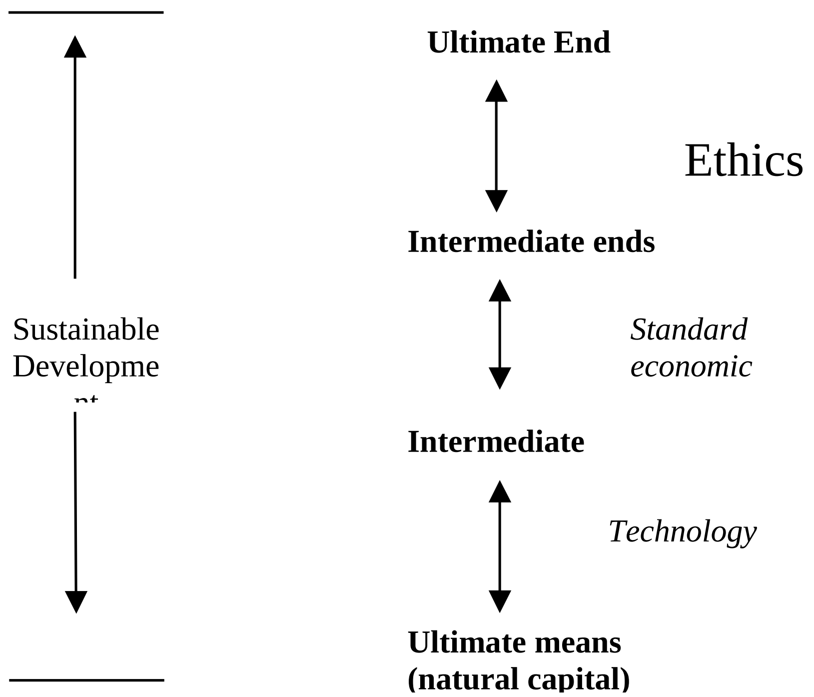

Figure 1: Ends-means spectrum (Lawn, 2001)

Figure 1 illustrates sustainable development from the perspective of ecological economics. The domain of ecological economics spans the end-points of natural capital and ethics. Natural capital includes the biophysical domain and recognises the laws of thermodynamics. The “ultimate end” is seen as an ethical issue, one that will vary across countries, communities and cultures.

Conclusions

The early literature on sustainable development draws upon two broad intellectual traditions; one concerned with the limits of nature, the other with the potential for human material development (Redclift, 1987). Today the literature on sustainable development has exploded and appears in many disciplines. Pezzoli (1997) identifies ten categories of literature in which a view on sustainable development is expressed including: managerialism; ecological economics; environmental sciences; environmental law; ecophilosophy; utopianism; and political ecology. The challenges, as Pezzoli (1997) sees them, include: (1) holism and co-evolution; (2) social justice and equity; (3) empowerment and community building; and (4) sustainable production and reproduction.

The following concepts are common to each definition of sustainable development:

- Sustainable development is multi-faceted, drawing on the concepts of many disciplines.
- Sustainable development links the welfare of generations with the capacity of the biosphere to sustain life.
- Sustainable development has a policy focus because it about the “design” of policy that ensures delivery of a set of quantitative and qualitative outcomes.

Although we might agree on high-level concepts, differences will arise out of the multiplicity of views taken of sustainable development. The potential differences are listed below. These will become more evident in the next section.

- Most definitions of sustainable development are based on an ethical position, some (see Lawn, 2001) admit a number of ethical positions. It must be recognised that views on sustainable development depend on the particular ethic adopted. Thus the potential for a multiplicity of normative views exists. At the theoretical level, it is highly likely that there is no possible way of reconciling these views (Northrop, 1947). At the level of applied policy analysis, the discourse will be based on ethical values embedded in the analytical framework. These values, of course, must be transparent.
- The issue of substituting manufactured and natural capital has an ethical and technical feasibility component. The capacity (and likelihood) of technology, as expressed in manufactured capital, to provide likely substitutes for natural capital is an empirical issue that is unlikely to be resolved *ex ante*. Whether or not substitution is acceptable is an ethical issue.
- Methodological differences are apparent. Economics as a discipline has a long tradition of using mathematical models to analyse issues related to sustainable development. Methods used in ecological economics tend to be more pluralistic, look more to biological and physical sciences, and often adopt different ethical positions.

3 Elements of sustainable development

A great deal of effort has gone into developing frameworks for guiding policy directed at sustainable development. The disciplines of economics, ecology, and ethics, were prominent during the early stages of the search for a coherent framework. More recently, concepts from sociology and political science have been incorporated into the on-going search for a framework (Putman, 1995). To date there is no consensus, at least in the academic literature, of what is sustainable development. This of course, is not necessarily a bad thing. Some would argue that plurality of method serves to enrich the debate and the formation of policy (Norgaard, 1985). Given this state of affairs it seems important that at the least we understand the principles and reasoning behind the range of perspectives on sustainable development.

The dimensionality of sustainable development, its transdisciplinary content and the open endedness of the concept itself presents a considerable challenge. This Section provides an overview of some, but not all, of the concepts commonly used to underpin frameworks of sustainable development. The report does not dwell on the range of economic instruments available to manage externalities in the economy; these are well known (OECD, 2000). As noted earlier the topic of social sustainability falls outside the scope of the report. Where possible simple diagrams are used to illustrate formal mathematical relationships. This is not possible for many concepts because either mathematical expressions have not been developed or the concept is not well suited to diagrammatic representation.

3.1 Economic growth

The Solow (1956) growth model is the starting point for most analyses of growth (a modern treatment of growth theory is found in Romer (2001)). The Solow model focuses on four variables: output (*Q*), capital (*K*), labour (*L*) and knowledge (*A*), thus $Q(t) = F(K(t), A(t)L(t))$. Variable *A* is also referred to as the effectiveness of labour.

Economic growth is defined as rising aggregate consumption (*C*) or output (*Q*). Because growth is measured in value and not physical units, growth in economic output does not necessarily mean growth in physical throughput of materials (and by implication increased residuals) and energy. The model implies that regardless of its starting point the economy converges to a balanced growth path, where capital per worker (*K/L*) and output per worker (*Q/L*) is growing at a constant rate.

Growth in output per unit of labour is determined solely by the rate of technological progress. There are two possible sources of variation in output per worker: differences in capital per unit of labour (*K/L*) and differences in the effectiveness of labour (*A*). The principal conclusion of the Solow growth model is that the accumulation of physical capital alone cannot account for the growth over time in output per person or for the geographic differences in output per person. In other words the observed differences in real income are too large to be accounted for by differences in capital inputs. Growth in the effectiveness of labour *(A)* is exogenous in the Solow model. As a driving force of growth, the definition of (*A*) is not at all precise. For example, it could correspond to the stock of knowledge, education and skill levels in the work force (human capital), the quality of property rights, the quality of infrastructure, cultural attitudes toward work, and so on.

Natural resources, pollution and other environmental considerations are absent from the original Solow model. When considering how environmental limitations affect long-run growth the standard approach is to distinguish between environmental factors for which there are well-defined property rights (e.g. oil) and those for which there are not (e.g. air). If property rights exist then markets can provide useful signals on relative scarcity. For example, evidence that a finite stock of oil could limit production in the future is not a sufficient economic reason for government intervention; the market will address the issue of scarcity. In contrast, the case for government intervention is much stronger in situations where externalities arise from the use of environmental services for which there are no property rights.

Incorporating stock resources (e.g. natural gas) into the Solow model is relatively straightforward. Because the stock of non-renewable resource (*S*) is fixed use must eventually decline $\dot{S}(t) = -bS(t), b > 0$. On a balanced growth path, resource limitations can cause a drag on growth with output per unit of labour declining. But the overall impact on growth will depend on technological progress – if the rate of technological progress exceeds the drag of resource limitations then there will be sustained output per worker. This result clearly depends on the production function, more precisely the elasticity of substitution between inputs (for example, capital and natural resources). If elasticity is less than one – indicating a relatively low ability to substitute - then the share of income going to inputs becoming scarcer (e.g. natural gas) rises over time, and the fixed supply of the resource leads to steadily declining incomes.

Because some definitions of sustainability require the stock of natural assets to be kept "intact" introducing sustainability into a formal model requires the use of a principle of intergenerational equity. This of course requires the formulation of an objective function. To some, the conventional wisdom of using a net present value function tips the intertemporal scales of justice too much in favour of the present generation. But arbitrarily perturbing the interest rate does not solve the problem of achieving intergenerational equity. Like its static counterpart, in an intertemporal model there may be many allocations that are consistent with Pareto efficiency. To go beyond efficiency requires an intergenerational welfare function that reflects the community values associated with fairness.

Key issues:

- *Consumption/production is guided by net present value maximisation*
- *Technological progress is a key variable in traditional growth theory*
- *Theory suggests that the ability to sustain growth depends on the elasticity of substitution between inputs*

3.2 Intergenerational welfare

Concern for the well being of future generations takes centre-stage in most definitions of sustainable development. In a static general equilibrium framework it is well known that the competitive market will come up with a different efficient allocation of goods and services for each initial distribution of income. The efficiency criterion cannot decide between efficient allocations because the choice of the initial distribution of income is logically prior to the workings of efficiency (Page, 1977). Introducing time into a welfare indicator adds the complication of how to evaluate welfare over time and the appropriateness of discounting future welfare. The issue of discounting is discussed in the next section.

Pezzey (1992) provides the following distinctions between optimality, sustainability and survivability.

- Optimal welfare maximises the present value of future welfare $\int_0^\infty W(t)e^{-\delta t}dt$
- Sustainable welfare is such that $\frac{dW}{dt} \geq 0$ for all time.
- Survivable welfare is such that $W \geq W_{\min}$ for all time.

Each definition brings its own complication. All three definitions require an indicator *W* to measure sustainability. Survivable welfare requires welfare minima to be set. Optimal welfare requires use of a discount rate δ.

The utilitarian view – as epitomised in the optimal welfare formulation above – is not widely accepted. Rawls (1971) developed an alternative theory of justice based on a social contract in which individuals operate behind a “veil of ignorance” in that no-one knows which position in society she or he may be born into, or their endowments. The principles developed by Rawls have been incorporated into economics as a welfare function based on “maximising the minimum welfare”. Rawls did not develop rules for intertemporal social choice.

Solow (1974) and others (e.g. Dasgupta, 1974) examined the behaviour of a neo-classical growth model when the utilitarian objective function is replaced by a *maximin* objective function. The model allows output to be consumed now to gain utility or invested to increase the size of capital in the future. Transferring capital from an earlier to a later generation will in general mean that the later generation receives more, in terms of goods, than the earlier one gave up. The zero growth that results from the application of the *maximin* principle to the problem of intergenerational allocation, has led many economists to regard Rawls’ principles of justice as excessively conservative.

Pezzey (1992) offers the following three definitions. Let U_t^M equal the maximum utility that can be held constant for all $t \geq t_0$ and $\overline{U}$ equal the minimum level of utility consistent with the survival of a given population.

- Sustainable development is development that maintains welfare at least equal to, or possibly below, the maximum feasible level of welfare, that is:
  $U_t \leq U_t^M \ \forall t$
- Sustained development is development that provides for a non-declining path of welfare, that is:
  $\Delta U_t \geq 0 \ \forall t$
- Survivable development is development that provides utility levels that at least satisfy the minimum required for the population, that is:
  $U_t \geq \overline{U} \ \forall t$

Later, Pezzey (1997) considered the first definition more acceptable; the second definition of non-declining utility is considered too strong; and the third definition is considered too weak an expression of intertemporal concern.

> ***Key issues:***
> - *Concern for future generations is of central importance in models of intertemporal choice*
> - *Different ethical conceptions of intertemporal welfare can lead to different paths of growth and environment*
> - *Ultimately, concern for future generations is an ethical issue*

3.3 Discounting

The role of discounting is a contentious issue in the sustainability debate. Environmentalists have long criticised discounting because it is claimed that:

- High discount rates increase the approval rate of potentially ecologically destructive projects. This concern is linked to the time it takes for ecological damage to become apparent, such as water eutrophication and desertification.

- Environmental rehabilitation projects may take a long time to produce beneficial effects. It may take decades for the rehabilitation of indigenous forests to yield significant beneficial outcomes.
- Simple models of optimal resource utilisation show that it is rational to harvest a natural resource to extinction.

Ecological economists (Daly and Cobb, 1994; Lawn, 2001) are also critical of discounting. For example,

"… to extend it into the long run leads to unrealistic infinitesimal numbers, because of the exponential nature of compound interest rate." (Daly and Cobb, 1994 p.153)

This view also appears in the popular literature:

"Suppose a long-term discount rate of 7 percent (after inflation) is used … Suppose also that the project's benefits arrive 200 years from now … If global GDP grows by 3 percent a year during those two centuries, the value of the world's output in 2200 will be 8 quadrillion US dollars (a 16-figure number). In other words, it would not make sense for the world to spend any more than 10 billion US dollars (under US$2 a person) today on a measure that would prevent the loss of the planet's entire output 200 years from now" (The Economist, 26 June 1999).

Thus

"… we should not hesitate to reject the principle of discounting when it leads to results that do not promote welfare. Directing the market to serve total welfare may well involve rejection of discounting in certain social decisions where community with the future or other species is threatened." (Daly and Cobb, 1994 p.155).

Because the use of a positive discount rate attracts criticism it is worthwhile briefly outlining the economic theory of discounting. Let $\{C_t\}$ be a feasible consumption profile for the economy. The social rate of discount ρ_t is the rate at which it is found just desirable to substitute consumption at some period *t* for that in the next period *(t+1)*. Notice that ρ_t depends on the social welfare function *W*. The economy's consumption possibilities are described by the function T. If the social rate of return on investment at *t* is r_t then we arrive at the familiar result that the marginal rate of transformation between two dates, *t* and *t+1*, must equal the marginal rate of substitution, that is:

$r_t = \rho_t \; \forall t$ (Dasgupta and Heal, 1979).

This result, known as the Ramsey (1928) rule, is illustrated in Figure 2. At D, the rate at which consumption can be substituted in the economy equals the rate at which consumption is substituted in terms of social welfare. Point E is not optimal because welfare can be increased (that is W^1 to W^2) by reallocating consumption from the present (C_t) to the future (C_{t+1}).

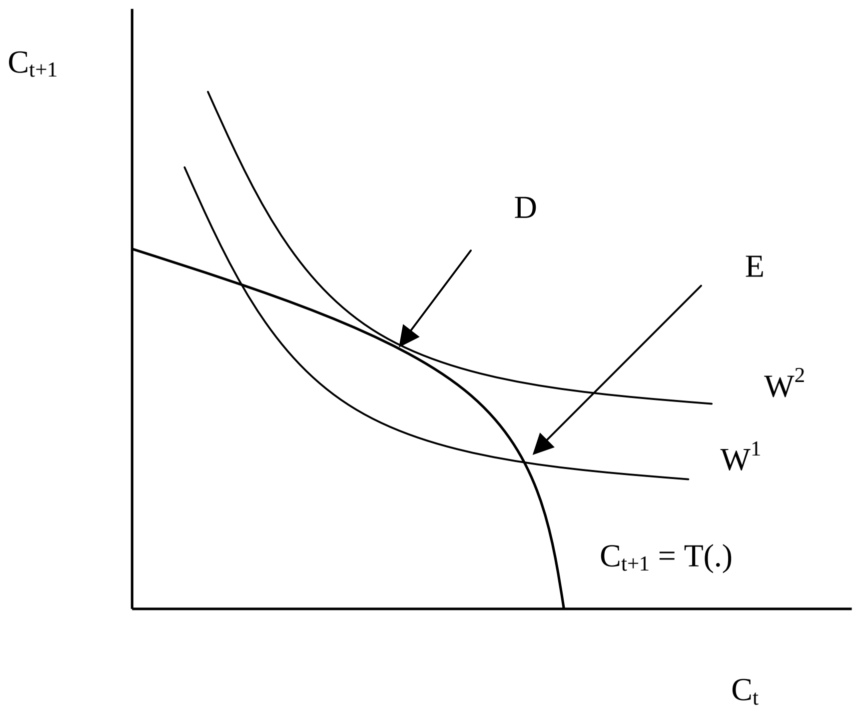

Figure 2: Social discount factor.

If for example, the return on marginal investment is less than the rate at which it is socially desirable to discount next period's consumption (that is $r_t < \rho_t$) then equality can be achieved by foregoing investment in period *t* (thus increasing r_t) and reducing consumption in *t+1* (thus reducing ρ_t). Or, if $r_t > \rho_t$ then the marginal investment should be undertaken, (reducing r_t) and (increasing ρ_t). Returning to the criticism of Daly and Cobb (1994) it should be obvious that the issue of discounting is linked to intertemporal justice. Justice among generations has been studied by economists for decades. The Ramsey Rule is based on a utilitarian approach.

In an economy where the government engages in policy reforms and the policies (such as climate change, and biodiversity) are chosen in a sequential manner then the implicit social discount rate connects investment and consumption over time. Returning to the Economist's article, there is a presumption that social discount rates are independent of the income associated with the policy.

Dasgupta (2000) shows that welfare depends on two parameters α and δ that reflect different concerns: α is an index of the value attached to intergenerational equity and δ is the weight attached to future generations' utility relative to the present generation. The larger α is the more egalitarian is the optimal consumption path. Dasgupta (2000) applies this line of reasoning to global warming. If global warming leads to declines in global consumption over an extended period in the future, then consumption rates of interest could well be negative. Thus from our present point of view future global losses would be amplified as opposed to reduced to negligible figures through discounting.

Thus the welfare economics of global warming needs to be developed within the context of optimising economies, as done in Nordhaus and Yang (1996). The Ramsey-Koopmans theory advocates that projects having long-run effects should be subjected to the same conceptual treatment as those that have near-term effects. Dasgupta (2000) has demonstrated it is incorrect to use project-specific discount rates.

However, Weitzman (2001) provides us with an argument for the use of a variable discount rate over time. He considers the choice of an appropriate discount rate to be one of the most critical problems in economics. Given a range of views on the role of government and the ethical foundations of intergenerational discounting, there is considerable scope for rational individuals to hold different views. At the empirical level, no consensus has ever existed about what actual rate of interest to use. In contrast to exponential discounting, Weitzman proposes a "sliding scale" social discount rate. A marginal discount rate of 4% is suggested for [0,5] years, decreasing to 0% for benefits and costs falling over 300 years.

A great deal of uncertainty surrounds the choice of an appropriate discount rate. Ethical differences and the absence of agreement on what rate to use are problematical because contemporary sustainable development challenges typically span generations. Given this state of affairs the proper procedure is to perform sensitivity analysis using several plausible discount rates and, perhaps, apply the sliding scale method advocated by Weitzman.

Key Issues:

- *Social discount rates are determined within the socioeconomic system*
- *The biosphere should not be considered external to the socioeconomic system*
- *Social discount rate may not be constant over time*
- *Project specific discount rates should not be used*

3.4 Ecology and physical laws

Ecology is the study of relationships between plants, animals, people, and their environment and the balance between these relationships. Explicitly incorporating the structure, functioning and dynamics of life supporting ecosystems into models of sustainable development, as noted earlier, is one of the three pillars of ecological economics.

Some ecologists emphasise system function and resilience of ecosystems, concepts that do not appear in standard economic treatments of sustainable development. This view holds that ecological systems are only malleable within certain limits. Acknowledging these limits constrains our ability to substitute natural and manufactured capital over time.

Two streams of analysis have their origins in the laws of thermodynamics. The first, known as the "materials balance approach", developed by Ayres and Kneese (1969), is based on the first law of thermodynamics *viz.* the law of the conservation of matter. All materials and energy used by economic activity are shown to go back into the environment. The framework is particularly useful in formulating and analysing policy responses to the inevitable externalities associated with production and consumption.

Recognition of the importance of the second law of thermodynamics is attributed to Georgescu-Roegen (1971). The second law recognises the qualitative distinction between the inputs of valuable resources (low entropy) and the final outputs of valueless waste (high entropy). Thus economic activity takes low entropy matter/energy inputs (e.g. fossil fuels) and converts them into high entropy matter/energy outputs (e.g. dispersed gases and particles). The energy liberated by this process is irreversibly lost. In the longest of time frames (e.g. astronomical time) the second law tells us that sustainable development is meaningless. This is not terribly helpful to contemporary decision makers other than to remind us that complete recycling is not feasible.

Deep ecology is an attempt to synthesise philosophical attitudes about the relationship between nature and human activity. Deep ecology places particular emphasis on ethical, social and spiritual aspects of the relationship. In addition to systems ecology, deep ecology draws eclectically on many schools of thought; for example, eastern philosophies and religions, concepts about justice and equity drawn from various religions and eco-feminism (Colby, 1991).

Deep ecology advocates a merging of systems ecology with a biocentric (as opposed to anthropocentric) view of the relationship between humans and nature. Among the basic tenets are: biospecies equality, reductions or constraints on the growth in human population, promotion of biological and cultural diversity, decentralised planning using multiple value systems, non-growth oriented economies and greater use of indigenous management and technological skills.

Key issues:

- *Ability to adjust natural capital over time is constrained by ecological feasibility*
- *Materials balance is an important principle to recognise in environmental policy*
- *Biocentric, relative to anthropocentric, views have markedly different implications for sustainable development policy*

3.5 Capital

In economics, capital goods *(K)* are produced commodities – incurring opportunity costs - which are required for production. The economy's stock of capital is a vector of different capital goods that can be valued provided they are used in production. The value that attaches to the services of capital provides the basis for valuing capital. Valuation therefore enables a stock of heterogeneous capital goods to be aggregated. The capital value of an economy's endowment of manufactured capital can change even though there is no change in the physical stock of capital.

The above treatment of capital can be extended as follows:

- Natural capital (K_N) is nature's goods and services. Natural capital is further broken down into renewable (e.g. fish stocks) natural capital K_N^R and non-renewable (e.g. coal) natural capital K_N^S. Thus the economy's endowment of natural capital is $K_N = K_N^R + K_N^S$.
- Manufactured capital (K_M) includes equipment, plant, buildings, dams, infrastructure, and so on.
- Human capital (K_H) comprises the stock of knowledge, health and skills of individuals.

In recent years the idea of "social capital" has been developed to capture the idea that social institutions are an important basis for sustainable livelihoods (see for example, Putman, 1995). Aspects of social capital – such as the structure of property rights, public participation, social cohesion, community values, and the duty of communities vis-à-vis future generations – are seen to act as resources for individuals to realise their personal and collective interests.

The characteristics of property rights can be likened to inputs and thus have value. Tony Scott (1996) uses duration, exclusivity, transferability, transformability and quality of title to describe the structure of property rights. The quality of property rights are an instrument of choice and can make a substantial contribution to sustainable development, as evidenced by New Zealand's fisheries quota management system (QMS). At another level, enhancing the collective-decision making process is an investment in social capital (Ostrom, 1998).

In this report the notion of social capital will be implicitly treated within the context of sustainable development policy. The use of an economic instrument (such as a carbon tax, or tradable rights) could be viewed as enhancing social capital. New Zealand's (QMS) is a practical example of institutional reform enhancing social capital. This is not to say that there are no welfare-enhancing improvements to be made to the QMS.

Key issues:

- *The nation's endowment of capital includes manufactured, natural human, and social capital*
- *These forms of capital can be viewed along the traditional lines of economics, viz. as stocks, flows, and investment in enhancement*
- *The notion of natural capital should explicitly recognise biophysical relationships and limits*

3.6 Substitution

Substitution is the process of replacing one factor of production with another factor of production while holding output constant. The issue of substitution arises in sustainable development when considering the ability to substitute natural capital *(K_N)* with manufactured capital *(K_M)* while holding the value of gross domestic product (GDP) constant. Figure 3 shows *(K_N,K_M)* used in the production of a given level of GDP. If there is no ability to substitute natural and manufactured capital then the elasticity of substitution (that is the relative ease of substitution) is zero. Figure 3 shows a range of elasticities.

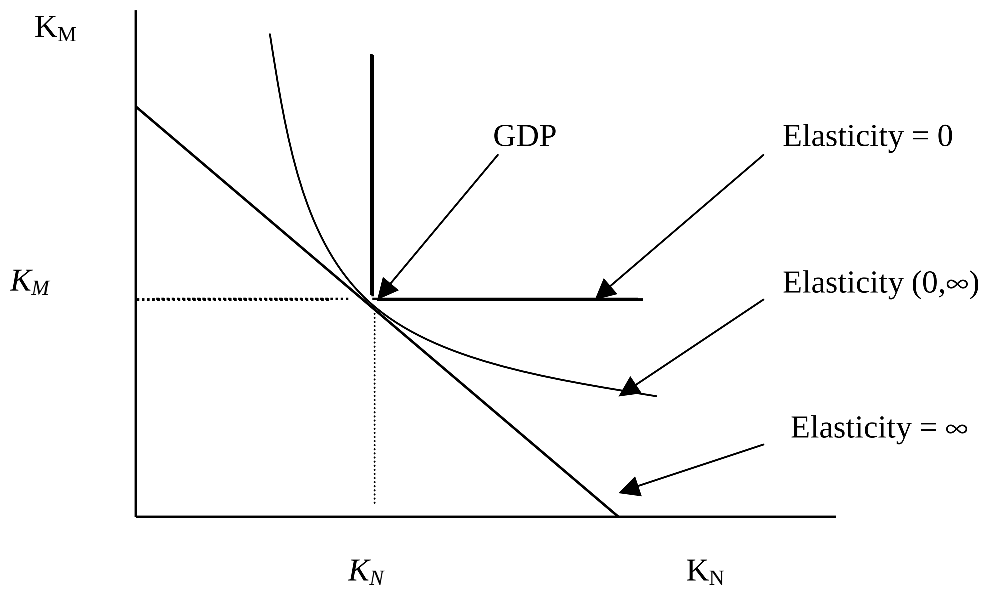

Figure 3: Three possible GDP isoquants

The issue of substitutability features prominently in the debate over sustainable development. As noted earlier, the Solow-type growth models highlight the importance of elasticity when replacing the services of an essential resource with manufactured capital. Reynolds (1999) reminds us that entropy works to limit the extent to which isoquants can be shifted in towards the origin through technology change. Empirical studies of the economic effects of CO_2 abatement also demonstrate the significance of energy-capital substitution (Kemfert and Welsh, 2000). Estimated sectoral substitution elasticities were all in the range (0,1) indicating that capital and energy are imperfect substitutes. Other things being equal, higher elasticities imply lower carbon tax rates and tax revenues with a given target amount of CO_2 reduction. Vlachou *et al.* (1996) use estimated elasticities for the electricity industry in Greece to show that carbon taxes will induce a shift away from lignite-based generation of electricity to hydro and energy conservation.

The degree to which it is possible to substitute natural capital with manufactured capital is an empirical issue. If sustainable development is constrained by ecological facts then it follows that the substitution between natural and manufactured capital will be limited. Additional constraints would be imposed if Daly's (1991) suggestion was adopted as a principle for sustainable development *viz.* that the depletion of stock resources should be limited by the investment in enhancing renewable sources. However, the precise nature of the pairing is not clear. For example, must the investment in renewable natural capital (e.g. solar energy) be a close substitute for the exploitation of non-renewable capital (e.g. natural gas)? Or should the investment yield an equal value of sustainable consumption (e.g. electricity)?

It should also be noted that technical progress is a separate issue from substitution. Technical progress occurs when a higher level of output can be produced from a given quantity of inputs. Humphreys (2001) shows that increases in environmental costs have been more than offset by technological developments in the mining industry.

Key issues:
- *Elasticity of substitution between, and within, the four broad forms of capital is largely unknown*
- *Ecological facts can limit substitution possibilities*
- *Additional limits to intertemporal substitution would further constrain economic growth*
- *Normative issue of whether substitution ought to be allowed*

3.7 Valuation

Economic analysis of the effectiveness of environmental policies requires the complex and controversial practice of valuing the exchanges between nature and the economy (Hannon, 2001). To measure the contributions of the environment Bockstael *et al.* (2000) suggest that evaluations should occur at the point of exchanges between environment (e.g. ecosystem functions associated with sustaining groundwater) and economy (e.g. use and non-use values that attach to groundwater). Valuing the services of nature has been tackled at a micro level and at the level of national accounting.

Total Economic Value

Adverse environmental impacts are often associated with economic growth, development and policy reform. The economic tools available to policy makers include, polluter-pays fees and tradable rights. Other policy instruments include regulation, education and the provision of information. Information on environmental damage is necessary in order to approximate an optimal response to the externality. Within the context of habitat preservation and biodiversity, estimates of value can be of assistance to policy makers.

The underlying assumption of economic valuation is that individuals are able to express preferences over alternative states of the environment. Environmental economists use the term total economic value (TEV) to include the sum of use values (UV) and nonuse value (NUV). Thus:

$$TEV = UV + NUV$$

For example, the TEV of groundwater includes the value of abstracted water used to irrigate crops (UV) plus the value attached to water *in situ* (NUV). Non-use value includes existence and bequest values. White *et al.* (2001) provide an illustration of how to estimate TEV and apply the results to the practical problem of allocating ground water between abstractive uses and the maintenance of *in situ* services. The notion of TEV could be used to analyse alternative policies for managing indigenous forests and marine resource management. It is important to point out that "money" value relates back to individual preferences. Monetary estimates of TEV have nothing to do with "making money", "privatising nature" or "profit at the expense of the environment".

Deep ecologists reject the above approach to valuing the services of nature, claiming that the services provided by the natural environment are not simple commodities and should not be measured in monetary terms. However environmental valuation has gained a reasonably strong presence in the context of environmental policy and environmental litigation. The total economic value framework was used by the OECD (2000) when developing its framework for sustainable development. In particular, the OECD concluded that the " … valuation of externalities is a key condition to work towards sustainable development." (OECD, 2000; p. 13). The use of environmental valuation in government decisions has been endorsed by the legal process in the UK (Moran, 1999). In the US, Exxon was sued for damages for both the loss of use values and non-use values, as well as having to pay for the clean-up costs (Willis and Corkindale, 1995).

National Accounting

The attempt by Costanza *et al*. (1997) [the *et al* has not been referenced]– ecological economists – to price the supply of ecological services to the global economy caused considerable debate. As an alternative, ecologists have demonstrated how ecological systems could be considered in a parallel way with economic systems. The input-output model provides the simplest method for linking economics and ecology. Figure 4 illustrates the combined economic-ecological accounting framework proposed by Hannon (2001). Gross system product (GSP) is the sum of gross domestic product (GDP) and gross ecological product (GEP) – an addition that obviously requires commensurability across the GDP and GEP accounting system. Hannon (2001) approaches the problem by expressing the metabolic inputs to the ecosystem using the money metric. The ratio of joules of metabolism per joule biomass (which is valued using non-market methods) provides the basis for calculating the economic value of the biomass for each biological sector. Estimates of the current rents can be used to provide a value of the irrecoverable loss of natural capital (for example, eroded soil and waste energy).

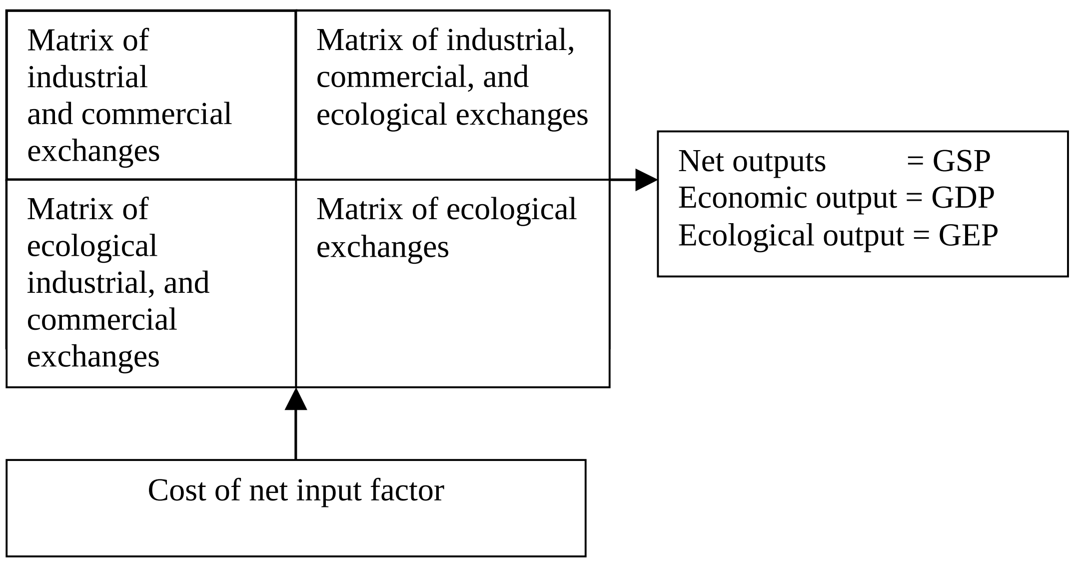

Figure 4: Combined economic-ecological accounting framework

Key issues:

- *Non-market valuation is necessary if government is concerned for efficient environmental policy*
- *Valuation techniques are accepted by governments and courts in a growing number of countries*
- *Valuation techniques have been developed at micro and macro level*
- *Valuation is not universally accepted.*

3.8 Risk and Uncertainty

Uncertainty in the context of sustainable development considerably expands and complicates the conceptual framework. Uncertainty is associated with the state of knowledge, the processes by which additional knowledge is created, beliefs and expectations about life supporting ecosystems, knowledge of both stock and renewable resources, the likely availability of substitutes, technological change, population growth and spatial concentrations, preferences of future generations, and so on.

In economics the study of behaviour under uncertainty assumes that individuals behave as if they are maximising the expected utility. Attitude to risk is reflected in the shape of the utility function defined over the set of possible outcomes. From a known set of probabilities that attach to “states of the world” and the shape of the utility function it is possible to calculate the expected value of the risks and expected utility. If the individual is risk averse then there is a maximum amount the individual would be willing to pay to avoid facing the risk.

The theory of social choice under risk is closely analogous to that used to describe the individual choice. If the social welfare function indicates risk aversion then the expected value of welfare is lowered when risk is present. The implication for sustainable development can be illustrated using risk about the arrival of renewable substitutes for non-renewable resources. If society is risk averse then it will reduce resource use relative to a risk neutral society.

Risk assessment requires input from both the physical and biological sciences and social sciences (Chapman and Howden-Chapman, 1997). Social science input is particularly important for more accurate assessments of risk consequences as well as analysing and explaining public responses to risk (Freudenburg, 1988). Factoring risk into sustainable development is a relatively recent development. Under pure uncertainty rational choice criteria focuses on the extremes of the possible states and not the mid-point as typically assumed when applying the expected utility model (Arrow and Hurwicz, 1972). Woodward and Bishop (1997) use the Arrow-Hurwicz framework to illustrate uncertainty-based choices about global warming policies.

According to Levy *et al.* (2000) the variability of ecosystems, where disturbances occur with uncertain frequency and magnitude over time and space, is essential for maintaining ecosystem integrity and resilience. In other words, probability models of uncertainty may be inappropriate because it is the extreme events that are critical to the health of systems. Furthermore, there is usually insufficient information to select and calibrate a probabilistic model with accurate tails. They propose a multi-attribute value theory procedure to identify policy alternatives that cope with uncertainty and meet threshold levels of welfare. In contrast, Tolmasquim *et al*. (2001) use environmental valuation techniques (as outlined above) for assessing projects and programmes. For example, they specify a willingness-to-pay value that reflects the probability of biodiversity loss.

Key issues:
- *Risk impacts most elements of sustainable development*
- *Healthy ecosystems may rely on extreme perturbations*
- *If risk aversion exists, then individuals and society would be willing to pay a positive amount to avoid exposure to risk*
- *The theory of rational choice under pure uncertainty is not well developed*
- *Multi-attribute theory and stated preference approaches to valuation provide a tool for explicitly considering risk within the context of sustainable development*

3.9 Indicators of sustainability

If sustainable development is to be used as a guide to practical policy it is necessary to have an operational indicator or set of indicators as an aid in monitoring progress towards sustainability.

Two criteria for sustainable development are associated with ecological economics:

- Weak sustainability: allows substitution between K_N and K_M and tends to be favoured by mainstream economists. The elasticity of substitution among forms of capital is an empirical matter and is not something that can be deduced from theory.
- Strong sustainability: in contrast, ecological economists typically support a principle that does not allow the stock of natural capital (K_N) to decline (Daly, 1991). The implications for resource use are that harvest levels should not exceed the rate at which natural regeneration occurs, and waste emissions should not exceed renewable assimilative capacity. Non-renewable resources are exploited at a rate equal to the creation of renewable substitutes.

Ecological footprint

Wackernagel and Rees (1996) introduced the concept of an ecological footprint. The basic idea is that every individual, process, activity and region has an impact on the earth. These impacts – such as resource use, generation of waste, and use of nature's services – are converted to a biologically productive unit and accounted for. The approach quantifies the biologically productive and mutually exclusive areas necessary to continuously provide for peoples' resource supplies and the absorption of their wastes using existing technology.

The ecological footprint focuses on providing an indicator of maintaining the stock of natural capital. Ecological services are seen to be a precondition for life – as opposed to a substitute. Energy and resource accounting is in biophysical units. Flows of energy and matter to and from specific activity are converted to the corresponding land and water area needed to support these flows. Three steps are involved:

- Estimate consumption for a given spatial domain
- Calculate the land area (fossil fuel, crop land, forest land, etc) appropriated by consumption, and
- Aggregate the area estimates to get an ecological footprint for the geographic area.

Table 1: Ecological footprint

	Ecological footprint (ha/capita)	Available capacity (ha/capita)	Ecological Surplus/deficit (ha/capita)
New Zealand	7.6	20.4	12.8
World	2.8	2.0	-0.8

Source: Wackernagel *et al.* (1999)

Bicknell, *et al.* (1997) use a modified input-output model to calculate the ecological footprint for New Zealand. They show that it takes 3.49 hectares of ecologically productive land sustain average capita consumption.

The ecological footprint concept has been criticised on the following points (Van den Bergh and Verbrugen, 1999):

- Aggregation: because it is a one-dimensional indicator, land of different qualities must be aggregated. Thus a unit of land used to support infrastructure would receive the same weight as a unit of land used by agriculture. Collapsing land into one-dimension may not greatly assist with policy analysis.
- Land use practices: sustainable as opposed to unsustainable land use practices are not distinguished.
- Energy use: land appropriated by fossil fuels makes up about 50 percent of the ecological footprint estimated for most developed economies. This assumption may not be ecologically feasible.
- Trade: the relationship between trade and regional sustainability is not clear. In particular it neglects to account for the comparative advantage of regions and countries with the result that some form of self-sufficiency (autarky) is the most desirable solution.

Thermodynamic indicators of sustainability

Daly (1991) proposes the following indicators:

- Limit human scale to a level, which, if not optimal, is at least within carrying capacity.
- Technical progress for sustainable development should be efficiency-increasing rather than through-put increasing.
- Harvest rates of renewable resources should not exceed regeneration rates and waste accumulation should not exceed the renewable assimilative capacity of the environment.
- Non-renewable resources should be exploited, but at a rate equal to the creation of renewable substitutes.

Capital theory

The Hartwick rule arose from the results of models of exhaustible resources. Keeping investment equal to resource rents yielded a path of constant consumption – intergenerational equality - over time (Hartwick, 1977). Constant consumption, in a closed economy, is achieved by reinvesting all resource rents in reproducible capital. Ashiem (1986) shows that a resource rich open economy can deviate from the Hartwick rule and use revenues arising from resource exports to finance additional consumption.

Hartwick (1990) provides a consistent framework for adjusting national accounts to incorporate the use of natural capital. An explicit economic depreciation of natural resource capital should be deducted from gross national product (GNP) to arrive at a correct measure of net national product (NNP). The correct measure of NNP includes the current loss in value of natural resource stocks (e.g. natural gas), and over-use of renewable and environmental resources. The approach highlights the fact that national accounts must be based on scarcity prices and not administered or distorted prices. The basic idea is to subtract rent – price less marginal cost multiplied by the change in the natural capital good – from GNP. For stock resources this requires netting out the Hotelling rents on the net reduction in stock over the period. For renewable resources (e.g. fish stocks) depreciation is marginal economic rent weighted by the change in the stock of renewable resources. Depreciation of the environment is estimated by multiplying abatement by the marginal cost of abatement. Clearly, depreciation can become positive by making positive improvements to the stock of clean environmental capital.

While there is no agreement on a precise definition of sustainable development there is general acceptance that sustainable development requires that the stock of capital passed from one generation to the next is at least maintained. The key assumption here is the ability to substitute between renewable and non-renewable resources. In this context the conclusion of Dasgupta and Heal (1979) is important because economic output can at least be maintained indefinitely through substitution.

> "Even in the absence of any technological progress, exhaustible resources do not pose a fundamental problem if reproducible capital is sufficiently substitutable for natural resources" (p.205)

The sustainable development debate raised doubts about whether the concept of natural capital adequately captures the economy-environment linkage (Victor, 1991). Pearce and Atkinson (1993) used the Hartwick rule to estimate the following indicator of weak sustainability *(Z).* An economy is considered sustainable if and only if *(iff)* it saves *(S)* more than the combined depreciation of natural capital K_N and manufactured capital K_M . That is

$$Z > 0 \;\; iff \;\; \frac{S}{Y} > [\frac{\delta_N}{Y} + \frac{\delta_M}{Y}]$$

where
δ_N is depreciation of natural capital
δ_M is depreciation of manufactured capital
Y is income

The United Nations System of National Accounts provide data on savings and income. Environmental degradation and resource depletion is estimated using the theory developed by Hartwick (1990). The empirical results of Pearce and Atkinson (1993) suggest that many countries failed to pass a weak sustainability test.

Hanley *et al.* (1999) develop a time series of alternative indicators of sustainability for Scotland. Their results show that the conclusion reached depends on the indicator used.

- Green NNP (Hartwick, 1990) – increasing sustainability.
- Weak sustainability (Pearce and Atkinson, 1993) – unsustainable.
- Index of Sustainable Economic Welfare (Daly and Cobb, 1994) – unsustainable.
- Ecological Footprint (Wackernagel and Rees, 1996) – marginally sustainable.

In contrast to the *ex post* stance used by the techniques described above, cost benefit analysis provides analysts with a practical tool for evaluating projects and environmental regulations *ex ante*. The technique has been developed to a stage where environmental values are routinely estimated and incorporated within the cost-benefit framework. Despite being criticised for its utilitarian foundation, discounting, and valuation of natures' services it remains one of the few practical economic tools available for the routine analysis of approaches to environmental problems.

Key issues:
- *A number of macro indicators of sustainable development are available*
- *Recent evidence shows indicators yield differing results*
- *Need for micro-level indicators to be developed*
- *The cost-benefit framework is a practical tool for ex ante analysis of development options*

3.10 Conclusions

Neoclassical economic theory brings an understanding of important elements in growth and sustainable development. The theory provides a way of organising one's thoughts on these matters. However, the question about whether environmental decline is bound to be associated with economic growth can't be answered decisively by the theory. The theory is useful because it assists us in pin pointing those considerations on which the answer depends.

The introduction of ecology and physical laws poses no special problems for the above theory provided they could be represented in an analytically rigorous way. Environmental economists have long attempted – probably in a minimalist way - to incorporate renewable resources and the ecology of life supporting systems into their models. The transdisciplinary field of ecological economics has reinforced this line of research.

It is at the level of ethics that resolution is not possible. It is simply not possible to resolve differences based on different ethical principles. In this case, modelling the different positions in a rigorous and transparent way will at least enable the implications to be drawn out and discussed.

Toman (1998) provides a summary of the current state of knowledge on sustainable development from the perspective of what practical guidance is offered by economic analysis to decision makers. In short he doubts the capacity any more or less of a mechanistic rule, economic, scientific or otherwise, to provide definitive and reliable answers about sustainable policies or conduct. He is however more optimistic about being able to identify processes and procedures that can guide decision-making. In particular, he argues for methodological pluralism and the need to recognise the range of different values at stake. A number of frameworks are described and discussed in the next section.

4 Frameworks of Sustainable Development

We now move from a discussion of the elements of sustainable development to an illustration of the range of frameworks that attempt to provide a basis for advancing sustainable development. The principles underpinning each framework are discussed in the previous section.

4.1 The Natural Step Framework

The Natural Step organisation was founded in Sweden in 1989. It uses a framework to integrate environmental issues into the frame of business reality and to move business toward sustainable development (Gehrke, 2000). Four key processes are:

1. Perceiving the nature of unsustainable direction of business and society and self-interest implicit in shifting to a sustainable direction.
2. Understanding the first-order principles of sustainability.
3. Strategic visioning through “back-casting” from a desired future.
4. Identifying strategic steps to move the company from its current reality toward its desired vision. (Nattras and Altomare, 1999, p.18)

The first-order principles are those that must be followed for a society to be sustainable. Four conditions are described as being necessary to sustain the environment’s life support systems:

Fossil fuels, metals and other minerals must not be extracted at a faster rate than their slow deposit on the earth’s crust.

Substances must not be produced faster than they can be broken down and reintegrated into the cycles of nature or to be deposited into the earth’s crust.

The productive services of nature must not be exploited at a higher rate than can be created and renewed.

Basic human needs must be met with the most resource-efficient methods possible, including equitable resource distribution. (Gehrke, 2000, p. 27)

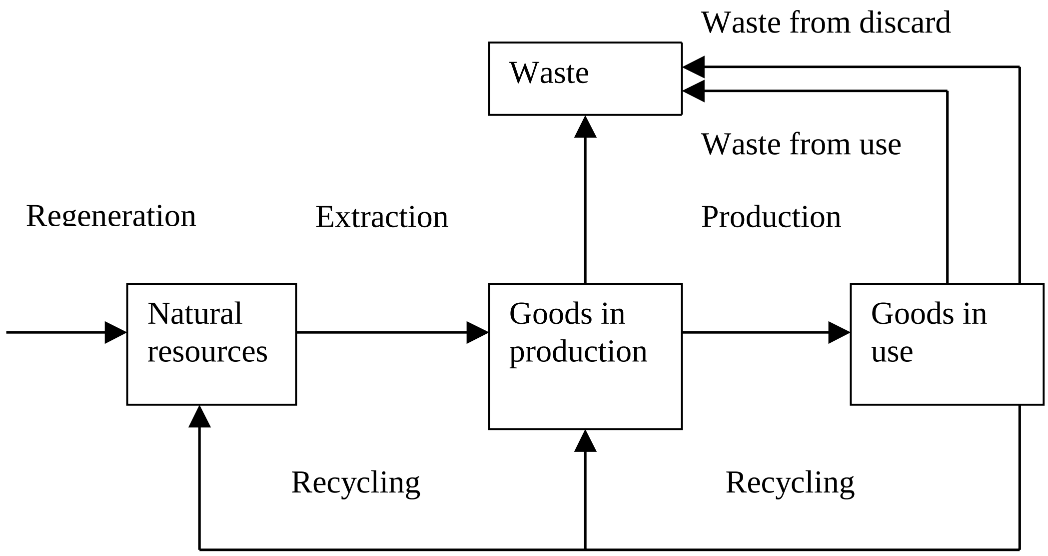

Figure 5: The Natural Steps Framework

4.2 New Zealand Ecological Society

The New Zealand Ecological Society recommends that sustained yields be set conservatively by agencies that have no economic stake in the exploitation. The Society defines ecological sustainability as:

> "… use of components of an ecosystem in ways that allow for the perpetuation of the character and natural processes of that ecosystem. Ecosystems have the ability to change and adapt to management impacts within certain limits. Sustainable management of these ecosystems must not exceed these limits.(New Zealand Ecological Society, undated) [reference?]"

In their definition of sustainability the Society argues for economic growth to be based on ecological principles. Resource harvesting and extraction should be constrained by setting ecological sustainable limits and renewable energy sources should replace non-renewable sources. Their view is that sustained economic growth is unrelated to sustainable development because it takes little account of future generations. The needs of future generations can only be met if ecosystems can be sustained.

The ecological goal of sustained yield harvesting is the population density or size from which the yield is taken, not the harvest. Therefore sustained yield harvest is a property of the particular biological population (such as a particular fish stock).

4.3 Ministry of Economic Development

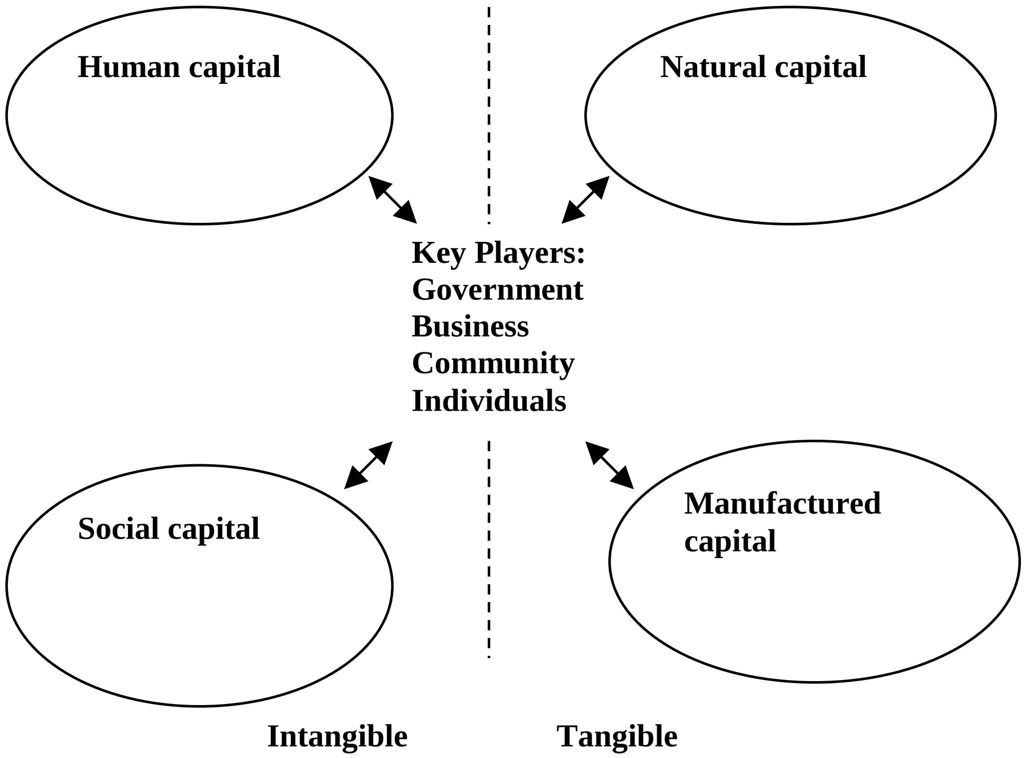

Figure 6: Capital-based model of sustainable development (Ministry of Economic Development, 2001)

The framework prepared by the Ministry of Economic Development (2001) is based largely on the concept of capital as the engine of economic growth. A connection is made between public policy objectives and the concepts of weak and strong sustainability. The view is that sustainability criteria provide the basis for achieving public policy objectives. The definition of capital is based on the OECD (2000) definitions and includes those listed above plus the notion of social capital. Social capital is taken to include “the networks and the shared norms, values and understanding that facilitate co-operation within and between groups.” The Ministry’s model sees efficient use of capital as a necessary condition for maximising benefit and achieving long-term efficiency. Interestingly, technological progress is seen to allow substitution between alternative forms of capital. Government plays a key role in the model because human well-being is seen to be contingent on the quality of institutions and public policy.

4.4 OECD Framework

The OECD initiative approached sustainable development from the perspective of economic development. It sees market forces and public policies promoting economic growth as measured by GDP while also contributing to the deterioration of environmental quality at local and global scale. The benefits of achieving sustainable development often have the characteristics of public goods (non-exclusion and non-rivalry) thus providing a basis for public policy. Integration across public agencies is considered important to the task of achieving sustainable outcomes. Policies aimed at achieving economic growth in the short-term may diverge from those directed at achieving sustainable development.

The OECD (2001) sees three elements in formulating policy within a sustainable development framework:

- Global dimension: even though action at a local level is necessary, there are some problems (e.g. global climate change) that require international cooperation. Success is therefore contingent upon international cooperation and coordination.
- Linkages: the organisational boundaries of public agencies are often defined in a way that may not be able to deal effectively with the crosscutting issues of sustainable development. Linkages between the economic, environmental and social dimensions of policy result in trade-offs between objectives that affect different constituencies. Issues that cut across the domains of individual public policy agencies require coordination.
- Participation: sole responsibility for meeting the challenge of sustainable development cannot rest on government. Other stakeholders within the community have to be encouraged to participate and become active partners.

The OECD (2001) framework emphasises accounting for the full costs of economic activities. In particular:

- An emphasis on how the capital base (total capital as defined earlier) of the economy is evolving.
- The importance of science, technology and human resource development in enhancing the productivity of existing capital.
- Assessment of the degree of substitutability or complementarity between different assets.

While the above concepts are seen to offer guidance to policy makers they are limited in at least two ways. First, our ability to value some ecological resources limits comparisons across generations. Two sub-issues are conflated here. For example, we may be able to estimate the benefits of climate change now, but a major difficulty arises when we attempt to estimate the benefits accruing to future generations who (may) have higher levels of material well-being. Shifting the costs on to current generations could, for example, mean that urgently needed funding for low income groups is no longer available. Second, the tools that we have to analyse uncertainty and irreversibility have limited ability to improve the quality of public policy analysis.

Externalities are considered a major obstacle in achieving sustainable development. An effective pursuit of sustainable development must correct for market failures and remove policy failures. The OECD has a well-established position recommending the use of economic instruments (tradeable rights, polluter pays mechanisms) in environmental policy. Open access to renewable resources would be an obvious example of policy failure that can be corrected by creating well-defined property rights. The removal of environmentally harmful subsidies is another example. Better framework conditions for sustainable development requires better *ex ante* integration of sectoral concerns at the policy design phase.

The OECD policy framework for sustainable development comprises three key dimensions: economic (growth in terms of both quantity and quality); social (well functioning institutions, social stability, equity); environment (stability of bio-physical systems, healthy environment). Linking these three dimensions provides scope for synergies to be exploited and tradeoffs to be made transparent. The linkages are illustrated in Figure 7.

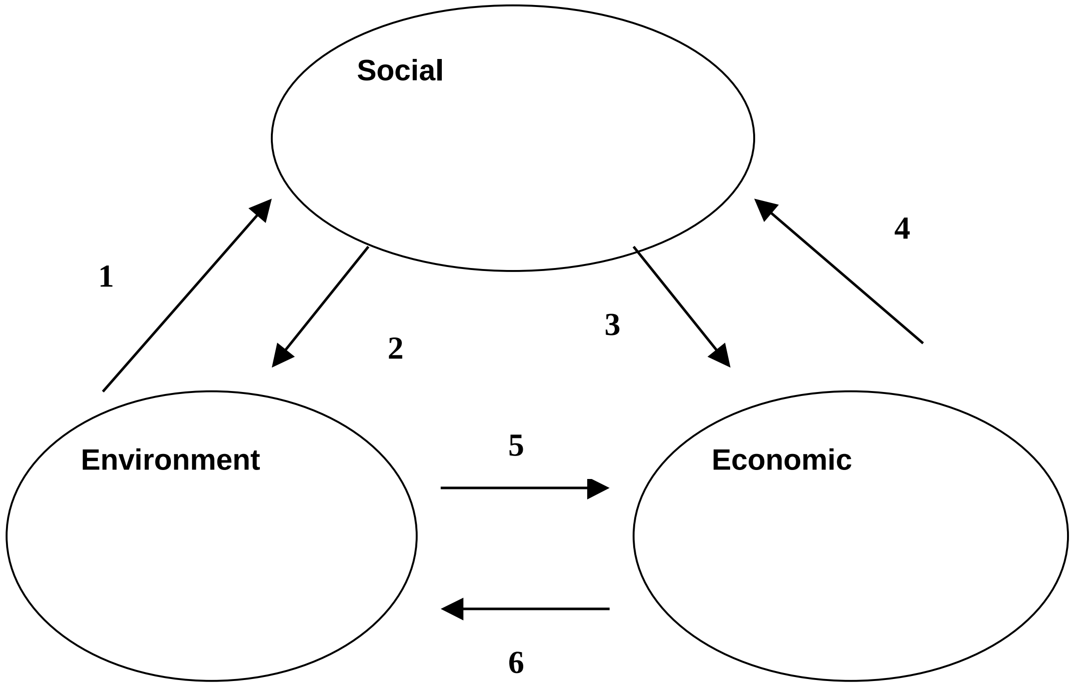

Figure 7: Economic, social and environmental interactions (OECD, 2001)

Notes:
1. Health hazards; impacts on living and working conditions
2. Pressure on environmental resources; environmental awareness
3. Quantity and quality of labour force, consumption
4. Income distribution, employment opportunities
5. Productive functions of the environment
6. Pressure on environmental resources, investment in environmental protection

The OECD framework is based on the notion of “pressure-state-response”. Pressure on the environment (for example, arising from economic and population growth) leads to changes in the state of the environment (for example, land degradation, water pollution) that in turn results in a response by government (for example, removal of production subsidies to agriculture). OECD does not consider a broad concept, such as “maximising human well-being”, as an appropriate objective. Rather, they prefer to interpret <u>sustainability as a set of boundary conditions which economic development should respect</u>. This, of course, shifts the problem of sustainable development from the objective function (attempts to remove notions of intergenerational justice) to the constraint set (to sit along side other constraints). Either way it must be defined and made operational.

The OECD approach suggests:

- That the stock of total capital (as defined earlier) should not decline.
- Application of the concepts of weak and strong sustainability.
- Capacity to preserve the capital base and the opportunities available to future generations will depend on technological progress.
- Maintaining a constant level of per capita well being over time requires that economic activity expands with population. Spatial concentrations of people also have implications for sustainable development.

- Public policy aimed at improving the three dimensions listed in Figure 7 will involve opportunity costs. Thus policy should be pursued in a cost-effective way.
- Balancing economic, environmental and social objectives in a sustainable development framework would be facilitated by valuing environmental and social resources in monetary terms. A total economic value framework is recommended. Uncertainty, irreversibility and the risks of catastrophic events create additional difficulties for valuation.
- Internalising externalities and correcting policy failures.
- Moving towards sustainable development requires improved institutional structures and, governance and decision-making.

The relationships illustrated in Figure 8 can be formalised using the extended input-output accounting framework pioneered by Ayres and Kneese (1969). The input-output model accounts for material flows from the environment, the various stages of production, consumption and finally the residuals receiving media. The model is based on the conservation of matter. The original work of Ayres and Kneese was static and Toman *et al*. (1998) show how the static input-output framework can be adapted to account for changes in the quantity and quality of natural and environmental resources.

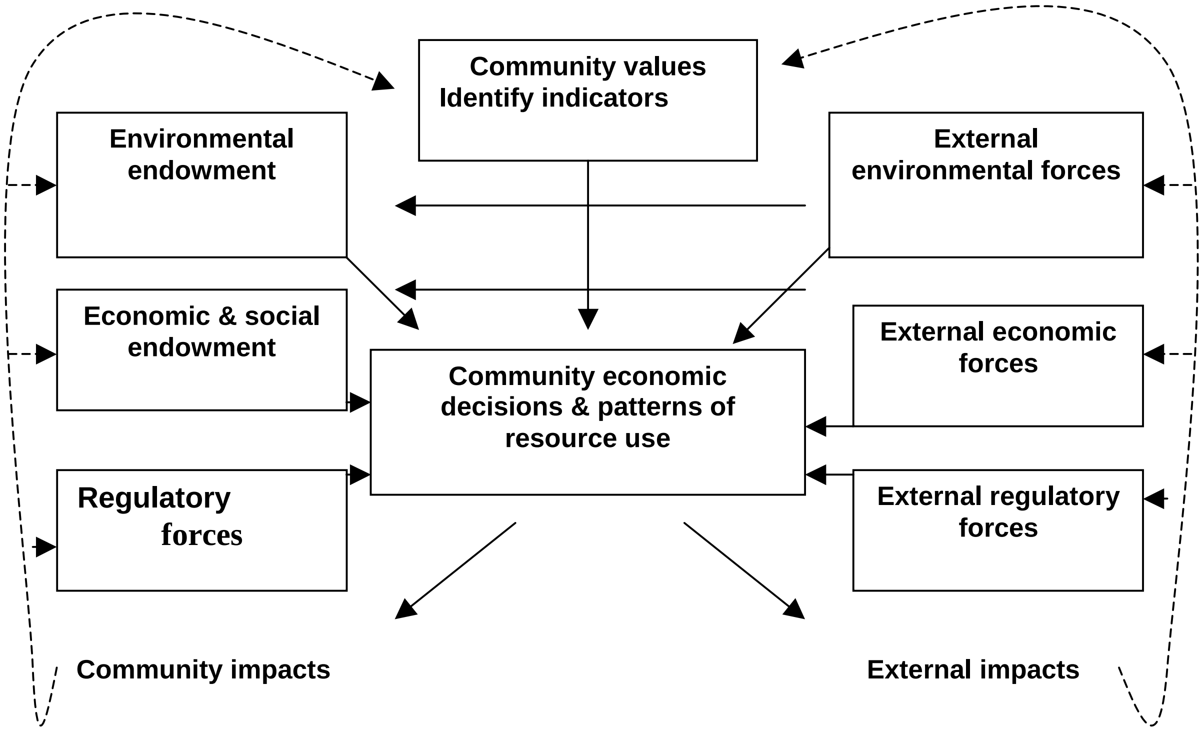

Figure 8: Further refinements to the OECD framework (Toman *et al*. 1998)

The OECD “pressure-state-response” framework provided a basis for Toman *et al.* (1998) to organise information about the elements of sustainability. The solid lines in Figure 8 depict interactions among community values and indicators and the dashed lines depict the resulting feedback from the community’s economic and resource use decisions.

If such a model were to be developed and used to estimate spatial and temporal changes in “states” then how might the information be used? This of course comes down to identifying criteria for assessing sustainability. Applied cost-benefit analysis would approach this by using appropriately defined prices, corrected for externalities, and a discount rate to reflect social rate of time preference. Imposing other criteria exogenously - such as non-declining utility and weak/strong sustainability - has important theoretical shortcomings. In particular, these additional restrictions may provide a mapping of outcomes at odds with sustainable development.

4.5 Ministry for the Environment

The Ministry for the Environment (1995) report attempts to bridge the gap between theory, economic instruments and internalisation, and environmental problems, within the context of sustainable management of resources:

- Environmental philosophy: Ethical beliefs are considered an important influence on the relationship between people and the environment.
- Ethical beliefs falling under the banner of ecocentrism covers a wide range of philosophical positions, including the rights of living organisms and deep ecology. From this ethical position, the ecocentric ethic calls for a consideration of both human and non-human living organisms. In particular, non-humans are considered to have interests beyond their use to humans.
- In contrast, anthropocentric ethics considers environmental externalities and resource degradation from the perspective of individuals – present and in the future - and the community.
- Clearly, different ethical concepts and propositions could lead to different normative (that is, ought to) theories about sustainable development. In logic, there is no solution to this. In practice, it would appear that New Zealand legislation, while focussing on the well being of individuals also considers the needs of ecosystems and other non-human organisms. Although both ethical positions recognise ecological limits tensions arise over the extent and degree of tradeoffs considered acceptable.

- Systems view: resources are defined in terms of what individuals find useful (provide utility) and are considered as a system of interdependent relationships. Viewed in this way, the joint products (e.g. urban land development and sediment) associated with the use of a particular resource (land) are linked in a systematic way.
- What is considered a resource will change with time.
- Analysis of the sustainable resource use is usefully grounded in considerations of the patterns of relationships supporting the living system. For example, an analysis of the sustainable fisheries harvest would adopt a systems view of the biophysical relationships that comprise the fishery.
- The systems view better enables integration of resource management policies across components of the environment.

- Living systems: Living systems are considered wider and more encompassing than ecosystems and are used to provide a focus for analysing sustainable use.
- A dynamic balance is seen to exist between the living system as a whole and its constituent parts. Different scales of analysis will highlight different aspects of sustainable use. For example, choosing a water catchment as the unit of analysis as opposed to permanent streams.
- Uncertainty arises from incomplete knowledge and the inherent stochastic nature of natural systems. Setting aside the costs and benefits of additional information, the pursuit of scientific certainty is not feasible. The approach to managing living systems can alter the distribution of risk across the community.
- A living systems approach to sustainability aims to allow living systems to continue to sustain themselves broadly in their current pattern or form. Although the report is careful to distinguish sustainability from preservation the relative "constraints" implied by the two approaches are not clearly defined. Much hinges on the term "broadly" – given natural stochasticity in the environment one possible interpretation would have preservation coinciding with sustainability.
- Sustainability means interacting with other living systems in a way that enables those systems to continue functioning without loss of resilience. The so-called living system approach is seen to require integrated management.

- Social choice: social institutions (e.g. rights, regulations, rules, law, educational instruments) provide a basis for human interactions within living systems:
- Social institutions are objects of collective decision-making. Viewed this way, living systems are not seen as having rights independent of people. The view is anthropocentric. Extending the notion into a “rights/duties” framework enables policy to encompass considerations of future generations who obviously are not able to enter the policy debate.

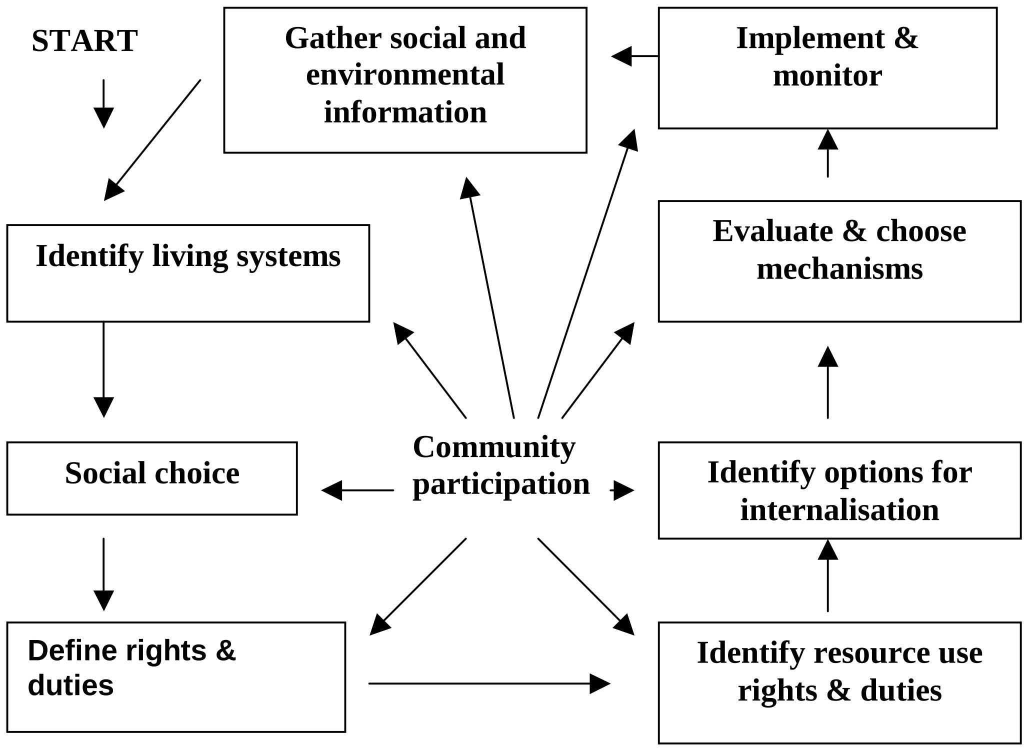

Figure 9: Living systems approach (Ministry for the Environment, 1995)

- Dimensions of a living system approach
- Resource use considered within a systems context.
- Allow living systems to maintain their integrity.
- Link rights and duties with respect to living systems.
- Data collection and monitoring
- Adaptive management
- Consider human behaviour within context of a living system.
- Community choice

- Internalisation: in economics internalisation means including the cost (for example) of an externality within the decision making calculus of the firm. Economic instruments for achieving internalisation are considered later in the report.

- Summary: The framework developed by the Ministry for the Environment shifts the emphasis away from a resource-based to a living system approach. From this point of view, social choice is seen to be primarily constrained by the needs of the system. Given the level of uncertainty that exists about living systems, the framework implies a cautious approach to environmental management.

4.6 Conclusions

The above frameworks illustrate both diversity and the emphasis placed on different aspects of sustainable development. If adopted, principles supported by the Natural Step Framework would have a significant impact on the utilisation of stock resources and their use in the economy. Similar constraints would come into effect if some of the recommendations of the New Zealand Ecological Society were adopted. Frameworks offered by two Ministries include the features of natural capital and emphasise the role of government in sustainable development. This emphasis on public policy is reinforced in the OECD framework. The OECD framework offers considerable detail on the techniques that can be used to guide collective decision-making – such as total economic value – and the policy instruments that are available to achieve sustainable development outcomes.

Returning to the perspective of ecological economics, Lawn (2001) suggests that sustainable development is an ethical guiding principle and not a futuristic state. Thus:

- It is not possible to design an optimal set of instruments to achieve sustainable development.
- The sustainable development concept must incorporate “decision making” rules to guide appropriate action.

Clearly, it is not possible to design an optimal set of instruments if the end-state cannot be specified. This view leaves the policy analyst with an indeterminate model to work with.

The blueprint for sustainable decision-making offered by Toman (1998) is aimed at promoting sustainable development:

- Prior assessment of what criteria and evaluation tools should apply to the issue.
- Assessment of physical impacts across time and space.
- Assessment of economic benefits and costs.
- Identification of whether and how social values and norms may be affected.
- Engagement in public discourse about the consequences of different actions.
- Pluralistic decision-making.
- Using the results of the decision process to incorporate new information.

The guidelines offered by Toman require transparency in the setting of goals, measurement where possible, analysis of alternatives, pluralism and monitoring of progress towards sustainable development.

5 Framework Integration

This report started with some of the definitions used to describe sustainable development, followed by a discussion of key elements and an overview of a number of sustainable development frameworks. This section attempts to synthesise the elements of sustainable development with the view to developing a framework for integrating economic advice on environmental issues.

5.1 Positive and normative aspects of sustainable development

The literature on sustainable development uses a range of analytical concepts. Some concepts are well supported (e.g. materials balance) by science; others (e.g. elasticity of substitution) are based on propositions that can, in principle, be subjected to empirical investigation. An over-riding concern for equity, amongst others things, introduces a normative dimension into the framework. Figure 10 relates the empirical (or positive) aspects of sustainable development with the normative.

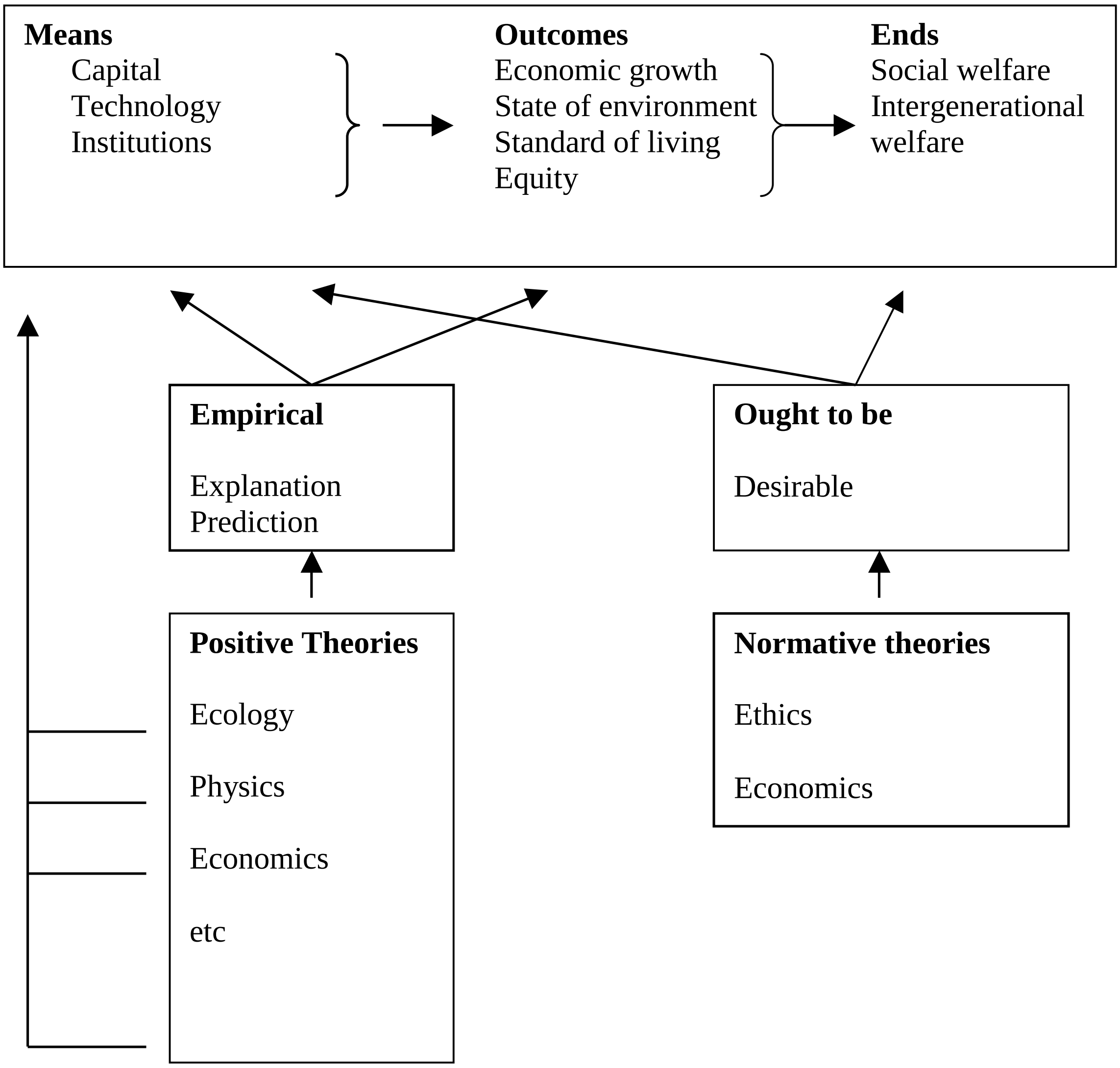

Figure 10: Relationship between positive and normative theories of nature and society

Figure 10 can assist advisers to government to categorise the parts of a sustainable development framework that are positive and those that are normative. For example, if the framework advocates economic efficiency then we know that applied economic analysis – say, for example, cost-benefit analysis – combines empirical estimates of the costs and benefits of sustainable development strategies within a utilitarian framework.

5.2 Towards a framework of sustainable development

The key to sustainable development is choosing robust policies whenever we can. Figure 11 shows an essential linkage between "problem identification", relevant concepts, and the sustainable development framework. The mapping process takes elements described in section 3 and combines them in a particular way to address "the problem".

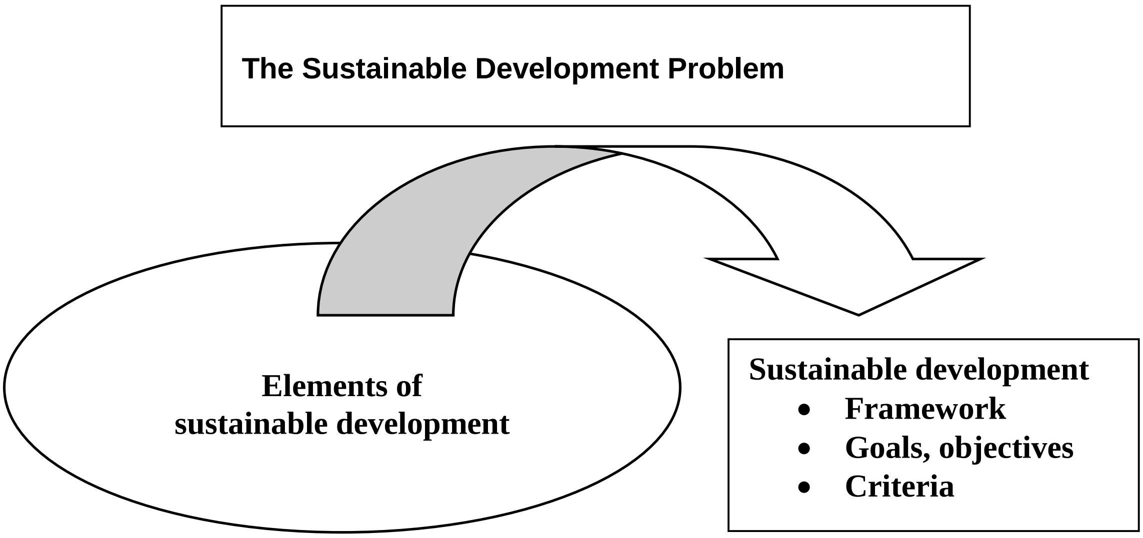

Figure 11: Mapping process

Two initial steps must be taken at the early stages of developing an integrated framework:

- What is the problem? A clear understanding of the problem is essential. Each policy initiative will have its own peculiar dimensions. A policy regarding the marine environment will have dimensions that differ from CO_2 emissions policy. There is no "model" in the literature that has universal applicability.

- Integrate the elements into a specific framework for analysis: Although there is a good range of analytical tools available, it behoves the policy analyst to build a framework that captures the essence of the problem. Although this is an art, transparency and rigour are essential when mapping the elements into a framework for application.

    - Transparency is important because of the range of possible beliefs that can be incorporated into a framework. Those subscribing to the notion of strict sustainability will not admit to the possibility of substituting manufactured and natural capital. Those subscribing to an ecocentric view of the world will not adopt the total economic valuation framework. It is not possible to resolve these differences. But it is possible to present a framework that makes the various views of sustainability transparent. Transparency will also help to focus debate and assist with tracing out the implications of adopting one framework relative to another.
    - Rigour is essential because loose reasoning is easily translated into practical policy that incurs significant opportunity costs to both the economy and environment. For example, if intergenerational equity is an issue, then rigorous

measures of equity should be developed and analysed within the context of policy. The expected outcomes should then be set alongside the alternatives, so that the implications for the environment and economy are transparent.

- Time is an essential element to include in the analytical framework. It is essential that we understand, at least in a qualitative sense, the expected temporal response of ecosystems, individuals, groups, and communities to the instruments of sustainable development policy.

Table 2 lists the concepts of sustainable development identified in Section 2 and describes the elements discussed in Section 3. The objectives are not meant to convey a notion that we can, or should attempt to, achieve a high degree of numerical accuracy. In some instances – such as regional rules for setting minimum river flows – it might be possible to estimate net present value (comprehensively defined) with reasonable accuracy. In other cases – such as a national energy conservation strategy – the framework will provide, at best, a general guide to policy formation, supported, if at all possible with empirical data on investment, market structure, externalities, conservation and energy efficiency.

Table 2: Sustainable development, from concepts to criteria

<table>
<tr><th>Concepts</th><th>Elements</th><th>Sustainable development goals, objectives</th></tr>
<tr><td>Scale/space</td><td>Global, national, regional</td><td rowspan="9">(1) Single objective
e.g. maximise NPV

(2) Constrained single objective
e.g. maximise NPV s.t. strong sustainability

(3) Multiple objective
e.g. efficiency-environment

(4) Multicriteria analysis</td></tr>
<tr><td>Linkages</td><td>Ecological, organisational, policy, cross-cutting issues</td></tr>
<tr><td>Capital</td><td>Manufactured, natural, human, and social</td></tr>
<tr><td>Value</td><td>Use values, non-use values, ecological measures</td></tr>
<tr><td>Institutions</td><td>Property rights, duties, governance</td></tr>
<tr><td>Participation</td><td>Stakeholder consultation, democratic process</td></tr>
<tr><td>Equity</td><td>Intragenerational, intergenerational</td></tr>
<tr><td>Knowledge</td><td>Risk, uncertainty, technology</td></tr>
<tr><td>Time</td><td>Horizon, discounting</td></tr>
</table>

Given the policy focus of sustainable development the framework must be linked to existing institutional foundations of our society in order for practical reforms to be identified and analysed. This report has not emphasised the significance of institutions vis-à-vis sustainable development policy.

Objectives are specific statements of what policies and programmes are meant to accomplish and since they are expressed in terms of direct outputs of policy operation, they should be quantitatively stated. Failure to quantitatively state specific objectives dilutes the prospect for rigorous analysis *ex ante* and limits the scope for policy appraisal *ex post*.

- Dealing with single objectives is the most straightforward. Analysis based on maximising net present value includes a number of elements – discounting, utilitarian foundations, total economic valuation – that could be disputed by ecological economists that subscribe to different value systems.
- Optimising an economic objective subject to constraints provides a framework for incorporating biophysical constraints. The impact of constraining the objective function, such as maintaining natural capital, can be described and, in principle, quantified.
- A framework adopting multiple objectives escapes the discipline of commensurability and may offer opportunities for making competing objectives more explicit.

Complementarities and differences would become apparent. However, in general it is not possible to simultaneously optimise multiple objectives. Figure 12 illustrates a maximisation problem with two objectives - for example, water quality (θ_1) and net present value (θ_2) - defined over a decision variable x. Trade-offs between θ_1 and θ_2 occur with values of x within the range x*, both objectives can't be simultaneously maximised. A trade-off surface using θ_1 and θ_2 may be sufficient for advising decision-makers.

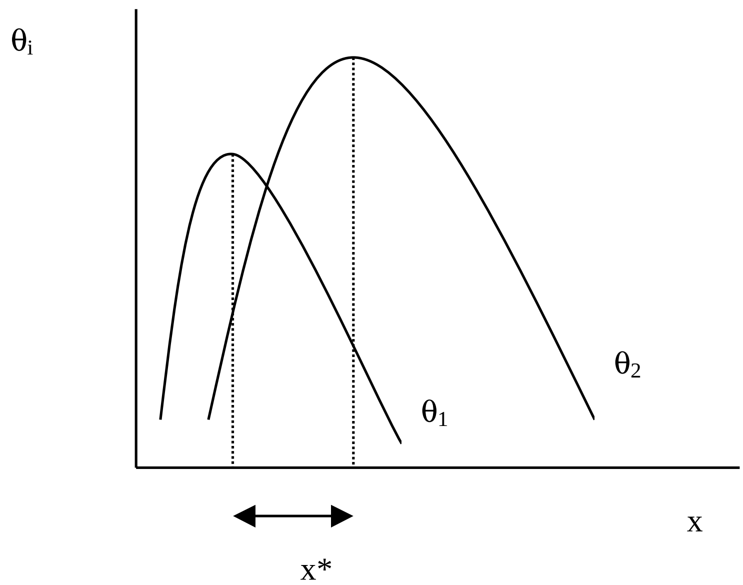

Figure 12: Decision making with multiple objectives

- Going beyond the trade-off surface and selecting an optimum requires a set of preferences – analogous to a welfare function. Preferences used in multi-criteria analysis could be gauged as part of the public consultation process. Alternatively, the opinion of experts and/or elected representatives could be used to select the preferred action.

Monitoring the outcomes of policy is an essential ingredient of sustainable development.

We now illustrate how an integrated framework can be formed from the elements of sustainable development and applied to three case studies.

5.3 Case studies

The integrated framework is applied to the following three case studies. The aim of each case study is to see whether the integrated framework can address policy from the view of point of sustainable development. No attempt is made to evaluate policy. Each case study is based on a limited number of publicly available reports. Furthermore, policy formation has probably advanced beyond that reported below.

5.3.1 *Future Management of Aquaculture*

Aquaculture is the propagation and husbandry of aquatic plants and animals to supplement natural supply. Aquaculture can occur in natural waters and in artificial impoundments. The main aquaculture industry in New Zealand is the farming of filter feeders in natural waters below high tide mark. The aquaculture industry contributes around $200 million to the national economy. Recent growth, and expectations for future growth, has led to strong demand for water space.

The Ministry of Fisheries' discussion document *Aquaculture* (August 2000) claims that aquaculture could make a greater contribution to the economy, if the existing legislative framework was updated. The purpose of *Aquaculture* is to provide stakeholders with an opportunity to comment on proposals aimed at improving the management of aquaculture. A sector growth model shows "sustainable development" as a function of time. Legislative reform is shown to be a key factor in shifting the "sustainable development" onto a higher trajectory. The model is highly stylised and indicates the pivotal role of legislation rather than providing a formal model of sustainable development.

Difficulties with current legislation include:

- uncertainty around existing aquaculture harvesting rights
- overlapping responsibility for managing environmental effects
- poor integration with the management of wild fisheries, and
- outdated management of land-based aquaculture.

While the existing management framework addresses environmental effects, it does not deal with the question of

> "… how to allocate coastal space in a way that enables the greatest value to be obtained over time." (p. 6)

<u>Proposal</u>

The challenge presented in *Aquaculture* is to:

> "… enable the greatest benefit to be obtained from the use of coastal space, without undermining the rights of existing fishers or allowing undue adverse impacts on the aquatic environment." (p.4)

Aquaculture describes four legislative proposals without describing the property rights associated with each alternative. It is noted that the Crown has specific, and unresolved, obligations to Maori *viz.* customary fishing rights, customary title to the foreshore and seabed. Thus other than acknowledging the need to uphold the Crown's relationship with Maori, the legal aspects of the proposals are set-aside for the purposes of this report. The proposals are summarised below.

1. Single form of aquaculture harvesting right
    a. Consolidate current and future harvest rights into an aqua-permit under Fisheries Act 1996. Rights to occupy space require regional council resource consent.
    b. Automatic right provided under the Fisheries Act 1996, resource consent required for occupation.

2. Responsibility to manage the effects of aquaculture on aquatic fauna, habitat and sustainability of fisheries vested in a single agency.
    a. Regional councils continue to manage all effects except those in aquatic fauna and habitat, Ministry of Fisheries manages the effects on aquatic fauna and habitat, or
    b. Regional councils assume management of all effects under the RMA.

3. Develop mechanisms to improve the planning process and encourage area-use trade agreements between new marine farms, fishers and other stakeholders
    a. Separate but concurrent RMA and Fisheries Act application processes, or
    b. Single hearing under RMA.

4. Streamline the management of land-based aquaculture. Harvest right considered under the Fisheries Act; RMA consent required for environmental effects.

Applying the integrated framework
The proposals outlined in *Aquaculture* are illustrated in Figure 12. Sustainable development is facilitated by a proposal to change the legislation (shown as Δ legislation) associated with aquaculture including the management of the ambient environment within which productive activity occurs.

Aquaculture is a discussion document that fits in well with frameworks that emphasise the importance of identifying community values and encouraging community participation. An integrated framework of sustainable development raises the following points for more detailed analysis.

- Capital: By definition, aquaculture augments the productivity of the natural environment, thus the stock of natural capital and manufactured capital is enhanced in the first instance. The quality of legislation (which is not defined in detail) should lead to an increase in social capital and the demands placed on science, technology and management should enhance human capital stocks. Whether the augmentation of natural capital can be sustained over time will depend *inter alia* on the dynamics of aquaculture within its marine (and terrestrial) ecosystem. For example, intensive aquaculture could have an adverse impact on proximate marine ecosystems. The net effect could be that the stock of natural capital declines at some point in the future. There is no discussion of this possibility.

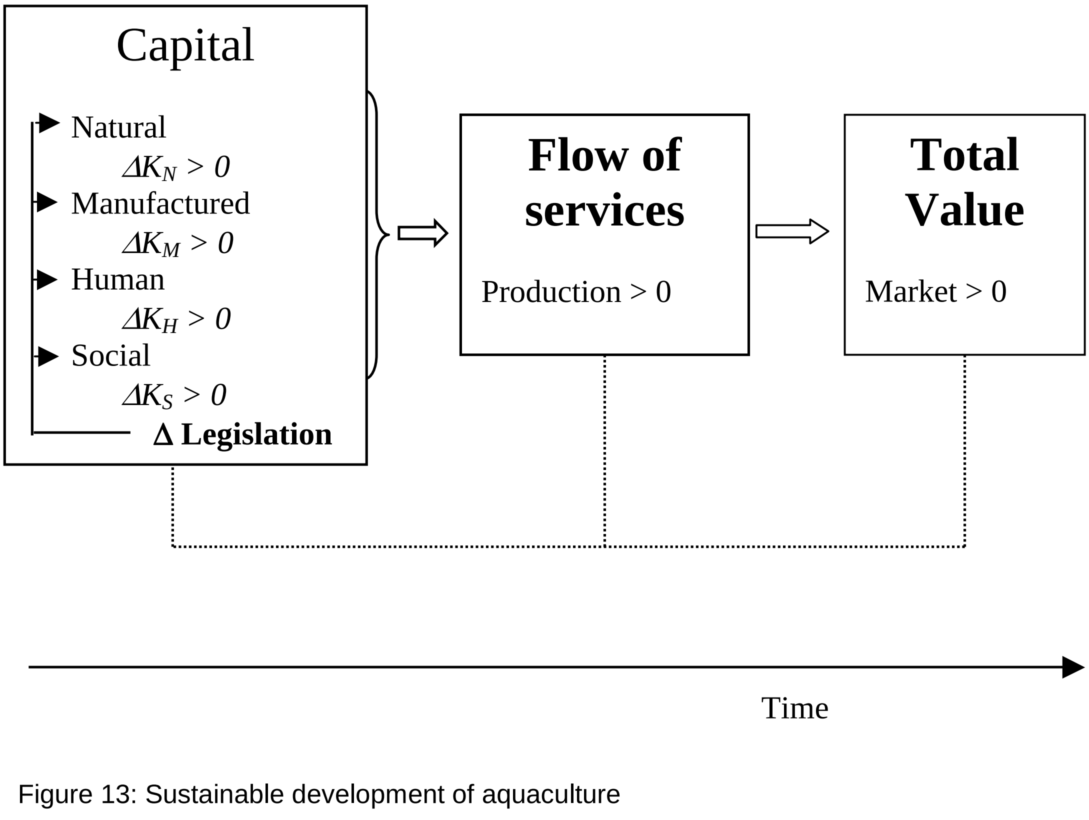

Figure 13: Sustainable development of aquaculture

- Flow of services: The productivity of services from the marine (and land based) environments will be enhanced and the flow of market valued services increased. Without site-specific research, it is not possible to conclude that the total economic value associated with the aquatic and terrestrial environment will increase. The result will depend on the legislation and mechanisms used to manage adverse effects. Thus Figure 13 shows a loop back to “Capital”.

- Value: *Aquaculture* does not address the issue of the marine environment's total economic value. Values not measured in the market – for example, loss of access, aesthetics, external impacts on marine ecosystems - should be considered alongside the value of increased production.

- Risk: The risks of adverse impacts on the marine environment would have to be addressed *ex ante*. The distribution of risk – both contemporaneously and intertemporaly – will depend on the reformed structure of property rights.

- Equity: There will be equity issues (both intergenerational and intragenerational) to address with aquaculture development.

- *Ex ante* indicators of sustainable development:

    - Without the benefit of detailed analysis, aquaculture (within limits) should satisfy the principle of weak sustainability by increasing GDP without reducing the stock of natural capital.
    - Aquaculture has the potential to lead to sustained increases in GDP per capita.
    - Aquaculture offers an opportunity for sustained economic growth to occur in low income, high unemployment areas.
    - It is not possible to draw general conclusions with respect to intergenerational equity.

Conclusions

Aquaculture is clearly targeted at involving stakeholders and the general community in the process of policy reform. Analysing the discussion paper from the point of view of sustainable development raises the issues and questions listed above. Presumably, these issues will be addressed within the reform process outlined by the Ministry of Fisheries.

5.3.2 *Energy Efficiency and Conservation Strategy*

Concern has been expressed that New Zealand is falling behind other OECD countries in terms of energy efficiency and renewable energy policy, and the implementation of new technology (Parliamentary Commissioner for the Environment, 2000). Energy use is seen to play a key role in progress towards a more ecologically sustainable society. Concern about energy use also spills over into New Zealand's responsibilities in greenhouse gas emissions.

The Parliamentary Commissioner's report identifies five challenges facing New Zealand:

- Depletion of Maui gas and development of new fields
- Limited access to traditional renewable sources
- Commitment to reduction of CO_2 emissions
- Reduction in adverse environmental effects associated with transport
- Integration of renewable sources

Energy efficiency and renewable energy initiatives are viewed as a contribution to sustainable development as defined in *Our Common Future (WCED, 1987)* . The notion of a sustainable energy system is likened to a natural ecosystem in terms of its ability to deliver services within available resources. There are two limbs to energy efficiency:

- Achieve more efficient use of stock resources, such as oil and gas.
- Increase the use of energy derived from renewable sources, such as hydro.

The indicator of improved energy efficiency is defined as

$$\Delta energy\, efficiency = \Delta\left(\frac{net\, benefits}{unit\ of\ energy}\right) > 0$$

Net benefits appear in the numerator of the indicator and are taken to include both market and non-market valued benefits and costs. Inclusion of non-market benefits and costs is consistent with the valuation framework proposed in Section 3.

The energy supply chain provides structure for a more detailed assessment of energy efficiency:

- Extraction/construction – habitat, impact on taonga
- Generation/conversion/processing – gases, particulates
- Distribution/transmission – spills, aesthetics
- Use – gases, particulates

In 2000, the *Draft National Energy Efficiency and Conservation Strategy* was released (EECA and Ministry for the Environment, 2000). Two key policy directions are described:

- continuing to improve energy efficiency, and
- progressive transition to renewable sources of energy.

<u>Applying the Integrated Framework</u>

- <u>Scale</u>: The Draft Strategy is focused on the national economy and New Zealand's responsibilities to the Kyoto Protocol. The ecological-economic *genre* of sustainable development models (e.g. Hannon (2001), Patterson (1998)), described in Section 3, could be applied to characterise the structure and efficiency of New Zealand's energy system and to analyse its evolution over time. These models should be capable of capturing many of the above concerns, with the exception of cultural values and possibly the adverse impacts on aesthetics. At the project level – say development of a new oil field, construction of a dam – the cost-benefit framework could provide useful information to decision makers.

- <u>Targets and goals</u>: two targets and seven goals are identified in the *Draft Strategy*. Both targets are set for 2012 and the energy efficiency target (a 20% improvement economy-wide) is measurable.

- <u>Linkages</u>: The *Draft* links policy with sectors of the economy and other aspects of policy that are related to achieving the goals. For example, administration of the Resource Management Act is seen as a key determinant of how effectively externalities are managed.

- <u>Time</u>: The implications of continuing on the existing path are outlined in terms of energy use.

- <u>Capital</u>: The underlying approach is consistent with maintaining natural capital and substituting renewable sources of energy for stock-based sources. Substitution is expected to impose short-term costs on the economy. Cost-benefit analysis appears to have informed policy formulation.

- <u>Value:</u> Although not explicit, the *Draft* appears to endorse the principle of total economic value. This is evident in Government policy that prices should reflect the full costs of supply, including environmental costs (p.33).

- Risk: While the world is not running out of oil, the *Draft* notes the risks that attach to price instability in the near future. Risks within New Zealand's energy supply chain are also outlined.

- Institutions: The *Draft* recognises the significance of institutional development in achieving the targets. Strategy programmes (means) are distributed across sectors and linked in with objectives.

- Indicators of sustainable development:

  - Multiple (seven) goals have been suggested. Monitoring over time should provide qualitative indications of whether or not the goals are being attained. Improvements in energy efficiency can be quantified and benchmarked. The target set for renewables is not as well defined.
  - Cost-benefit analysis is seen as a useful tool for analysing industry and project level policy initiatives.

Conclusions

The report of the Parliamentary Commissioner for the Environment provides useful background to the *Draft Strategy*. As a word of caution, the Commissioner's report attaches three different qualifiers (resource, energy and economic) to the main noun efficiency. Economic and energy efficiency are defined, resource efficiency is not.

The *Draft Strategy* provides a comprehensive framework for developing energy policy. The framework is consistent with the integrated framework for sustainable development. Proposals within the *Draft Strategy* – such as energy efficiency targets, development of renewable sources of energy, and regulations - should be rigorously analysed using the integrated framework. Particular attention should be paid to the costs and benefits – broadly defined – of alternative policy actions.

5.3.3 *Conservation on private land*

The New Zealand Biodiversity Strategy (2000) notes that New Zealand has one of the worst records of indigenous biodiversity loss (p. 4). Historically we have focused on protecting alpine areas and native forests, leaving many other distinctive natural habitats vulnerable to change. The most threatened natural ecosystems are in lowland areas. New Zealand has an international responsibility under the Convention on Biological Diversity, ratified in 1993. The Convention's objectives are:

- The conservation of biological diversity.
- The sustainable use of its components.
- The fair and equitable sharing of the benefits arising out of the utilisation of genetic resources.

These objectives fit within the notion of sustainable development.

Applying the Integrated framework

- Scale: The *Strategy* shows that the policy context spans international obligations and the need for a national strategy through local management organisations.

- Targets and goals: Four goals are outlined in the *Strategy*. An index of biological diversity shows a declining trend in biological diversity and shows the strategy reducing the rate of decline. The index is not mathematically defined. Each theme links the desired outcome to the current state. A plan of action is linked with goals and desired outcomes.

- Natural capital: Conserving biodiversity does not preclude use, provided that the use is ecologically sustainable and does not result in a decrease in the long-term sustainability of biodiversity. This definition closely resembles the definition of strong sustainability. If the above goals are achieved then the value of natural capital will be enhanced over time.

- Total economic value: The concept of total economic value is used in the *Strategy* to highlight the economic significance of biodiversity.

- Institutions: Respect for property rights – as they relate to landowners, users and public agencies - is essential to achieving the desired outcomes. Seventy percent of land is in private ownership. Most of the remnant natural areas on private land are there by choice of landowners. Instruments for protecting habitats on private land include covenants and resource consent provisions. The action plan linked to conservation on private land calls for:

    - A national policy statement to guide local authorities on implementing provisions of the Resource Management Act.
    - An expansion of existing funding mechanisms to meet current demand by landowners and communities.
    - Greater use of economic incentives.

- Risk: The strategy distributes risk in favour of conservation and sustainable use. In particular the "precautionary principle" is applied when there is a lack of knowledge about the outcomes, especially when there is a risk of irreversibility.

- Participation: The *Strategy* incorporated input from over 7800 submissions.

- Equity: Intergenerational equity is clearly identified as a key issue.

Conclusions

The *Biodiversity Strategy* is targeted at a range of complex issues, conservation of private land being only one aspect. The *Strategy* does not use well-defined objectives. Although the concept of total economic value is used to highlight the economic value of biodiversity, tradeoffs and opportunity costs are not described.

Achieving conservation goals on private land will put community values up against the values of individual landowners. Private property rights and the quality of social capital must be a critical interface in achieving the desired outcomes.

Finally, a word of caution. The precautionary principle should not become a *de facto* rule for *ad hoc* interventions. It might be that precaution is warranted, but the decision should be supported by a rigorous analysis of the values and risks associated with policy.

5.4 Conclusions

This section did not set out to criticise the content of the various strategies. The intention was to illustrate the utility of applying an integrated framework. The aim was to develop a general framework for integrating economic advice on environmental issues. The approach emphasised five steps:

- Problem identification.
- Transparent application of concepts.
- Rigorous analysis.
- Policy focus that linked objectives with institutions.

- Specific statements of objectives and constraints.

The specific framework to emerge from this process is conditional on "the problem" and the result of careful synthesis. No mechanistic rule was proposed.

The general framework was applied to three contemporary issues. This illustrated application of the concepts and how they might be synthesised into a coherent framework. Section 3 provides detail for more in-depth analysis.

6 Conclusions and Recommendations

So what is sustainable development?

Sustainable development is a multifaceted concept that has drawn on a number of disciplines including economics, ecology, ethics, sociology and political science. Sustainable development links the welfare of generations with the capacity of the biosphere to sustain life and has a policy focus because it is about the "design" of policy that ensures delivery of a set of quantitative and qualitative outcomes.

Sustainable development is not a fixed state but rather a process of change in which exploitation of resources, the direction of investments, the orientation of technological development and institutional change are made consistent with the future as well as present needs.

What key insights do we get from economics and ecology?

- Dynamic economics highlights the significance of technological progress *vis-à-vis* natural resource supply and illustrates the implications of different ethical positions for growth. Theory suggests that growth will slow down if the rate of technological change does not compensate for increasing resource scarcity.
- Intergenerational welfare occupies a pivotal position in contemporary models of intertemporal choice. Strict adherence to some ethical beliefs – for example, the Rawlsian criterion – can severely restrict economic growth.
- Time is an important dimension in sustainable development. The practice of discounting is controversial. Some advocate the application of fixed discount rates across all projects and policies. Others advocate a discount rate that decays with time.
- Ecological and physical laws remind us that the ability to adjust natural capital over time may be constrained by ecosystem capacity. Some ecologists consider random shocks produce healthy ecosystems.
- The traditional economic notion of capital (manufactured) is greatly expanded to include natural, human and social capital. These concepts provide an important building block for sustainable development criteria.
- There are two competing criteria for sustainable development - weak sustainability and strong sustainability. Each relies on assumptions regarding the ability to substitute different forms of capital.
- The concept of total economic value occupies a central position in sustainable development policy. It is in common use by both economists and ecological economists.
- As noted earlier healthy ecosystems are seen to rely on uncertain and often huge shocks. Our ability to model natural stochasticity is particularly limited at the extreme tails of the distribution. At least two alternative frameworks are available. Multi-attribute theory provides scope for quantifying the robustness of policy alternatives to uncertainty. Stated preference models (e.g. contingent valuation) can be used to estimate willingness-to-pay for different probabilistic states of the environment.

- A number of macro-level indicators of sustainable development have been developed. Only recently has attention been given to micro-level measures of sustainable development.

Is an integrating framework feasible?

In short yes, provided we do not focus on trying to discover an optimal policy. Given the plurality of views the prospect of a unifying theory is bleak. However, we should remember that sustainable development is not a fixed state but rather a process of change in which exploitation of resources, the direction of investments, the orientation of technological development and institutional change are made consistent with the future as well as present needs.

The integrated framework must incorporate policy instruments that are designed to promote sustainable development. Assessment of policy instruments is not discussed in this report. Clearly, it is not possible to design an optimal set of instruments if the end-state cannot be specified. This open-ended view should be closed so that the policy analyst can work with a determinate framework. The rigorous policy analysis necessary for promoting sustainable development cannot proceed without a coherent framework with sound theoretical underpinnings. In the absence of such a framework, public policy, as it relates to sustainable development, runs the risk of stifling economic growth and compromising environmental quality.

The aim was to develop a general framework for integrating economic advice on environmental issues. The approach emphasised five steps:

- Policy focus that linked objectives with institutions.
- Specific statements of objectives and constraints.
- Problem identification.
- Transparent application of concepts.
- Rigorous analysis.

The specific framework to emerge from this process is conditional on “the problem” and the result of careful synthesis. No mechanistic rule was proposed.

The general framework was applied to three contemporary issues. This illustrated application of sustainable development concepts and how they might be synthesised into a coherent framework. Although the approach differed in each case study a number of high-level themes are evident. First, each case study illustrated how environmental issues can be explicitly incorporated into a policy framework. Second, each case study underscored the significance of identifying an objective that either incorporates economic and environmental values or uses environmental considerations to constrain the economic objective. In each case the cost-benefit framework could be used as a basis for further detailed analysis. Third, the quality of public policy instruments – pricing, regulation, and property rights – are pivotal in achieving sustainable development outcomes. The documents reviewed were strategic in nature and a great deal of policy analysis is warranted before decisions are made. The integrated framework provides a basis for this analysis to proceed.

Recommendations for future work

This report has not considered the range of policy instruments that could be used in achieving sustainable development outcomes. The set of instruments is largely known but we have limited knowledge of their application and performance in practice. This important topic can be addressed in two ways:

a Survey the existing mechanisms and processes, across government departments, to see how they are being applied in practice and to what benefit.

b Analyse the quality of institutional arrangements using the theory and frameworks provided by the institutional economics and property rights literature. In some cases it might be possible to assess the quality of operational institutional arrangements. For example, the work of Oliver Williamson (1985) provides a basis for the analysis of the institutional underpinnings of sustainable development. Ragnor Arnason (2000) provides a specific example of how to analyse property rights in the context of fisheries management.

Sustainable development is critical to the welfare of New Zealand's population. The economy is relatively open and depends to a large degree – *viz.* the primary industries - on the functioning and integrity of its unique ecosystems. Global economic activity is dynamic and increasingly interdependent. International influences on sustainable development – especially from a small country perspective - are not well canvassed in the literature. For example, the dairy industry is a major exporter and makes a significant contribution to the New Zealand economy. The expansion of dairy farming is becoming increasingly dependent on access to water resources. It is perhaps appropriate that the sustainability of this expansion and, especially, the institutions that govern water allocation should be analysed. The integrated framework provides a basis for future research.

There are few, if any, sustainable development indicators in use. If we are serious about achieving sustainable outcomes then indicators are needed to inform policy makers. Future work could be directed at developing a range of indicators, for use at the macro and micro levels, and for *ex ante* policy analysis.

References

Arnason, R. 2000. Property Rights as a Means of Economic Organization, in *Use of Property Rights in Fisheries Management*, (ed.) R. Shotton, FAO Fisheries Technical Paper 404/1, Rome, p.15-25.

Arrow, K. J. and L. Hurwicz. 1972. An Optimality Criterion for Decision-making Under Ignorance, in C.F. Carter and J.L. Ford (eds.) *Uncertainty and Expectations in Economics*, Basil Blackwell, Oxford.

Asheim, G. 1986. Hartwick's Rule in Open Economies, *Canadian Journal of Economics*, 19(3):395-402.

Ayres, R.U. and A.V. Kneese. 1969. Production, Consumption and Externalities, *American Economic Review*, 59: 282-97.

Van den Bergh J.C.J.M. and H. Verbrugen. 1999. Spatial Sustainability, Trade and Indicators: an Evaluation of the Ecological Footprint, *Ecological Economics*, 29(1): 61-72.

Berlinski, D. 1976. *On Systems Analysis: An Essay Concerning the Limitations of Some Mathematical Methods in the Social, Political, and Biological Sciences*, The MIT Press, Cambridge, Massachusetts.

Bicknell, K.B. *et al*. 1997. New Methodology for the Ecological Footprint with an Application to the New Zealand Economy, *Ecological Economics*, 27(2):149-160.

Bockstael, N.E. *et al.* 2000. On Measuring Economic Values for Nature, *Environmental Science and Technology*, 34: 1384-1389.

Chapman, R. and P. Howden-Chapman. 1997. Risk and Uncertainty in Environmental and Environmental Health Policy, paper presented at the Third Interdisciplinary Conference on the Environment, Cambridge, Massachusetts, June 25-28, 1997.

Colby, M. 1991. Evolution of Environment-Development Paradigm, *Ecological Economics*, 4:193-213.

Colombo, U. 2001. The Club of Rome and Sustainable Development, *Futures*, 33(1): 7-11.

Costanza, R. 1989. What is Ecological Economics? *Ecological Economics*, 1: 1-7.

Costanza, R. (ed.) 1991. *Ecological Economics: the Science and Management of Sustainability*, New York, Columbia University Press.

Costanza, R. and H.E. Daly. 1992. Natural Capital and Sustainable Development, *Ecological Economics*, 6(1): 37-74.

Costanza, R. 1997. *Frontiers in Ecological Economics*, Edward Elgar Publishers Limited, Cheltenham.

Costanza, R. *et al.* 1997. The Value of the World's Ecosystem Services and Natural Capital, *Nature,* 387(May): 253-60.

Daly, H.E. 1991. *Sustainable Development: From Concept and Theory Towards Operational Principles, Steady State Economics,* (2nd edition) Island Press, Washington D.C..

Daly, H.E. and J.B. Cobb. 1994. *For the Common Good: Redirecting the Economy Towards Community, the Environment, and a Sustainable Future*, (2nd Edition) Beacon Press, Boston.
Dasgupta, P. 1974. On Some Problems Arising From Professor Rawls' Conception of Distributive Justice, *Theory and Decision*, 4(3-4) 325-344.

Dasgupta, P. 2000. Discounting: Why and How? Plenary Lecture, Tenth Annual Conference of the European Association of Environmental and Resource Economists, Crete, June 30 – July 3, 2000.

Dasgupta, P.S. and G. Heal. 1979. *Economic Theory and Exhaustible Resources*, Cambridge: Cambridge University Press.

Department of Conservation and the Ministry for the Environment. 2000. The New Zealand Biodiversity Strategy, Our Chance to Turn the Tide, Wellington.

Energy Efficiency and Conservation Agency (EECA) and the Ministry for the Environment. 2000, Draft National Energy Efficiency and Conservation Strategy, http://www.eeca.govt.nz/strategy.html.

Forrester, J.W. 1971. *World Dynamics*, Wright-Allen Press, Cambridge.

Freudenburg, W.R. 1988. Perceived Risk, Real Risk: Social Science and the Art of Probabilistic Risk Assessment, *Science*, 242 (4875): 44-49.

Gehrke, T. 2000. Towards the Implementation of Sustainable Business Practices in New Zealand Organisations – A Review of Current Activities and New Trends Such as The Natural Step Framework, Open Polytechnic of New Zealand, Working Papers Series (1-00) pp.28.

Georgescu-Roegen, N. 1971. *The Entropy Law and the Economic Process*, Harvard University Press, Massachusetts.

Gutes, M.C. 1996. The Concept of Weak Sustainability, *Ecological Economics*, 17: 147-56.

Hanley, N., I. Moffat, R. Faichney and M. Wilson. 1999. Measuring Sustainability: A Time Series of Alternative Indicators for Scotland, *Ecological Economics*, 28: 55-73.

Hannon, B. 2001. Ecological Pricing and Economic Efficiency, *Ecological Economics,* 36, 19-30.

Hartwick, J.M. 1977. Intergenerational Equity and the Investing of Rents from Exhaustible Resources, *American Economic Review*, 67(5): 972-974.

Hartwick, J.M. 1990. Natural Resources, National Accounting and Economic Depreciation, *Journal of Public Economics*, 43: 291-304

Howarth, R.B. 1995. Sustainability under Uncertainty: A Deontological Approach, *Land Economics*, 71(4): 417-27.

Hueting, R. and L. Reijnders. 1999. Uncertainty and Sustainability, *Ecological Economics*, 29(1): 9-11.

Humphreys, D. 2001. Sustainable Development: Can the Mining Industry Afford It? *Resources Policy*, 27: 1-7.

IUCN. 1980. *World Conservation Strategy*, International Union for the Conservation of Nature and Natural Resources, Glands, Switzerland.

Kemfert, C. and H. Welsh. 2000. Energy-Capital-Labor Substitution and the Economic Effects of CO_2 Abatement: Evidence for Germany, *Journal of Policy Modeling*, 22(6): 641-660.

Lawn, P.A. 2001. *Toward Sustainable Development: An Ecological Economics Approach*, Lewis Publishers, Washington D.C..

Levy, J.K., K.W. Hipel and D.M. Kilgour. 2000. Using Environmental Indicators to Quantify the Robustness of Policy Alternatives to Uncertainty, *Ecological Modelling*, 130(1-3): 79-86.

Meadows, D.H., D.L. Meadows, J. Randers and W.W. Behrens. 1972. *The Limits to Growth*, Earth Island Limited, London.

Ministry of Economic Development. 2001. Sustainable Development Framework, Ministry of Economic Development, Wellington.

Ministry of Fisheries. 2000. *Aquaculture, Join the Discussion*, Wellington.

Moran, D.1999. Benefit Transfer and Low Flow Alleviation: What Lessons for Environmental Valuation in the UK?, *Journal of Environmental Planning and Management*, 42(3):425-436.

Nattrass, B. and M. Altomare 1999. *The Natural Step for Business: Wealth, Ecology and the Evolutionary Corporation*, New Society Publishers, Gabriola Island BC.

New Zealand Ecological Society (undated). *Sustainability*, A Statement by The New Zealand Ecological Society, Christchurch.

Nordhaus, W.D. 1973. World Dynamics: Measurement Without Data, *Economic Journal,* 83(Dec):1156-1183.

Nordhaus, W.D. and Z. Yang. 1996. A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies, *American Economic Review*, 86(4): 741-65.

Norgaard, R.B. 1985. Environmental Economics: an Evolutionary Critique and a Plea for Pluralism, *Journal of Environmental Economics and Management*, 12(4): 382-394.

Northrop, F.S.C. 1947. *The Logic of the Sciences and the Humanities*, Reprinted 1959 by World Publishing Company, New York.

OECD. 1999. The Interim Report on the OECD Three-Year Project on Sustainable Development, OECD, Paris.

OECD. 2000. The OECD Initiative on Sustainable Development, Progress report to the 2000 Ministerial Council Meeting, OECD, Paris.

OECD. 2001. Sustainable Development, Final Version, 27 April 2001, OECD, Paris.

Ostrom, E. 1998. Social Capital: a Fad or Fundamental Concept? Center for the Study of Institutions, Population and Environmental Change, Indianna University, USA.

Page, T. 1977. *Conservation and Economic Efficiency*, The Johns Hopkins University Press, Washington D.C..

Parliamentary Commissioner for the Environment. 2000. *Getting More From Less*, Office of the Parliamentary Commissioner, Wellington.

Patterson, M. 1998. Commensuration and Theories of Value in Ecological Economics, *Ecological Economics*, 25: 105-125.

Pearce, D., A. Markandya, and E.B. Barbier. 1989. *Blueprint for a Green Economy*, Earthscan Publications Ltd., London.

Pearce, D.W. and G.D. Atkinson. 1993. Capital Theory and the Measurement of Sustainable Development: an Indicator of Weak Sustainability, *Ecological Economics*, 8, 103-108.

Pezzey, J. 1992. *Sustainable Development Concepts: An Economic Analysis*, The World Bank, Washington D.C.

Pezzey, J. 1997. Sustainability Constraints versus "Optimality" versus Intertemporal Concern, and Axioms versus Data, *Land Economics*, 73(4): 448-465.

Pezzoli, K. 1997. Sustainable Development: A Transdisciplinary Overview of the Literature, *Journal of Environmental Planning and Management*, 40(5): 549-574.

Productivity Commission. 1999. Implementation of Ecologically Sustainable Development by Commonwealth Departments and Agencies, Productivity Commission Inquiry Report, Report No. 5, May 1999.

Putman, R. 1995. Bowling Alone: America's Declining Social Capital, *Journal of Democracy* 6(1):65-78.

Ramsey, F.1928. A Mathematical Theory of Saving, *Economic Journal*, 38: 543-559.

Rawls, J. 1971. *A Theory of Justice*, Harvard University Press, Cambridge.

Reynolds, D.B. 1999. Entropy and Diminishing Elasticity of Substitution, *Resources Policy*, 25: 51-58.

Romer, D. 2001. *Advanced Macroeconomics* (2^{nd} Edition), New York, McGraw Hill.

Redclift, M. 1987. *Sustainable Development, Exploring the Contradictions*, London, Methuen and Co Ltd.

Scott, A.D. 1996. The ITQ as a Property Right, In Taking Ownership, in *Property Rights and Fishery Management on the Atlantic Coast*, (ed) B.L. Crowley, Atlantic Institute for Market Studies, Halifax, pp31-98.

Solow, R.M. 1956. A Contribution to the Theory of Economic Growth, *Quarterly Journal of Economics*, 70 (February) 65-94.

Solow, R.M. 1974. Intergenerational Equity and Exhaustible Resources, *The Review of Economic Studies*, Symposium on the Economics of Natural resources, 29-45.

The Economist, 1999. Deep Discount, 26 June,p.94.

Tisdell, C. 1994. Sustainability and Sustainable Development: Are These Concepts a Help or a Hindrance to Economics?, *Economic Analysis and Policy*, 24(2): 133-150.

Tolmasquim, M.T., et al., 2001. Environmental Valuation for Long-term Strategic Planning: the Case of the Brazilian Power Sector, *Ecological Economics*, 37(1): 39-51.

Toman, M.A. 1998 Sustainable Decisionmaking: The State of the Art from an Economics Perspective, Resources for the Future, Discussion Paper 98-39, June 1998, Washington D.C..

Toman, M.A., R. Lile and D. King. 1998. Assessing Sustainability: Some Conceptual and Empirical Challenges, Resources for the Future, Discussion Paper 98-42, July 1998, Washington D.C..

Victor, P.A. 1991. Indicators of Sustainable Development: Some Lessons from Capital Theory, *Ecological Economics*, 4: 191-213.

Vlachou, A., S. Vassos, and A. Andrikopolous. 1996. Energy and the Environment: Reducing CO_2 Emissions From the Electric Power Industry, *Journal of Policy Modeling*, 18(4): 343-376.

Wackernagel, M. and W. Rees 1996. Our Ecological Footprint: Reducing the Impact on Earth; The New Catalyst Bioregional Series, vol. 9, New Society Publishers, Gabriola Island, BC and Philadelphia, PA.

Wackernagel, M. *et al.* 1999. National Natural Capital Accounting with the Ecological Framework Concept, *Ecological Economics*, 29(3): 375-390.

Weitzman, M.L. 2001. Gamma Discounting, *American Economic Review*, 91(1): 260- 271.

White, P., B.M.H. Sharp and G.N. Kerr. 2001. Economic Valuation of the Waimea Plains Groundwater System, *Journal of Hydrology New Zealand*, 40(1): 59-76.

Williamson, O.E. 1985. *The Economic Institutions of Capitalism*, The Free Press, New York.

Willis, K.G. and J.T. Corkindale, 1995. *Environmental Valuation: New Perspectives*, CAB International, Wallingford.

Woodward, R.T. and R.C. Bishop. 1997. How to Decide When Experts Disagree: Uncertainty-Based Choice Rules in Environmental Policy, *Land Economics*, 73(4): 492-507.

World Commission on Environment and Development (WCED).1987. *Our Common Future*, Oxford University Press, Oxford.