MEC-10
Block-6

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Odisha State Open University
Sambalpur

MAEC
MASTER OF
ECONOMICS

ENVIRONMENTAL ECONOMICS

Theories of Optimal use of Resources and Environmental Sustainability

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Master of Arts
ECONOMICS (MAEC)

MAEC-10
ENVIRONMENTAL ECONOMICS

Block-6

THEORIES OF OPTIMAL USE OF RESOURCES AND ENVIRONMENTAL SUSTAINABILITY

UNIT-15 THEORIES OF OPTIMAL USE OF RENEWABLE RESOURCES

Structure

15.0 LEARNING OBJECTIVES

After completion of this unit, you shall be able to:

- Understand the concept of steady state harvests and the biological growth function of Renewable resources.
- Learn the process of arriving at bio-economic equilibrium outcome in an open access fishery and static private property fishery
- Undertake comparative static analysis for open access and private property models
- Analyze the role of property rights in optimal use of renewable resources

15.1 INTRODUCTION

Environmental resources are generally categorized into 2wide categories – renewable resources & exhaustible resources. The resources that have the capacity for reproduction and growth are usually known as renewable resources. This includes biological organisms such as fisheries and forests which have a natural capacity for growth, and water and atmospheric systems which are reproduced by physical or chemical processes. Solar, wind, wave and geothermal energy are also considered as renewable. Arable& grazing lands are also classified as renewable resources as their fertility levels can naturally regenerate so long as the demands made on the soil are not excessive. Given this description of renewable resources, it is important to distinguish between stocks & flows of the renewable resource. The stock is a measure of the quantity of the resource existing at a point in time, measured either as the aggregate mass of the biological material (the biomass) in question (such as the total weight of fish of particular age classes, or in terms of population numbers. The flow is the change in the stock over an interval of time, where the change results either from biological factors or from harvesting activity.

The management of natural resources is a comprehensively researched topic in environmental economics. The prime economic question in the optimal use of renewable natural resources has been regarding harvesting of renewable resources in both future & present time periods. In this context, it is also important to draw one basic similarity between renewable and non-renewable resources. Prolonged harvesting and extraction activity can bring down the stock levels of both types of resources to zero. Nonrenewable resources may exhaust due to their finite stocks whereas a few renewable resources may exhaust if the rate at which they are harvested, exceeds the rate at which they replenish themselves.

The exhaustion of renewable resources can be linked to the lack of enforceable property rights, regulation or combined control over harvesting behavior. Open-access resources incline to be overexploited in both biological and economic sense. If the access can be restricted through appropriate property rights, the resources might not get overexploited to the extent of near exhaustion. Literature on the economics of renewable resources largely revolves around fisheries and the economics of forestry. Most forms of renewable resource exploitation can be analyzed using certain modifications in fishery economics.

Fishery Economics can be studied under two sets of institutional arrangements: an open access fishery and a profit maximizing fishery in which enforceable private property rights exists. This module shall principally deal with both the institutional arrangements of fisheries.

15.2 BIOLOGICAL GROWTH PROCESSES OF FISHERY

Investigating the pattern of biological growth of the renewable resource is the first step taken in order study the economics of any renewable resource. It is first necessary to describe the pattern of biological (or other) growth of the resource. In the example of fishery, let S denote the population stock of fish and g denote the intrinsic (or potential) growth rate of population of fishery which can essentially be seen as the difference between the population’s birth and natural mortality rate. This is the proportional rate at which the fish stock would grow when its size is small relative to the carrying capacity of the fishery, and so the fish face no significant environmental constraints on their reproduction and survival.

Suppose that the population stock is S and it grows at a fixed rate g. Then in the absence of human predation, the rate of change of the population over time is given by

$$\frac{dS}{dt} \equiv \dot{S} = gS \quad (2.1)$$

Now let us suppose that under a given set of environmental conditions there is a finite upper bound on the size to which the population can grow (its carrying capacity). We will denote this as SMAX.

In this case let the logistic function determine the actual population growth rate. We may therefore write the biological growth function as

$$\dot{S} \equiv \frac{dS}{dt} = g\left(1 - \frac{S}{S_{MAX}}\right)S \qquad (2.2)$$

g>0. The changes taking place in the fish population that we have been referring to so far are ‘natural’ changes. But in order to reserve the use the notation S and $\frac{ds}{dt}$ in further analysis to refer to the *net* effect of natural changes and human predation, this module shall use the alternative symbol G(S){as G depends upon S} to refer to stock changes due only to natural causes. With this change the logistic biological growth function becomes

$$G(S) = g\left(1 - \frac{S}{S_{MAX}}\right)S \qquad (2.3)$$

This notation defines a logistic growth function for the case where the species does not possess (any non-zero) lower threshold population level. Biological growth function that can captures the natural growth process of many fish, bird and animal populations is the logistic growth function and hence it has been extensively used in the literature.

15.3 STEADY-STATE HARVESTS

A steady state harvest is an important concept and shall be used repeatedly in this module. If for a period of time the stock being harvested (H) remains equal to the amount of net natural growth of the resource (G) and these magnitudes remain constant over a sequence of consecutive periods, it is called the *steady-state* harvesting. The constant magnitude being harvested is called the sustainable yield.

Using the notations described earlier, S& being the actual rate of change of the renewable resource stock, and hence S& = G - H . A steady state harvesting is denoted S& = 0 & so the resource stock remains constant over time. The diagram 3.1 depicts two different steady state harvests. The inverted U-shaped curve is the logistic growth function for the resource, fish in our example.

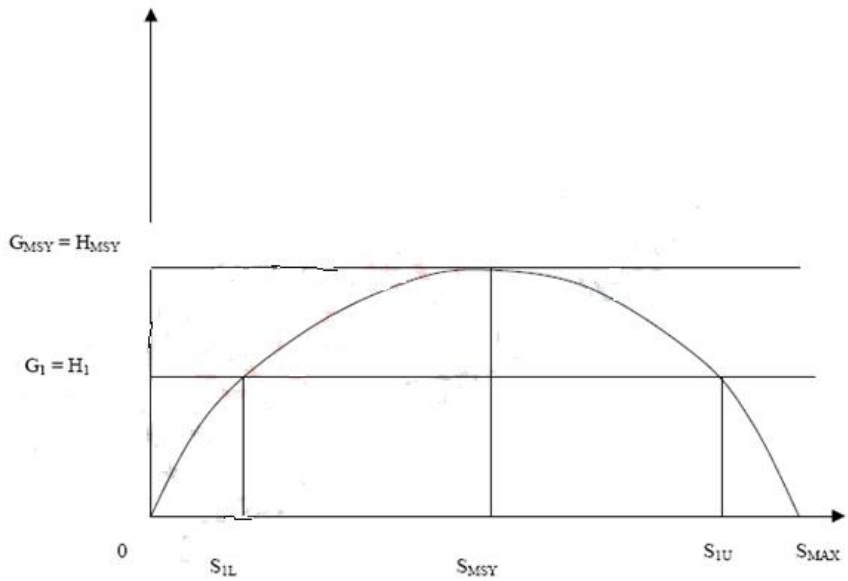


Figure 3.1 Steady State Harvests

The logistic growth model implies that an environmental system will have maximum carrying capacity SMAXas shown in the figure 3.1 There is 1precise stock size (SMSY) at which the quantity of net natural growth is at its maximum (GMSY). If at a stock of SMSY, harvest is set at the constant rate HMSY , then the steady state *maximum sustainable yield* (MSY) can be obtained. However, HMSY is not the only possible steady state harvest. There may exist other realistic steady state harvest between 0 & HMSY that can be supported by any stock between O & SMAX.

For example in fig 3.1 , H1 is a realistic steady-state harvest if the stock size is retained at either S1L or S1U. Optimal management of renewable resources like fishery, forest must involve strategies to ensure maximum sustainable yield.

15.4 OPEN ACCESS FISHERY MODEL

In the literature of environmental economics, open access fishery share a few features of standard perfect competition model. First, large number of independent fishing firms is involved in exploiting fishery for commercial purpose and hence each fishing firm takes the price of fishery as given.

Second, there are no impediments to entry into &exit from the fishery. However, the free entry assumption in open access fishery comes with an additional rider of no enforceable property rights to the *in situ* fishery resources, including the fish in the water. But firms do have individual property rights to their fishing capital and to any fish that they have actually caught. Moreover, if any firm chooses to leave some fish in the pond, contemplating investment to enhance growth of fishes, that firm has no enforceable rights to the fruits of that investment. Any firm that catch the fishes at any future date owns the fish and keeps its catch.

Algebraically, the open access model has 2 components:

(1) A biological sub-model, defining the natural growth process of the fishery.
(2) An economic sub-model, explaning the economic behaviour of the fishing boat owners.

The analysis involves arriving at steady state equilibrium which consists of a set of circumstances in which the resource stock size is unchanging over time (a biological equilibrium) &the fishing fleet is constant with no net inflow or outflow of vessels (an economic equilibrium). Because the steady state equilibrium is a joint biological-economic equilibrium, it is often denoted as *bio-economic* equilibrium.

15.4.1 Biological sub-model

In the absence of harvesting and other human interference, the rate of change of the stock depends on the prevailing stock size
$dS/dt = G(S)$ (4.1)

15.4.2 Economic sub-model

The harvest function (or fishery production function)

Harvest function may depend on the amount of resources devoted to fishing. The size of the harvest is assumed to depend upon one magnitude called *effort*, E. Harvest may also depend on the size of resource stock referred to as S. Other things being equal, the larger the stock the greater the harvest for any given level of effort.
Hence we obtain $H = H(E,S)$ (4.2)

This relationship can take a variety of particular forms. One very simple form appears to be a good approximation to actual relationships (see Schaeffer, 1954 and Munro, 1981, 1982), and is given by

H = eES (4.3)

where e is a constant number, often called the catch coefficient. Dividing each side by E, we have

$$\frac{H}{E} = eS \qquad (4.4)$$

which says that the quantity harvested per unit effort is equal to some multiple (e) of the stock size. The growth function of fish stock with human predation can take the form of the biological growth function less the quantity harvested. That is

S = G(S) - H (4.5)

The costs, benefits and profits of fishing

The total cost of harvesting, C, depends on the amount of effort being expended

C = C(E) (4.6)

For simplicity, harvesting costs are taken to be a linear function of effort

C = wE (4.7)

where w is the cost per unit of harvesting effort, taken to be a constant.

If B denotes the gross benefit from harvesting some quantity of fish, it will depend on the quantity harvested, so we have

B = B(H)

In a commercial fishery, the appropriate measure of gross benefits is the total revenue that accrues to firms. Assuming that fish are sold in a competitive market, each firm takes the market price P as given and so the revenue obtained from a harvest H is given by

B = PH (4.8)

Fishing profit is given by

NB = B – C (4.9)

Entry into and exit from the fishery

The harvesting effort supplied in open access fishery depends upon the level of economic profit prevailing in fishery. Economic profit is the difference between the total revenue from the sale of harvested resources and the total cost incurred in resource harvesting. Free entry of firms into open access fishery continues(thereby increasing the harvesting effort) as long as it is possible to earn positive economic profit. Conversely, individuals or firms will leave the fishery if revenues are insufficient to cover the costs of fishing. The change in harvesting effort as a dependent on level of economic profit can be algebraically shown with the following

$dE/dt = d \times NB$ (4.10)

where d is a positive parameter indicating the responsiveness of industry size to industry profitability.

When economic profit (NB) is positive, firms will enter the industry; and when it is negative they will leave. The magnitude of that response, for any given level of profit or loss, will be determined byd. Although the true nature of the relationship is unlikely to be of the simple, linear form in Equation 4.10 to capture what is essential.

Bioeconomic equilibrium

Two equilibrium conditions that must be satisfied jointly are now discussed.

Biological equilibrium occurs where the resource stock is constant through time (that is, it is in a steady state). This requires that the amount being harvested equals the amount of net natural growth:

$G = H$ (4.11)

Economic equilibrium requires that the amount of fishing effort be constant through time. Such an equilibrium is only possible in open-access fisheries when rents have been driven to zero, so that there is no longer an incentive for entry into or exit from the industry, nor for the fishing effort on the part of existing fishermen to change.

We express this by the equation

$NB = B – C = 0$ (4.12)

which implies (under our assumptions) that $PH = wE$. Notice that when this condition is satisfied,

$dE/dt = 0$ and so effort is constant at its equilibrium (or steady state) level $E = E^*$.

15.5 STEADY STATE EQUILIBRIUM

We can envisage open access fishery steady state equilibrium by means of what is known as the fishery's yield-effort relationship. To obtain this, substituting the assumed functions for H and G from Equations 4.3 and 2.3 respectively in biological equilibrium H = G to obtain:

$$gS\left(1 - \frac{S}{S_{MAX}}\right) = eES \qquad (4.13)$$

which can be rearranged to give

$$S = S_{MAX}\left(1 - \frac{e}{g}E\right) \qquad (4.14)$$

Next substitute Equation 4.14 into Equation (H = eES) giving

$$H = eES_{MAX}\left(1 - \frac{e}{g}E\right) \qquad (4.15)$$

In an open access economic equilibrium, profit is zero, so
PH = wE (4.16)

Equations 4.15 and 4.16 constitute two equations in two unknowns (H and E); these can be solved for the equilibrium values of the two unknowns as functions of the parameters alone.

This solution method can also be represented graphically, as shown in Figures 4.1 and 4.2.

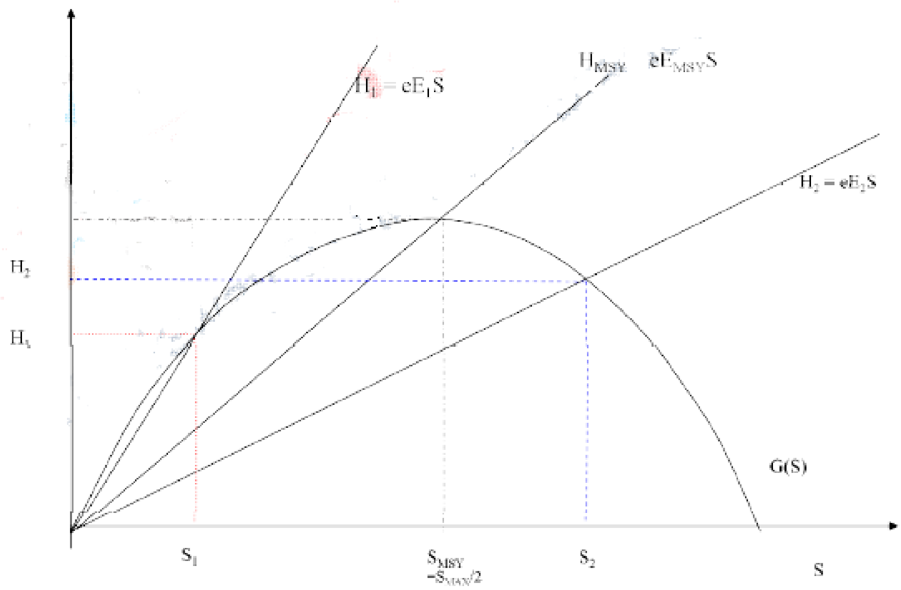


Fig 4.1 Steady state equilibrium fish harvests and stocks at various effort levels

Figure 4.1 shows equilibrium relationships in stock-harvest space. The inverted U-shape curve is the logistic growth function for the resource. Three rays emanating from the origin portray the harveststock relationships (from the function H = eES) for three different levels of effort. If effort were at the constant level E1, then the unique intersection of the harvest-stock relationship and biological growth function determines a steady state harvest level H1 at stock S1. The lower effort level E2 determines a second steady state equilibrium (the pair {H2, S2}). An intermediate effort level labelled EMSY depicts harvest-stock relationship associated with the maximum sustainable yield. . The various points of intersection satisfy Equation 4.14, being equilibrium values of S for particular levels of E. Clearly there is an infinite quantity of possible equilibria, depending on what constant level of fishing effort is being applied. The equilibrium {E, S} combinations also map into equilibrium {E, H} combinations. As the points of intersection in Figure 4.1 not only satisfy Equation 4.14 but they also satisfy Equation 4.15. The result of this mapping from {E, S} space into {E, H} space is shown in Figure 4.2.

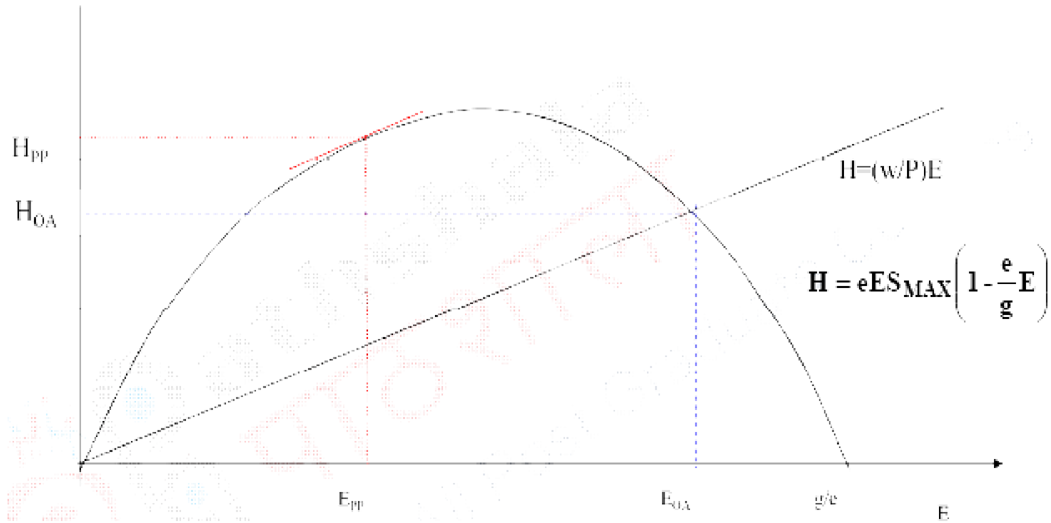


Fig 4.2 Steady state equilibrium yield-effort relationship

The inverted U shape curve here portrays the steady state harvests that correspond to each possible effort level. It describes what is often called the fishery's yield-effort relationship. Mathematically, it is a plot of Equation 4.15.The particular point on this yield-effort curve that corresponds to open access equilibrium will be the one that generates zero economic profit. How do we find this? The zero economic profit equilibrium condition PH = wE can be written as H = (w/P) E. For given values of P and w, this plots as a ray from the origin with slope w/P in Figure 4.2. The intersection of this ray with the yield-effort curve locates the unique open access equilibrium outcome given by HOA and EOA.

15.6 PRIVATE PROPERTY FISHERY

In an open access fishery, the firms tend to exploit available stocks as long as positive profit is available. From the perspective of the fishermen, allowing fish stocks to recover and grow by reducing the catch today is in the collective interest of all. However, no guaranteed reward for the restraint of fisherman in terms of higher catches later prevents him from individually restricting the fishing effort.

From a social perspective, open access fishery tends to overexploit the resource, posing danger for the stock of fishery to reach biologically dangerous levels.

Private Property rights can provide an institutional framework within which these problems can be tackled. The private property fishery has the following three characteristics:

1. There is a large number of fishing firms, each behaving as a price-taker and so regarding price as being equal to marginal revenue. It is for this reason that the industry is often described as being competitive.

2. Each firm is profit (or wealth) maximising.
3. There is a particular structure of well-defined and enforceable property rights to the fishery, such that owners can control access to the fishery and appropriate any rents that it is capable of delivering.

Economic literature offers many variants of private property fishery. This module shall cover only the static profit maximising private property fishery model.

The static fishery model estimates the aggregate level of effort, stock and harvest that can be achieved at an arbitrarily chosen period of time, in a set up where the individual profit maximizing firm operates with enforceable private property rights. The analysis supposes that biological and economic conditions remain constant over some span of time. This way of dealing with time – in effect, abstracting from it, and looking at decisions in only one time period (but which are replicated over successive periods) – leads to its description as a *static* fishery model. More specifically, the static private property fishery turns out to be a special case of a multi-period fishery model; the special case in which owners use a zero discount rate.

The biological and economic equations of the static private property fishery model are identical to those of the open access fishery in all respects but one; the open access entry rule ($dE/dt = d \times NB$), which in turn implies a zero profit economic equilibrium, no longer applies. Instead, owners choose effort to maximise economic profit from the fishery. This can be visualised with the help of Figure 4.2. We multiply both functions by the market price of fish. So the inverted U shape yield-effort equation then becomes a revenue-effort equation. And the ray emerging from the origin becomes $PH = wE$, with the right-hand side thereby denoting fishing costs. Profit is maximised at the effort level which maximises the surplus of revenue over costs. Diagrammatically, this happens when the slopes of the TC & TR curves are equal. This in indicated in Figure 4.2 by the tangent to the yield-effort function at EPP being parallel to the slope of the $H = (w/P) E$ line.

Thus the static private property equilibrium leads to a higher resource stock than that prevails under open access. The level of effort is also lower in comparison to open access model thereby suggesting less exploitation of fishery in private property model under the assumptions made about functional forms. Open access regimes usually give inefficient outcomes.

15.7 SUMMARY

- The logistic growth equation can be used to trace the biological growth process of renewable resources.
- The module captures the example of fishery under two organized provisions: open access and private property regimes. Both static & dynamic analysis can be carried out. However, dynamic analysis remains out of scope of this module.
- Harvesting of renewable resources can be analysed using the concept of sustainable yield. It is advisable to manage stocks so as to extract a maximum sustainable yield but this is economically efficient only under special circumstances.
- Open access fisheries share some of its features with perfect competition. But the firms in this set up are unable to appropriate the gains of their investment in fish stocks.
- Open access fishery is likely to be characterised by an economically excessive amount of fishing effort.
- Economic (and biological) over-harvesting are more likely to occur where the enforceable property rights exist and the stock is exploited under conditions of open access than where access can be regulated.

UNIT-16 THEORIES OF OPTIMAL USE OF NON - RENEWABLE RESOURCES

Structure

16.0 LEARNING OBJECTIVES

After completion of this unit, you shall be able to:

- Understand the concept of non-renewable resources
- Identify problems associated with their unchecked extraction.
- Construct the model for efficient and optimal use of non-renewable resources.
- Understand the static and dynamic efficiency conditions of the resource optimization problem.
- Understand the Hotelling's rule in the context of optimal use of non-renewable resources.

16.1 INTRODUCTION

Non- renewable resources are those mineral deposits whose crude forms are produced over very long periods of time by biological, chemical and physical processes. Their rate of formation is sufficiently slow in times scales and hence in physical sense, the non-renewable sources are said to be existing in fixed quantities. Depletion of exhaustible resources is a cause of serious concern and hence requires immediate attention in terms of regulation of their exploitation. Conservation and management of exhaustible resources has an explicit temporal dimension. The time horizon is first specified (when to start and when to stop) and then introduced as a decision variable.

16.2 THE MODEL FOR EFFICIENT AND OPTIMAL USE OF NON-RENEWABLE RESOURCES

We first establish the conditions that must be satisfied for optimal allocation of non-renewable resources so that the social welfare function can be maximized. Assume that the economy's (social) utility function at each point in time: Ut = U (Ct) for all t where utility in each time period is the concave function of consumption. With Uc> 0 and Ucc<0. Then the economy's intertemporal social welfare function in continuous time notation and infinite time horizons will be represented as

$$W = \int_{t=0}^{t=\infty} U(C_t)e^{-\rho t}\,dt \qquad (2.1)$$

Here, C = consumption
U= aggregate utility flow
r = social utility discount rate
Variables are indexed by the time subscript t, where t = 0,..., T, with t = 0 being the initial period and t = T (where T may be infinity) being the final period.
In order to reach any optimal solution, two constraints must be satisfied.

First Constraint on Welfare Optimisation
As we are considering non-renewable resources, all of the resource stock is to be extracted and used by the end on the time horizon as after this any remaining stock has no effect on social well-being. As renewable resources have fixed and finite initial stock, the total use of the resource overtime is constrained to be equal to the fixed initial stock.

Now, we specify the environmental resource stock-flow relationship for a non-renewable resource:

$$S_t = S_0 - \int_{\tau=0}^{\tau=t} R_\tau\, d\tau \qquad (2.2)$$

where
R = environmental resource **flow** [amount extracted and used (per period)]
St = environmental resource **stock**
S0 = initial stock (at t = 0)

The equation 2.2 states that the stock remaining at time t, (St) is equal to the magnitude of initial stock (S0) less the amount of resource extracted over the time interval from 0 to t, which is nothing but the integral term on right hand side of the Equation 2.2

This resource stock constraint can be alternatively written as
or

$$\dot{S}_t = -R_t \qquad (2.3)$$

where $\dot{S}_t$ = dS/dt.

The dot on the variable represents the time derivative and the equation 2.3can be interpreted as the rate of depletion of the stock, - *t S* &, is equal to the rate of resource stock extraction, Rt.

Second Constraint on Welfare Optimisation

We here consider the accounting identity relating consumption, output and the change in the economy's stock of capital. The part of output that is not consumed, results in changes to the capital stock of the economy. This relationship or national income accounting identity can be expressed in continuous time form as

$$\dot{K}_t = Q_t - C_t \quad (2.4)$$

where K = manufactured capital stock
Q = output produced in the economy
C = consumption

Let output Q be represented in form of a production function involving two inputs: capital K and a non-renewable resource R.

The economy's production function: Qt = Q (Kt, Rt) (2.5) and let

$Q_R = \partial Q/\partial R$ = marginal product of the resource

$Q_K = \partial Q/\partial K$ = marginal product of capital

Substituting for Qt in equation 2.4 from the production function in 2.5, the accounting identity can be rewritten as.

$$\dot{K}_t = Q(K_t, R_t) - C_t \qquad (2.6)$$

2.3 SOLUTION TO THE OPTIMIZATION PROBLEM

Using the stock flow constraint of non-renewable resource and the national income identity, we can find the solution for the socially optimal intertemporal allocation of the non-renewable resource. We need to solve the constrained optimization problem to maximise the social welfare function subject to the aforementioned two constraints.

Select values for the choice variables Ct and Rt for t = 0...∞ to maximize

$$W = \int_{t=0}^{t=\infty} U(C_t) e^{-\rho t} dt \qquad (2.7)$$

subject to

$$\dot{S}_t = -R_t$$

and

$$\dot{K}_t = Q(K_t, R_t) - C_t$$

S(0) = S_0, fixed.

Solving the above problem using constrained optimization techniques, we arrive at four equations that characterise the optimal solution:

$$U_{C,t} = \omega_t \qquad (2.8)$$

$$P_t = \omega_t Q_{R,t} \qquad (2.9)$$

$$\dot{P}_t = \rho P_t \qquad (2.10)$$

$$\dot{\omega}_t = \rho \omega_t - Q_{K,t} \omega_t \qquad (2.11)$$

where

QRt and QKt are the partial derivatives of output with respect to non- renewable resource and capital. These marginal products bear time subscript, indicating that their values will vary with overtime in optimal solution.

t t P w , are the shadow prices of resource and the capital. Time subscripts indicate that the shadow prices will also vary overtime. A shadow price is the price that emerges as a solution to an optimization problem. Alternatively it is an implicit or planning price that a good (productive input in this case) will take if resources are allocated optimally over time.

The shadow prices are expressed in terms of utils and not in terms of consumption or income

16.3 ECONOMIC INTERPRETATION OF THE SOLUTION TO OPTIMIZATION PROBLEM

The first two of the equations characterize static efficiency conditions and the latter two are dynamic efficiency conditions that must be satisfied for the optimal solution.

Static Efficiency Conditions

Static efficiency requires that marginal value of the services from the use of resource should be equal to the marginal value of the resource stock.

First equation states that the marginal utility of consumption is equal to the shadow price of the capital. It has been noted earlier that the shadow prices used for this analysis are in units of utility. So we can say on the basis of this condition that marginal unit of output can be either consumed (yielding Uctunits of utility) or added to the capital stock (yielding an amount of capital value ωtin utility units). This represents an efficient outcome because the marginal net benefit from using one unit of output for consumption is equal to its marginal net benefit when it is added to the capital stock. The second equation states that the value of marginal product of the natural resource must be equal to the shadow price of the natural resource stock. The shadow price (or the marginal value) of the natural resource is Pt. And value of the marginal product of the natural resource is the marginal product in the units of output i.e. QRT multiplied by the value of one unit of output ωt. One must note that in this analysis value of marginal unit of output is identical to the value of marginal unit of capital stock (along an optimal path). This is so because it is assumed that if the output is not consumed, it adds to the capital.

So ωt can be taken as both the value of marginal product of one unit of capital and value of marginal product of one unit of output.

Dynamic Efficiency Conditions

Dynamic Efficiency Conditions state that the rate of return earned be the same across each asset or resource and also be the same at all points in time. In addition, this rate of return must be equal to the social rate of discount.

The third Equation states that the growth of rate of shadow price of the natural resource is equal to the social utility discount rate. This can be seen be seen by dividing the third equation with Pt.

Finally dividing both the sides of fourth equation by ωt., we obtain the equation which states that the return to physical capital(its appreciation plus its marginal productivity) must be equal to the social discount rate.

16.4 HOTELLING'S RULE

The hotelling rule is an intertemporal efficiency condition which must be satisfied by an efficient process of resource extraction. The third equation is also known as Hotelling's rule for the extraction of non-renewable resources.

$$\dot{P}_t = \rho P_t \quad (4.1)$$

or

$$\frac{dP}{dt} = \rho P_t \quad (4.2)$$

where Pt is the shadow price of the resource at time t

By integrating the above equation we get

$$P_t = P_0 e^{\rho t} \quad (4.3)$$

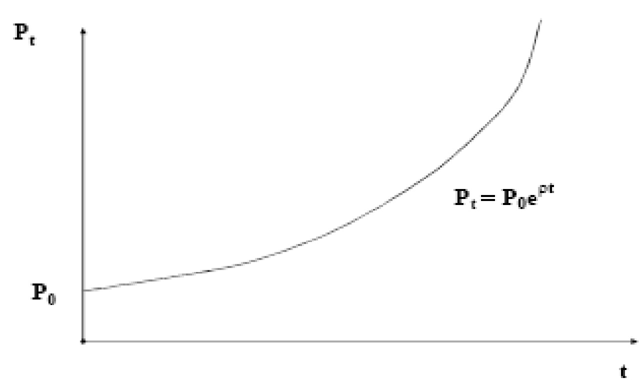
In the equation 4.3, Pt is the undiscounted price of the natural resource. If Pt is discounted at the social utility discount rate of ρ, we arrive at

$$P_t^* = P_t e^{-\rho t} = P_0 (4.4)$$

where *P** is the discounted resource price

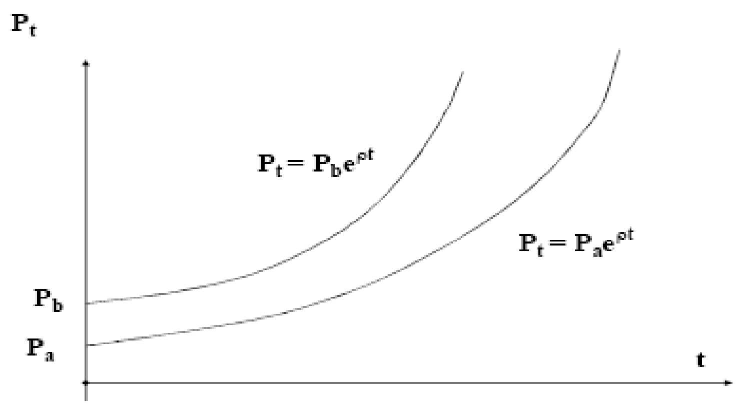
The equation 4.4 states that the discounted price of natural resource is constant along an efficient resource extraction path. This is another way of saying that the discounted value of the resource should be the same at all time periods. Diagrammatically it may be expressed as

Figure 4.1 Hotelling's rule: the time path of the resource price



The Hotelling rule may be a necessary condition but not a sufficient one. Hotelling rule requires that the growth rate of price of a resource to be equal to the social discount rate, but this may not be enough to generate a unique price path. The figure 4.2 exihibits two different initial prices Pa and Pb growing at the same social discount rate. Both these paths are efficient as they both satisfy hotelling rule.

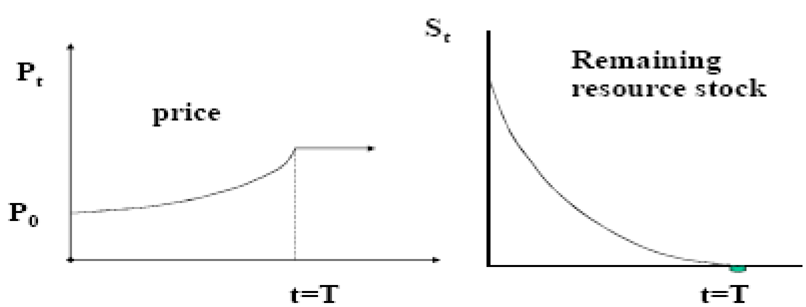
Figure 4.2 Hotelling's rule: non-uniqueness of efficient time paths of the resource net price



There could be infinite price path like the ones depicted in fig 4.2. and all of them may be efficient, but only one of them can be optimal path.

The optimal solution to the optimization problem given by equations 2.8 to 2.11 requires that all the above listed four conditions be satisfied simultaneously along with the initial values for stocks of capital and natural resource. The solution hence obtained yield's unique time path for Kt and Rt. and their associated prices that maximize the social welfare function.

Figure 4.3 the time paths of the resource price and stock



The relationship between the price and the resource stock is depicted in the figure 4.3.It is important to note that the rate at which the exhaustible resource is extracted depends upon its price. Given is the initial resource stock and the information that the resource stock must converge to zero when the economy approaches the end of the planning horizon. Too low initial prices would lead to too large amounts of resource use in each period and all the resource stock would get depleted before the end of the planning horizon. Conversely if the initial price is too high, then each period may record too small amount of resource use and some stock may remain wastefully undepleted by the end of the planning horizon.

Hence, this suggests that there is one optimal initial price that brings about the rate of extraction consistent with the resource stock being fully depleted at the end of the planning period.

16.8 SUMMARY

- Non renewable resources are those mineral deposits whose crude forms are produced over very long periods of time by biological, chemical and physical processes
- Once extracted non- renewable, they cannot be regenerated in the timescales relevant to humans.
- Optimal allocation of non renewable resources involves maximizing the social welfare function.
- The efficient price path for a non renewable resource must follow hotelling’s rule.

UNIT-17 CONCEPT OF ENVIRONMENTAL SUSTAINABILITY: ENVIRONMENT AND DEVELOPMENT DEBATE

17.0 LEARNING OBJECTIVES

After studying this module, you will be able to:

- Acknowledge the limits that environmental constraints offer to economic growth
- Review the ways in which economic activity affects the natural environment
- Introduce the concepts of sustainability
- Explain the distinction between the concept of 'weak' and 'strong' sustainability
- Learn about the importance of substitution possibilities in ensuring constant consumption opportunities far into the future

17.1 INTRODUCTION

Development and sustainability issues have remained at the core of concern for a majority of class of environmental economists. These issues were first highlighted in a book *The Limits to Growth* (Meadows et al, 1972), which held environmental constraints as a significant factor in slowing down of world economic system in the middle of the twenty-first century. The book received a mixed response from the economists but was able to stimulate economists' interest in environmental resources. The limits discussed in this book were in terms of:

- The amount of land available for agriculture;
- The amount of agricultural output producible per unit of land in use;
- The amounts of non-renewable resources available for extraction;

The ability of the environment to assimilate wastes arising in production and consumption, which falls as the level of pollution increases.

All these proposed limits would result in sudden and uncontrollable decline in both population and industrial output amid unrestricted industrialization and resource extraction. Concerted efforts would then be needed to restore ecological and economic stability that is sustainable far into the future. Thus it becomes important to explore existing and effective substitutes of environmental services to overcome various limits to growth. Daly (1987) discussed two aspects of limits to growth. First the bio-physical limits governed by laws of thermodynamics and other dynamics of ecosystems. The second aspect talks about the will or desirability of growth, rather than its feasibility. Daly states the following propositions about limits to growth:

- The future generations pays the price of current generations' pursuits of growth in terms of depleted stock of resources.
- Growth is in turn affected by the extinction or reduction in the number non-human species whose habitat is taken over for higher growth rates.
- The growth or will to grow is usually driven by vested interests and a scientific-technocratic worldview.

The discussion on limits to growth brings to the fore the interrelationship between economics and environmental sciences which can be understood with examples of environmental impacts of trade expansion and climate change.

Trade expansion does offer economic benefits and various empirical studies testify that these economic benefits trickle down to elevate living standards of poor people as a group in the society. However, the environment consequences of trade expansion need to be assessed before a case for free trade is proposed on the basis of economic benefits it offers. Poor countries are usually rich in endowment of natural resources like forests or fisheries. Expansion of trade may only mean extraction of these resources at the expense of livelihood of many poor people. For eg. timber concessions to private logging firms in order to promote exports cause deforestation which in turn leads to increased siltation and risk of floods. The victims are the scattered group of poor farmers and coastal fishermen who are usually not compensated by private logging firms, making the firms' private cost of logging less than the true cost of logging. This reasserts that the environmental impacts of free trade must not be ignored. Climate change is another concern that intertwines the environment and economics. Intergovernmental Panel on Climate Change (IPCC), an organization representing mainstream scientific opinion, apprehends climate change to be the result of exploitative human activity. Emission of carbon dioxide (CO_2) into the atmosphere is one of the most important factors that influence climate change. CO_2 absorbs infra-red heat at a constant rate and at a higher rate than nitrogen and oxygen—the main constituent parts of the atmosphere. Hence an increased amount of CO_2 in the air leads to warming up of air. According to scientists at IPCC, indiscriminate burning of fossil fuels to catalyze economic growth is responsible for large increases in CO_2. In the United States, for example, 38% of the CO_2 produced in 2012 came from generating electricity and 32% came from vehicle emissions (the rest came from industrial processes, buildings and other smaller CO_2 production). People also contribute to release of CO2 when they cut down forests for farmland and pasture (The Economist, 2 Nov 2014).

Sustainable Development has many dimensions to it apart from just ecology and environment. In this module we discuss various concepts of sustainability emanating from its interdisciplinary nature.

17.2 CONCEPT OF SUSTAINABILITY

Sustainability translates into the ethical concern for future generations and the need to incorporate this concern into current planning and decision making of economic activities. The concern for future generation affects the use of environmental resources in current production and also the current decision making process. There are various parameters through which sustainability issues can be comprehended and one of them is through our understanding of different consumption patterns. Utility functions where consumption is the only argument, and where utility increases with consumption is a standard proposition to address intertemporal distribution issues. The idea of sustainability as non-declining consumption is the concept of sustainability that is most widely used in economic analysis. However, constant consumption for indefinite time period into the future, at any rate other than zero, satisfying various constraints of social welfare maximization problem might not be sufficient to explain and address sustainability issues in totality.

The six core concepts of sustainability

The following core concepts of sustainability define a sustainable state as where:

1) The utility or consumption is non-declining through time.
2) The resources are managed so as to maintain production opportunities for the future.
3) The natural capital stock is non-declining through time.
4) The resources are managed so as to maintain a sustainable yield of resource services.
5) The minimum conditions for ecosystem resilience is satisfied through time.
6) The consumption approach to environmental sustainability, where consumption needs to be optimized over time and space.

7) Consensus building and institutional development are considered imperatives for sustainable development.

17.3 ECONOMISTS' VIEWPOINT

Two first two concepts are the economic concepts of sustainability. A sustainable state is one in which utility/consumption is non-declining through time and in which resources are managed so as to maintain production opportunities for the future. Definitions proposed by various economists in support of these concepts are given in table 4.1

Table 4.1

Definitions of Sustainability	
Pezzy 1992, pg 323	Sustainability is defined as non-declining utility of a representative member of society for millennia into the future
Page 1977, pg 202; 1982, pg 205	Preserving opportunities for future generations as a common sense minimal notion of intergenerational justice
Brundtland Report, WECD (1987, P43)	Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs
Solow 1986	We have no obligation to our successors to bequeath a share of this or that resource. Our obligation refers to generalised productive capacity or, even wider, to certain standards of consumption/living possibilities over time
Jha and Murthy (2000)	When we say that a contemporaneous profile of consumption is not sustainable, then it probably means that a switch in consumption either spatially and/or over time would improve global welfare, again perceived as a magnitude referring to the indefinite future

Constant consumption and equal opportunities are closely linked in economics. For many economists, the opportunities that matter are consumption opportunities. In this sense sustainable development is not only about leaving behind stocks of resources for our future generations, but rather the capability to do things we do with those resources. In other words sustainability involves providing same consumption opportunities if not any more to our future generations so that they have the capabilities to do the same things that we do using the current stock of resources. If we cannot bequeath to our successors something that is a substitute for non-renewable resources, then to honour our ethical commitment, we do have an obligation 'to bequeath a share of the resources that we currently use.

The third concept of sustainable state (non declining natural capital) brings us to the differentiation between weak and strong sustainability. Both the perspectives of sustainability (weak and strong) define sustainability in form of constant utility or consumption through time. However they differ in the ways in which the state of constant consumption (or utility) is realized. As developed in the literature, the weak versus strong sustainability debate makes extensive use of the notion of 'natural capital'. To explain this concept we first define total stock of capital as sum of human made capital and natural capital. Human made capital consists of physical (plant, equipment, buildings and other infrastructure), human capital (stocks of learned skills) and intellectual capital (disembodied skills and knowledge like state of technology).Whereas, the natural capital may refer to all naturally provided stock like water, soil, forest, fisheries etc.

This way of classifying production inputs helps in denoting the economy's production function in summary representative form as

$$Q = F(L, KN, KH)$$

where L represents labour, KN natural capital and KH human-made capital. Within this framework, the difference between weak and strong sustainability lies in the extent of the substitution possibilities between KN and KH. Proponents of strong sustainability argue that sustainability requires the level of KN to be non-declining. This conforms to the third core concept of sustainability. Proponents of weak sustainability argue that it requires the sum of KN and KH must be non-declining. Sustainability as non-declining KN assumes that possibilities for substituting KH for KN are limited.

17.4 ECOLOGISTS' VIEWPOINT

The fourth and fifth core concepts of sustainability reflect the viewpoint of ecologists. The fourth core concept is based on the sustainable yields in the economy and the fifth is based on meeting minimum requirements to uphold resilience of ecosystem. Both the concepts are explained below along with the observations on the general approach to policymaking process that is frequently advocated by ecologists.

17.4.1 Sustainable yields

Existing stocks of renewable resources like flaura and fauna have the potential to grow by the means of natural reproduction. Their stock size in any given period depends upon the balance between the rate of their natural growth and the rate of harvest. If in any period the resource harvest exceeds its natural growth, stock size reduces. However, if the harvest is less than natural growth, stock size grows. Stock size of a few renewable resources may fall continuously or even exhaust if the rate at which they are harvested, exceeds the rate at which they replenish themselves. If the rate of harvest is the same as the rate of natural growth, stock size remains constant and the resource can be used indefinitely into the future at a constant rate. If for a period of time the stock being harvested remains equal to the amount of net natural growth of the resource and these magnitudes remain constant over a sequence of consecutive periods, it is called the *steady-state* harvesting. The constant magnitude being harvested is called the sustainable yield as, in the absence of exogenous shocks; it can be maintained or sustained, indefinitely. The concept of sustainable yield runs into difficulty in the case of extraction of non-renewable natural resources. For non-renewable resources, natural growth is zero, so that the only sustainable rate of harvest for a non-renewable resource is zero. However, this situation may be partly countered if some proceeds from the economic progress made with the use of non renewable resources can be used to generate the capacity to provide substitutes for the resource.

17.4.2 Resilience

Concept of resilience is of fundamental importance in ecology. Holling (1973, 1986) describes resilience as the propensity of an ecosystem to retain its functional and organizational structure following a disturbance, without undergoing catastrophic or discontinuous change. Resilient ecosystem does not necessarily imply that all of its component populations remain stable. If the ecosystem continues to function in the same way, even after a component population disappearing as a result of disturbance, the ecosystem is said to exhibit resilience.

In more technical interpretation, resilience relates to the size of the parameters of the relationships determining ecosystem structure and function in terms, say, of energy flows through the system. A resilient ecosystem is characterized by parameters that are not affected by shocks to the system. However, some economic activities appear to reduce resilience, but the extent of this cannot be known *ex-ante.* In other words, we can judge the resilience of ecosystem after a disturbance has taken place but we may not be able to infer ex-ante that ecosystem will remain resilient far in future against any shock that comes by. Uncertainty pervades the behaviour of ecological systems, and hence one cannot know in advance that whether some system is resilient or not.

This is the reason why ecologists give more importance to uncertain nature of ecosystem while conceptualising the sustainability problem and considering policy responses to it. Ecologists advocated the precautionary principle according to which, valid opinions against any action that may have adverse environmental impacts must be presented, before the action is permitted. Thus for approval on the action, it should be necessary to show convincingly that such adverse impacts will not occur. Maintaining the safe minimum standard is another closely related idea wherein actions that may entail irreversible adverse environmental impacts should not be undertaken unless it can be shown that not undertaking the action, would give rise to un-acceptably large social costs.

17.4.3 Consumption Priority View

"Human activity (anthropogenic) is essentially the cause of environmental degradation. In as much as human activity as is necessary for a minimal standard of living, it is justified. Accordingly, much of degradation that is caused in the process of such human activity is warranted. This lays down the basis for the notion of sustainability. If current economic activity causes degradation of the environment beyond such justifiable limits it compromises the health, standard of living and the very existence of future generations (Murthy (2011), p. 289).

This notion of sustainability does not endorse 'non-declining consumption through time,' which is based on the notion of a continuous increase in the level of consumption. The alternative though in this approach is that sustainability is a problem of optimization and not the sustenance of a certain level of consumption. This can be achieved by redistribution of consumption across time and space. It does not rule out increase in consumption in repressed economies. It does not rule out suppression of consumption in such economies where it is excessive. In this sense, 'non-declining consumption' is not desirable in any absolute sense. This new notion of sustainability is not based on natural resource economics. Nor is it based on neo-classical economics. It is also not based exclusively on social discount rate. It does not treat technology and production as the basis of sustainability. The level and distribution of consumption is the purported basis of the new notion of sustainability.

17.5 SOCIO-POLITICAL VIEWPOINT

The sixth core concept of sustainability puts in place consensus building and institutional development as vital components in discussion of sustainability. Although economists and ecologists do recognize that sustainability issues entail both socio-political and cultural dimensions, this sort of view of sustainability is found mainly in the writings of political scientists and sociologists. This view lays primary focus on developing processes to ensure sustainable development, rather than looking at outcomes or constraints. Some important definitions of sustainability justifying this view point were proposed by de Graaf et al (1996) development of a socio-environmental system with a high potential for continuity because it is kept within economic, social, cultural, ecological and physical constraint it is kept within economic, social, cultural, ecological and physical constraints and development on which the people involved have reached consensus

For many years, it was thought that the eradication of poverty required well-designed development programmes that were largely independent of considerations relating to the natural environment. But perspectives have changed post 1970's. During the 1970s, a concern for sustainability took form of the international political agenda as was widely discussed in a series of international conferences. The common feature of these debates was the interrelationship between poverty, socio-economic & cultural development and the state of the natural environment. It has now become difficult to separate environmental objectives from other social and political objectives as their interdependence cannot be ignored. Rather such interdependence is seen as both pervasive and complex. Perhaps the 1987 report of the World Commission on Environment and Development, popularly known as Brundtland report set the agenda for much of the subsequent discussion of sustainability with the institutional dimension.

In political terms the Brundtland report was an influential piece of work which highlighted that sustainability problems are set in the framework of economy-environment interdependence. Thus, according to the Brundtland report Environment and development are not separate challenges: they are inexorably linked. Development cannot subsist on a deteriorating environmental base; the environment cannot be protected when growth leaves out of account the costs of environmental protection (p37).

The Brundtland report simply urges that national governments merge environmental and other s considerations in their decision making as conventional approaches to the sustainability issues may not be sufficient. Though the brundtland report stressed upon economic systems with environmental dimensions, the proponents of institution and consensus building consider cultural development, political will and feasibility as additional core components of sustainability. In proposing a new strategy, de Graaf et al. urge that one must not view the attainment of sustainability as simply a technical problem. Necessary and sufficient conditions for sustanaibility cannot represent the problem comprehensively in the presence of fundamental limits to our ability to know the consequences of human behaviour.

Consensus building should be attempted through negotiations. The notion of negotiation that de Graaf et al had in mind was very broad, referring to an institutional process of social choice that involves people as widely as possible, and involves a process of trade-offs in which all benefit from the avoidance of environmental disturbances. According to de Graaf et al, research should be focused on the structure and management of these negotiations, and on the supply of relevant information about avertable problems steerable development.

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17.6 SUMMARY

The sustainability from economic perspective is constant, or non-declining, consumption (or utility) whereas ecologists are more concerned about properties of biosphere such as resilience and maintaining healthy equilibrium between man-made and natural processes. Ecologists' perspective is similar to the idea strong sustainability, whereas economists' are drawn towards the concept of weak sustainability. However, one must also note that these concepts fall somewhat short in explicitly specifying the duration of time over which sustainability is to operate. If the idea of sustainability is to influence the policy makers, it must lay focus the time horizons in which the state of sustainability can be reproduced in perpetuity.

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