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## **CHAPTER 9            THERMOECONOMICS AND SUSTAINABILITY**

In neo-classical economics, sustainability in practice boils down to maximising utility in the form of consumption, usually of goods and services arising from economic production – so called economic capital. While natural capital can be included in this definition, unlimited substitution can be made between man-made and natural capital. Thus the only constraint placed upon consumers is that of a budget constraint – how much consumers have available to spend. This says little or nothing about outside systems – biological, ecological or other – which may have a bearing on consumers' choices. It is just assumed that these can if necessary be replaced or augmented over time by human ingenuity through the economic process.

If it is accepted that economic systems, and by definition human driven ones, seek to maximise entropy gain in some manner, subject to prevailing constraints, one might proceed further to consider the question of whether such a goal is consistent with sustainability of *both* economic and ecological systems.

This debate has been summarised by Brekke (1997) and Ayres (1998) as the difference between 'weak' and 'strong' sustainability, and the substitutability between natural capital and manufactured capital. Weak sustainability may be consistent with preserving the development of the human economic system, but this may be at the expense of reducing the effectiveness of the ecological environment, such as irrevocable resource depletion and ecosystem damage, which do not appear in traditional economic assessment. Strong sustainability on the other hand seeks to conserve natural capital as well as manufactured capital.

Economic management is still highly orientated towards giving humans what they want, a better life, usually enshrined as more GDP per capita, and certainly not less.

Significant variations also exist of individual per capita economic wealth, both at international and national levels. More than 60% of world GDP is attributed to countries counting for only 20% of world population (source: CIA 2006). It is a matter of evidence as to the geographic source of the resources contributing to this economic wealth. Japan for example has few natural resources, yet managed in the second half of the 20<sup>th</sup> century to build an economy based on processing resource value imported from elsewhere, such as metal ores and energy, combined with technology know-how.

Economic life is not equal, and it can be readily appreciated that those with a 'poorer' lot might aspire to catch up with those more fortunate, particularly if economic and technological tools are at hand to facilitate this. In the more recent past both China and India, with very large burgeoning populations, have grasped the economic genie that economics has offered other economies, and are setting about becoming the manufacturing hub of the world. This involves consuming increasingly large amounts of energy and other resources.

The evidence appears to indicate, however, that the world is gradually moving from a position where the only constraints to human economic growth have been those of human, monetary and economic capital, to a position where natural capital also is seen as being of prime importance as a constraint in the scheme of things. Moreover, because natural capital is complex and involves some long timescales, the current position has been developing for some time without humankind being generally aware of the situation. Climate change is an example where scientific evidence and accepted opinion indicates a constraint arising from man's interaction with the eco-system. There are other examples however, including resource depletion, fishing, farming, soil nutrient systems, deforestation, the hydrological cycle, the polar regions, the ozone layer, and waste accumulation and disposal. At a wider level humankind is only just beginning to comprehend how complex the eco-systems of planet Earth are, and what *Homo Economicus* may be doing to move them away from their equilibrium position, perhaps irrevocably. Numerous species of animate life are now threatened with decimation and some with extinction. Would Darwin, credited with the theory of evolution, have contemplated such a significant acceleration in extinction rates over such a short time?

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Perhaps the biggest constraint that now exists is the sheer size of the human population that has grown on the back of economic capital based on non-renewable energy and renewable resources.

Neo-classical economics is not able to cater for this change in affairs, primarily because it is built on a circular flow of value between labour and economic capital, with little recognition that true value ultimately comes from resources and from natural capital, albeit that humankind provides the intelligence and management to harvest and garner these treasures. This has meant that until recently ecological economics has been regarded overwhelmingly as a side issue to mainstream economic thought. A considerable shift in accepted wisdom is now needed, away from a viewpoint that science has little or nothing to offer economics, towards structuring around disciplines incorporating terms and measures that relate to current accepted scientific views of the way the world works. A thermodynamic approach must be among the leading contenders for such a change in viewpoint.

From the thermo-economic development at chapter 3, it was shown that the notion of utility in an economic sense is closely related to that of entropy, and in chapter 7 it was also posited that maximising potential entropy gain is consistent with both natural processes and those arising in 'man-made' economic systems. A formal link between output value flow and maximisation of potential entropy gain can only be established however if account is taken of constraints acting upon economic systems. These constraints take the form of factors that can affect flow of output value; not just a budget constraint, but specific factors that can influence whether output value goes up or down. Factors identified in this book include not only traditional economic ones such as money supply and capacity/unemployment, but those involving natural capital, such as resource constraints – both renewable and non-renewable – and those constraints arising from the eco-system such as climate change.

From a thermodynamic viewpoint a process is more sustainable if less harmful losses of exergy/productive content occur. This is more likely for a renewable resource, as losses generated from consumption can gradually be replaced by those of new resources entering the flow, nurtured by nature and the sun. However the position with a renewable resource is not guaranteed, for if over time the rate of productive content/exergy usage inclusive of Second Law losses is greater than the rate of replacement of productive content/exergy, it is likely that the resource will gradually reduce in size, in the manner of a non-renewable resource. Strong sustainability on a thermodynamic basis therefore will only be achieved if humankind abstracts value that can be fully replaced by the sun through the interlinking eco-system and subsystems humankind relates to, such that future generations of humanity and life on earth can prosper in sustainable harmony, without the ecological system being compromised.

For example, draining marine life from some oceanic areas (including removing seabed life via trawling) to a level where the stock biomass has negative marginal growth, affects reproduction, with an ensuing decline in stock levels, which may also affect other higher and lower level species in the aquatic system. It follows that if the human population is still growing, with a declining marine stock, then those particular oceanic areas as a source of food per capita will decline markedly.

The same logic follows regarding use of land to grow food and nurture farm animals. Consuming even more energy to produce fertilisers may improve yields, but forever reducing arable land in favour of production of consumptive products is a negative a factor. No amount of exponential projection of human GDP will restore the source of food.

The net effect of a global policy that followed the weak sustainability path is that irretrievable natural resource depletion and ecosystem damage could escalate to a position where global constraints might force a severe retrenchment, if not something much more serious.

All of the above suggests that the key input to promoting strong sustainability may not be by humankind burning its way out by producing more GDP to feed its growing population in the hope that technology will solve the problem, but by consuming less. It is however quite contrary to human nature to reduce voluntarily an appetite for more, if not faced with an immediate constraint, and it is unlikely

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that individual nations and people would be willing to give up their way of living to the benefit of others unless, by international agreement and enforcement of such an agreement, each may be persuaded to reduce consumption if all suffer together. To date, international agreements on climate change policy, destruction of rainforests and harvesting of the oceans have not so far resulted in a significant change from the path of 'same as usual'.

Even if action were taken, it is human nature (the potential entropy maximisation principle again) that humankind having made a saving in one direction, would wish to go out and use the saving for something else. Thus just reducing expenditure on a non-renewable form of energy to replace it with another 'sustainable' form may leave GDP proceeding apace, but the threat of more population and short-term consumption of other resources such as food, and potential overloading of the eco-system would remain.

While global taxation might provide a means at the international level of persuading those who consume natural capital to pay and fund for their preservation, it is another matter to obtain acknowledgment of their liability and to enforce the economic redistribution involved. For example, it is a matter of evidence as to whether carbon taxes so far have reduced demand for fossil-fired energy, and attempts to enforce fishing quotas in parts of the world have been met by many trying to circumvent them.

In times past, the most effective occurrences that have persuaded both governments and populace to pull together to solve a problem have been in times of war and of recession/depression with reduced income. These were times when the populace experienced 'real' pain from a constraint or force, as opposed to being told that a 'threat' of pain might occur in some period ahead.

Human actions to ensure a high level of strong sustainability rest on the populace of all countries taking a much longer term view than hitherto has been the case, based on continued review and research into links between human and ecological systems. Nevertheless the advent of modern communications has meant that most people in the world are by now aware of the problem, even if singly and collectively they have so far done little to change their ways. Ingenuity and thought may play a part in the solution, but technology on its own will not provide an answer.

All this suggests that possibly a more likely outcome in the decades to come is eventually some reduced sustainability of natural capital, affecting carrying capacity, with an associated effect on human activity, a levelling out or even a decline in population and, over time, moderation of economic output to levels commensurate with prevailing constraints.

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**LIST OF SYMBOLS**

<b>Symbol</b>	<b>Thermo-Economic</b>	<b>Thermodynamic</b>
<b>t</b>	Time	Time
<b>P</b>	Price	Pressure
<b>V</b>	Volume flow rate	Volume (3-D)
<b>N</b>	Number of stock units	Number of molecules
<b>v (=V/N)</b>	Specific Volume Rate	Specific Volume (1/density)
<b>G (=PV)</b>	Value flow rate	Energy
<b>k</b>	Productive Content/unit	Boltzmann constant
<b>Nk</b>	Stock Productive Content	n.a.
<b>T</b>	Index of Trading Value	Temperature
<b>S</b>	Entropy	Entropy
<b>s (=S/N)</b>	Entropy per unit	Entropy per unit
<b>F</b>	Free Value (flow)	Free Energy (Helmholtz)
<b>X</b>	Free Value (flow)	Free Energy (Gibb)
<b>f (=F/N)</b>	Free Value per unit	Free Energy per unit
<b>C<sub>v</sub></b>	Specific Value (Const volume)	Specific Heat (Const volume)
<b>C<sub>p</sub></b>	Specific Value (Const price)	Specific Heat (Const pressure)
<b>n</b>	Elastic Index	Index Expansion/Compression
<b>γ (=C<sub>p</sub>/C<sub>v</sub>)</b>	Isentropic Index	Isentropic Index
<b>Q</b>	Entropic Value flow	Heat Supplied/lost
<b>W</b>	Work Value flow	Work Done
<b>U</b>	Internal Value (stock value)	Internal Energy
<b>u (=U/N)</b>	Internal Value per unit	Internal Energy per unit
<b>ψ</b>	Equilibrium Constant	Equilibrium Constant
<b>ξ</b>	Lifetime Ratio	n.a.
<b>ω</b>	Value Capacity Coefficient C <sub>v</sub> /k	C <sub>v</sub> /k
<b>Ξ</b>	Growth Factor	n.a.