Environment, workplace, and employment: an introduction

Philip Lawn

University of South Australia, GPO Box 2100,
Adelaide, SA, 5001 Australia
Fax: 61 8 8201 5071 E-mail: phil.lawn@flinders.edu.au

Abstract: A potential conflict has emerged between the desire to achieve ecological sustainability on the one hand and full employment on the other. The conflict exists because of the incongruent prescriptions being advised to resolve both problems – a reduced, if not zero, growth rate in the case of ecological sustainability, and a high growth rate in the case of full employment. Very little work has been undertaken to address this crucial issue and no forum specifically exists to deal with it. That is, until now, with the establishment of IJEWE. Its foremost aim is to reconcile the potential conflict between the sustainability and full employment objectives and to find ways to establish sustainable, equitable, and efficient economies. In dealing with this conflict, many other issues emerge – namely, the impact of the sustainability objective on industry structure, on forms of employment, on skills formation, on the workplace and workplace relations, on the development of 'green' technologies, on competitive advantage, and on corporate management strategies.

Addressing these issues is a secondary but no less important aim of IJEWE. But all the above issues need to be tackled on the understanding that economic systems are subsystems of the natural environment upon which they depend; that systems of all types are subject to various physical laws and coevolutionary principles; and human well-being is dependent upon the adequate satisfaction of lower- and higher-order needs.


Keywords: ecological sustainability; steady-state economy; full employment; technological progress.

Biographical notes: Philip Lawn is a Lecturer in Environmental and Ecological Economics at the Flinders University of South Australia. Over the past six years Philip has published a number of papers on ecological economics issues as well as a book entitled Toward Sustainable Development. Philip is currently working on environmental macroeconomic models and a comprehensive set of sustainable development indicators to assess Australia’s sustainable development performance. One of Philip’s recent interests is the potential conflict between the ecological sustainability and full employment objectives.
1 Introduction

For some time now, a number of commentators have called for the growth of macroeconomic systems to be curtailed to achieve ecological sustainability [1–9]. Moreover, because of alleged biophysical limits to growth, some of these commentators have argued that all but impoverished nations should commence a rapid transition towards a steady-state economy [10]. A relatively new group of economists labelled ‘ecological economists’ hold this view but believe there is a more pressing reason why nations should make this transition [11]. They argue that an economic limit to growth precedes the biophysical limit and that macroeconomic systems should be stabilised at a physical scale much smaller than their maximum sustainable scale [7–8,12–13]. Ecological economists have therefore called for an immediate cessation to the high-growth policies being widely adopted by most governments. Naturally, this demands that limitations be in some way placed on real Gross Domestic Product (GDP).

The problem with non-increasing or declining real GDP is that under the institutional arrangements of most countries, a growth rate of around 2% to 3% is required to prevent unemployment from escalating. This raises the following question: ‘How can low rates of unemployment or, preferably, full employment be achieved in a low-growth or steady-state economy?’ Ecological economists have been largely silent on this issue. Their failure to adequately respond to this question has significantly harmed their cause.

This paper will not so much address the above question, but outline, in some detail, why the potential conflict between the sustainability and full employment goals has emerged. In doing so, the paper will reveal the many reasons why a journal such as IJEWE is needed and, in the process, lay the foundation upon which the editorial policy of the journal is based. To achieve its aims, the paper is structured as follows. First, the notion of a steady-state economy is briefly outlined. Second, it is explained why, initially, there is a need to move towards a low-growth economy and, eventually, to a steady-state economy. Third, empirical evidence is provided to show that most countries are already suffering from their obsession with a high-growth policy. Fourth, the claim that ecological and economic limits to growth can be averted by shifting the socio-economic process away from the production of goods to the provision of services is refuted. Fifth, and assuming the eventual necessity of the steady-state economy, some of the more fundamental factors that underlie the conflict between the sustainability and full employment goals are outlined. The final section of the paper involves a brief discussion of the many ancillary issues that emerge as a consequence of dealing with the sustainability/full employment conundrum.

2 What is a steady-state economy?

A steady-state economy is an economy comprised of a constant magnitude of physical goods maintained by a resource flow consistent with the regenerative and waste assimilative capacities of the natural environment. Thus, first and foremost, a steady-state economy is designed to be ecologically sustainable. Also constant in a steady-state economy is the population of human beings. The second major feature of a steady-state economy is that it need not be static, dull, or stultifying. Through improvements in product design and a variation over time in the market allocation of the incoming
resource flow, a steady-state economy can be as dynamic as any economy. Moreover, qualitative improvement or ‘development’ can still be achieved provided consumed or worn out goods are replaced by new goods exhibiting higher benefit-yielding qualities. An increase in time devoted to leisure activities and a greater sense of purpose can also contribute to the development process in a steady-state economy. More on this later.

How does the low-growth economy differ to the steady-state economy? In many ways, they are the same. Indeed, the institutional arrangements are likely to be very similar for both economies. Perhaps the best way to describe the difference between the two is by explaining why a shift from a low-growth economy to a steady-state economy need not be mandated by a central government. Certainly, the initial transition away from a high-growth economy requires some form of government intervention since ecological sustainability demands the imposition of a quantitative restriction on the incoming resource flow [8]. It is this restriction on the rate of resource throughput that precludes any continuation of high rates of growth (i.e., the source of most growth is the increase in the rate of resource throughput). Provided there is scope for efficiency-increasing technological progress that allows a larger stock of physical goods to be maintained by a given resource flow, growth spurs are ‘ecologically’ permissible. But the likelihood of marginal and sporadic future gains in technology means that any form of physical growth would be small [14] – hence the immediate prospect of a low-growth economy. It is a consequence of thermodynamic and biophysical realities that efficiency gains from technological progress are destined to be of a negligible nature [15]. Once we arrive at this point, physical growth effectively grinds to a halt and the steady-state economy becomes a long-run inevitability [16]. Hence, while the shift away from an unsustainable high-growth economy is subject to a government mandate, the transition from a low-growth economy to steady-state economy occurs naturally.

3 Why the eventual need for a steady-state economy?

An explanation as to why a country should eventually make the transition to a steady-state economy is best undertaken within the context of a concrete representation of the socio-economic process. Unfortunately, the majority of past analyses of the socio-economic process have been falsely premised on a circular flow representation of the macroeconomy – a model that forms the centrepiece of mainstream economics. Indeed, find any undergraduate textbook and the standard representation of the socio-economic process is that of a pendulum movement between production and consumption within a completely closed and isolated system. Totally ignored is the ‘throughput’ of matter-energy that connects the circular flow of exchange value (prices) to the natural environment. Of course, provided one is thinking only in terms of abstract exchange value, the circular flow model is entirely reasonable, indeed useful, since it constitutes the basis of many important macroeconomic identities. Such a representation also reveals why markets – when they are operating effectively – are able to generate price signals that accurately reflect the marginal benefits and costs of economic activity and are thus able to facilitate the maximisation of total values through exchange. Hence, by focusing on the circular flow of exchange value, economists have come to understand the circumstances under which markets ‘fail’ and the solutions required to overcome them. What mainstream economists have not yet learned is that markets offer no guide in terms of what we should be maximising. Maximisation through exchange, the equivalent
of achieving a Pareto efficient allocation of resources, is of greatly reduced value if (a) the distribution of income and wealth is inequitable; (b) the needs and wants of individual consumers are inappropriately ranked (since this leads to spending decisions that fail to maximise individual well-being); and the total resource flow is ecologically unsustainable. Most mainstream economists freely admit that Pareto efficiency does not ensure distributional equity or desirable spending decisions. Few, however, are willing to concede that Pareto efficiency does not guarantee ecological sustainability. “Get the prices right”, as they say, and the efficient allocation of each resource unit supposedly brings forth a sustainable incoming resource flow. Yet the failure of Pareto efficiency to coincide with ecological sustainability is entirely conceivable, indeed, most probable, because price signals merely provide information about the scarcity of one thing relative to another – for instance, the scarcity of one type of resource (oil) relative to another (coal). It is because the market is very adept at revealing relative scarcities that it constitutes an effective allocative mechanism. But sustainability is a question of the absolute scarcity of the very non-substitutable stuff that sustains the economic process – namely, low entropy matter-energy [17] – and no amount of relative scarcity information can render the market effective at ensuring the sustainable use of natural resources [7,18–20].

What if the economic process is viewed in terms of the physical goods required to experience the enjoyment of life? The focus of attention automatically moves to the production and consumption of physical goods. Since both activities are physical transformation processes, it is the linear throughput of matter-energy that is now dominant and the circular flow of exchange value that is incidental [21]. Unfortunately, mainstream economists continue to view the economy from the perspective of a circular flow and erroneously believe that what is true of the abstract symbol that measures the exchange value of physical goods is also true of physical goods themselves (i.e., physical goods have the ability to circulate independently of the natural environment).

3.1 Basic features of the coevolutionary paradigm

There is another crucial deficiency of the circular flow model that mainstream economists overlook – it reflects an outmoded, atomistic-mechanistic worldview. As such, it fails to recognise the coevolutionary nature of economic, social, and ecological change [22]. What is coevolution? Coevolution is a term used to describe the evolving relationships and feedback responses typically associated with two or more interdependent systems. Coevolution takes place when at least one feedback loop is altered by within-system activity that, in turn, initiates an ongoing and reciprocal process of change [23–24]. A coevolutionary worldview provides a more realistic and concrete understanding of the many critical relationships that bind together the various systems that make up the global system.

There are a number of fundamental features of the coevolutionary worldview worthy of elaboration. First, the coevolutionary paradigm begins from the premise that the Earth is a system comprised of closely interacting and interdependent subsystems. Second, it recognises the Earth and its constituent systems as dissipative structures [25] – i.e., the Earth as a dissipative structure open with respect to energy (a solar gradient); and the Earth’s constituent subsystems as dissipative structures open with respect to energy, matter, and information [26]. Third, since each system is connected to and dependent on
all others, everything evolves together over time. Even the rules governing the relationships between systems are in a constant state of flux. Fourth, coevolution is characterised by path-dependency – a proclivity of systems to be inextricably related to their past characteristics and to thus exhibit structural inertia [27–28]. Fifth and given its complexity, the global system is envisaged by the coevolutionary worldview as one that is far greater and richer than the mere sum of its parts. Sixth, the coevolutionary worldview regards disequilibria and change as the rule rather than the exception. For many people accustomed to atomistic-mechanistic paradigms, this sounds at best unsettling, and at worst debilitating. But this need not be the case. As Norgaard [23] has pointed out, disequilibria and change should be seen as an ongoing process offering a plethora of opportunities for humankind to engage in positive coevolution which, for the purposes of this paper, can be construed as a coevolutionary process consistent with achieving sustainable development [29]. Finally, the coevolutionary worldview is based on a principle of system embeddedness that is sometimes referred to as the logos of nature. Metaphorically, logos is a term used as a principal concept embracing the natural order of the universe. By acknowledging the logos of the global system, the coevolutionary worldview recognises, firstly, that the world is characterised by self-organisation [30]. Second, it recognises that systems exist at varying levels of complexity and, as such, are characteristically stratified and multi-levelled [31]. The logos of the global system and the embedded relationship between the three major spheres of influence – the macroeconomy, sociosphere, and ecosphere – are illustrated by way of Figure 1 below.

**Figure 1** A coevolutionary interpretation of the interdependent relationship between the economy, sociosphere, and ecosphere

In Figure 1, the three major spheres of influence represent different systems at varying degrees of complexity. Each can be considered a holon insofar as they manifest the independent and autonomous properties of wholes and the dependent properties of parts
[32]. Thus, each sphere consists of smaller parts while simultaneously acting as the part of a larger whole (i.e., the macroeconomy serves as a component of the sociosphere while the sociosphere serves as a component of the ecosphere). In a sense, Figure 1 represents the sociosphere as the interfacial system between the macroeconomy and the larger ecosphere, thereby highlighting the crucial role played by institutions and social capital in promoting stable human behaviour in the face of indeterminacy, novelty, and surprise [30,33–34].

3.2 The linear throughput representation of the socio-economic process

In order to diagrammatically convey the coevolutionary worldview in greater detail, consider the linear throughput representation of the socio-economic process in Figure 2. In keeping with the coevolutionary paradigm, the linear throughput model: (a) depicts the macroeconomy as a subsystem of the sociosphere that, in turn, is depicted as a subsystem of the ecosphere; (b) recognises the ongoing exchange of matter, energy, and information between the three major spheres of influence and all constituent subsystems; and (c) acknowledges the evolving relationships and feedback responses typically associated with coevolutionary change.

Figure 2  Linear throughput representation of the socio-economic process

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1. Net psychic income
2. Human-made capital (ECONOMY)
3. Throughput (production, consumption)
4. Natural capital (ECOSPHERE)
5. Lost natural capital services
Although the dynamics of the linear throughput model involve a multitude of elements, each element can be conveniently classified into five broad elemental categories. The first elemental category, natural capital, constitutes the original source of all human endeavours. This is because natural capital is the only source of low entropy resources; it is the ultimate waste assimilating sink; and it is the sole provider of the life-support services that maintain the habitability of the Earth. The second elemental category is the throughput of matter-energy – that is, the input into the macroeconomy of low entropy resources and the subsequent output of high entropy wastes. The throughput flow is the physical intermediary connecting natural and human-made capital. Human-made capital is the third elemental category and is needed for human welfare to be greater than it would otherwise be if the socio-economic process did not take place. Conventionally, human-made capital is confined to producer goods such as plant, machinery, and equipment. From a Fisherian [35] perspective, capital is interpreted as all physical objects subject to ownership that are capable of directly or indirectly satisfying human needs and wants. Hence, human-made capital best refers to durable consumer goods as well as producer goods. Although not subject to ownership (other than by the individual who possesses productive knowledge and skills), labour can also be included as part of the stock of human-made capital.

The fourth important elemental category is a psychic rather than physical category. Contrary to some opinions, human well-being does not depend on the rate of production and consumption, but on the psychic enjoyment of life [7,36–37]. Fisher [35] referred to such a flux as 'psychic income'. Most economists refer to the psychic enjoyment of life as utility satisfaction. Psychic income is the true benefit of all socio-economic activity and has four main sources. The first source of psychic income comes from the consumption and use (wearing out) of human-made capital. The second source of psychic income is derived from being directly engaged in production activities (e.g., the enjoyment and self-worth obtained from work). A third source of psychic income comes from non-economic pursuits such as time spent with family and friends, volunteer work, and leisure activities. The final source of psychic income flows from the natural environment in terms of its aesthetic and recreational qualities. It is true that this final source of psychic income does not come directly from socio-economic activity. If anything, such activity tends to destroy rather than enhance such values. It is therefore better that these values be taken as a given and their subsequent destruction be counted as an opportunity cost of the socio-economic process.

This last point reminds us that not all socio-economic activity enhances the psychic enjoyment of life. Consumption of some portion of human-made capital can reduce the psychic enjoyment of life if consumers make bad choices or if needs and wants have been inappropriately ranked. In addition, while benefits can be enjoyed by individuals engaged in production activities, for most people, production activities are unpleasant. Unpleasant things that lower one's psychic enjoyment of life (e.g., noise pollution and commuting to work) represent the 'psychic outgo' of economic activity. It is the subtraction of psychic outgo from psychic income that leads to a measure of net psychic income – the fourth elemental category. Net psychic income is, in effect, the 'uncancelled benefit' of socio-economic activity [38]. Why? Imagine tracing the socio-economic process from natural capital to its final psychic conclusion. Every intermediate transaction involves the cancelling out of a receipt and expenditure of the same magnitude (i.e., the seller receives what the buyer pays). Once a physical good is in the possession of the final consumer, there is no further exchange and, thus, no further
cancelling out of transactions. Apart from the good itself, what remains at the end of the process is the uncancelled exchange value of the psychic income that the ultimate consumer expects to gain from the good plus any psychic disbenefits and other costs associated with the good's production. Note, therefore, that if the costs are subtracted from the good's final selling price, the difference constitutes the 'use value' added to low entropy matter-energy during the production process. Presumably the difference is positive otherwise the socio-economic process is a pointless exercise.

The fifth and final elemental category is the cost of lost natural capital services and arises because, in obtaining the throughput to produce and maintain human-made capital, natural capital must be manipulated and exploited both as a source of low entropy and as a high entropy waste absorbing sink. Perrings has shown that no matter how benignly human beings conduct their exploitative activities, the resultant disarrangement of matter-energy and inevitable coevolutionary feedback responses has deleterious impacts on the natural environment [39]. Consequently, human beings must accept some loss of the free source, sink, and life-support services provided by natural capital as some portion of the low entropy it provides is transformed into physical goods and returns, once they have been consumed, as high entropy waste. In a similar way to net psychic income, lost natural capital services constitute the 'uncancelled cost' of socio-economic activity [38]. Why? Imagine tracing the socio-economic process from its psychic conclusion back to natural capital. Once again, all transactions cancel out. What remains on this occasion is the opportunity cost of resource use or, more definitively, the uncancelled exchange value of any natural capital services sacrificed in obtaining the throughput of matter-energy to fuel the socio-economic process [40].

In sum, the linear throughput model illustrates the following. Natural capital provides the throughput of matter-energy that is needed to produce and maintain the stock of human-made capital. Human-made capital is needed to enjoy a level of net psychic income greater than what would otherwise be experienced if the socio-economic process did not take place. Finally, in manipulating and exploiting natural capital for the throughput of matter-energy, the three instrumental services that natural capital provides are, to some degree, unavoidably sacrificed.

3.3 Achieving ecological sustainability

If humankind wishes to engage in a coevolutionary process consistent with achieving sustainable development, it must ensure, first and foremost, that it operates in an ecologically sustainable manner. This requires an understanding of a range of ecological and biophysical factors and, ultimately, an adherence to various sustainability precepts.

Let us begin the quest for appropriate sustainability precepts with a brief discussion of critical ecological and biophysical factors. It was previously mentioned that the throughput of matter-energy is the physical intermediary connecting natural and human-made capital. It is because of this fundamental connection that low entropy resources and high entropy wastes respectively constitute the 'true' input and output of the socio-economic process. A conclusion of this kind has great significance. There are three main reasons why. First, most people are taught that labour plus human-made capital are also inputs. However, what is taught is not strictly correct since labour and human-made capital are the low entropy-transforming agents of the production process. Both constitute the efficient or value-adding cause of production [38]. Only low entropy
matter-energy embodied in natural resources constitutes the *material* cause of production, the absence of which precludes the production of any physical goods whatsoever, indeed, the very existence of human-made capital.

Second, most people are also taught that physical goods, not wastes, are the output of the socio-economic process. This, again, is incorrect. Physical goods, along with some unavoidable high entropy production wastes, are merely the output of the initial production phase of the socio-economic process. In due course, physical goods become the input of the final consumption phase. Ultimately, and as a consequence of consuming physical goods to experience their benefit-yielding qualities, the output of the consumption phase is high entropy waste. Thus, having begun with low entropy resources, high entropy waste emerges both at the end of the production and consumption phases of the socio-economic process.

Finally, there are many who believe that viewing the input and output of the socio-economic process in the above way renders it devoid of purpose. This is not so since it is during the transformation of low entropy resources to high entropy wastes that ‘use value’ is created and momentarily ‘frozen’ in physical goods. Until such time as the use value is eventually destroyed through consumption, human beings are able to experience a level of psychic income higher than if the economic process had not taken place.

It has also been pointed out that natural capital effectively constitutes the tap-root of the socio-economic process because natural capital is the only source of low entropy resources; it is the ultimate waste assimilating sink; and is a critical generator of the life-support services that maintain the human habitability of the planet. Given the obvious importance of natural capital in achieving ecological sustainability, one must ask themselves the following questions:

- How much natural capital is required to ensure the ecological sustainability objective is not recklessly put at risk?

- Should natural capital maintenance be a necessary sustainability tenet, what rules-of-thumb should human beings adhere to in order to prevent the wholesale decline in both the quantity and quality of natural capital stocks?

I will endeavour to answer the first question by beginning with a consideration of production possibilities. Ever since Hicks [41] defined income as the maximum amount that can be produced and consumed in the present without comprising the ability to produce and consume the same amount in the future, it has been widely recognised that sustaining the production of a particular quantity of physical goods requires the maintenance of income-generating capital. Where debate has raged is in relation to what form the capital should take. While some observers believe natural and human-made capital should be individually maintained, others believe it is only necessary to maintain an appropriately combined stock of both forms of capital. In order to differentiate between the two schools of thought, the former is now commonly referred to as the ‘strong sustainability’ approach to capital maintenance. The latter is labelled as the ‘weak sustainability’ approach. Which of the two approaches stands as the most appropriate form of action depends critically upon whether human-made capital and the technology embodied within it is able to serve as an adequate substitute for the low entropy matter-energy that only natural capital can provide. Should it fail to do so, the requisite capital maintenance policy is that advocated by the strong sustainability proponents.
It is undeniably true that advances in the technology embodied in human-made capital can, for some time at least, reduce the resource flow required from natural capital to produce a given physical quantity of goods. However, for three related reasons, this does not amount to substitution [42]. First, technological progress only reduces the high entropy waste generated in the transformation of natural capital to human-made capital. It does not allow human-made capital to ‘take the place of’ natural capital. Second, because the first and second laws of thermodynamics, there is a limit to how much production waste can be reduced by technological progress. This is because 100% production efficiency is physically impossible; there can never be 100% recycling of matter; and there is no way to recycle energy at all [43]. Third, a value of one or more for the elasticity of substitution between human-made and natural capital is necessary to demonstrate the adequate long-run substitutability of the former for the latter. It has recently been shown that the value of the elasticity of substitution derived from a production function obeying the first and second laws of thermodynamics is always less one [15]. Thus, the production of a given quantity of human-made capital requires a minimum resource flow and, therefore, a minimum amount of resource-providing natural capital [7–16,44–47]. It is for this reason that natural and human-made capital must be regarded as complementary forms of capital – not a substitute for each other – and the strong sustainability approach to capital maintenance as a necessary course of action to ensure sustainability of the socio-economic process.

But before one can give a satisfactory answer to the first of the above questions, it is still necessary to consider what constitutes the minimum amount of natural capital that needs to be kept intact to ensure ecological sustainability. It is at this point that we must go beyond production possibilities and turn our attention to the life-support function of natural capital.

The ability of natural capital or the ecosphere to support life exists because, as a far-from-thermodynamic-equilibrium system characterised by a range of biogeochemical clocks and essential feedback mechanisms, it has developed the self-organisational capacity to regulate the temperature and composition of the Earth’s surface and atmosphere [48]. There has, unfortunately, been a growing tendency for human beings to take for granted the conditions for life – a consequence of technological optimism and the growing detachment most people have from the vagaries of the natural world. In particular, two falsely held beliefs have emerged. The first is a widely held belief that the Earth’s current uniqueness for life was preordained. This is not so since, as Blum [49] explains, had the Earth been a little smaller, or a little hotter, or had any one of an infinite number of past events occurred only marginally differently, the evolution of living organisms on Earth might never have eventuated. Moreover, the coevolutionary process need not have included the participation of human beings. Second, it is widely believed that organic evolution is confined to living organisms responding to exogenously determined environmental factors. However, it is now transparently clear that ‘fitness’ is a byproduct of the coevolutionary relationship that exists between the ecosphere and its constituent species. Indeed, the ecosphere is as uniquely suited to existing species as are the latter to the ambient characteristics of the ecosphere. Hence, according to Blum [49], it is ‘impossible to treat the environment as a separable aspect of the problem of organic evolution; it becomes an integral part thereof’. Unequivocally, just as current environmental conditions were not preordained, nor are the environmental conditions of
the future. They will always be influenced by the evolution of constituent species and, in particular, the actions of recalcitrant species.

An awareness of the above brings to bear a critical point. While human intervention can never ensure the Earth remains eternally fit for human habitability, humankind does have the capacity to bring about a premature change in its prevailing comfortable state. Many people believe that global warming, ozone depletion, and acid rain are already the first signs of a radical change in the planet’s comfortable conditions. Nonetheless, there are some observers who argue that these events, if they are occurring at all, are of no great concern since they are little more than symptoms of a benign coevolutionary adjustment brought about by the eccentricities of humankind. That is, any malady caused by human activity is short-lived because whatever may threaten the human habitability of the planet induces the evolution of a new and more comfortable environmental state. For such observers, humankind is potentially immune from the consequences of its own actions.

Nothing, however, could be farther from the truth. The quasi-immortality of the ecosphere prevails only because of the informal association that exists between the global system and its constituent species. But quasi-immortality in no way extends to any particular species. Indeed, historical evidence indicates a tendency for the global system to correct ecological imbalances in ways that are invariably unpleasant for incumbent species. Hence, while the Earth has revealed itself to be immune to the emergence of wayward species (e.g., oxygen bearers in the past), individual species – including human beings – are in no way immune from the consequences of their own collective folly. We can therefore conclude that the minimum amount of natural capital required to ensure ecological sustainability may greatly exceed the quantity necessary for production purposes alone. Of course, this still leaves the first of the above questions unanswered.

Deeper insight into the minimum required natural capital can be gained by considering what bestows natural capital with the unique capacity to support life. Is it the quantity of natural capital or is it some particular aspect of it? Lovelock leaves us in no doubt by emphasising that a minimum number and complexity of species are required to establish, develop, and maintain the Earth’s biogeochemical clocks and essential feedback mechanisms. To wit:

"The presence of a sufficient array of living organisms on a planet is needed for the regulation of the environment. Where there is incomplete occupation, the ineluctable forces of physical or chemical evolution soon render it uninhabitable." [48,p.63]

It is, therefore, a combination of the convoluted interactions and interdependencies between the various species, the diversity of species, and the complexity of ecological systems – in all, the biodiversity present in natural capital – that underpins its life-supporting function. That is not to say that the quantity of natural capital is unimportant. It is if only because the biodiversity needed to maintain the Earth’s habitable status requires a full, not partial, occupation by living organisms. But the quantity of natural capital, itself, should never be equated with biodiversity.

If the sheer magnitude of natural capital is an inadequate indication of the effectiveness with which it can foreseeably support life, what is the minimum level of biodiversity needed to maintain the ecosphere’s life-support function? Unfortunately, this is not known, although there is general agreement that some semblance of a biodiversity threshold does exist. What we do know about biodiversity is that in the same way
biodiversity begets greater biodiversity, so diminutions beget further diminutions [50]. It is also known that the present rate of species extinction is far exceeding the rate of speciation – indeed, so much so that biodiversity has, on any relevant time scale, become a non-renewable resource [51]. Given that a rise in the global rate of extinction will unquestionably increase the vulnerability of human beings to its own extinction, a sensible risk-averse strategy for humankind to adopt is a rigid adherence to a biodiversity ‘line in the sand’. Ehrlich [52] provides a hint as to where this line should be drawn by pointing out that humankind knows enough about the value of biodiversity to operate on the principle that ‘all reductions in biodiversity should be avoided because of the potential threats to ecosystem functioning and its life-support role’. As a corollary of Ehrlich’s dictum, humankind should draw a line at the currently existing level of biodiversity. Conscious efforts should also be made to preserve remnant vegetation and important ecosystems [53]. In all, a systematic decline in both a nation’s natural capital stocks and the biodiversity contained within should be viewed as a failure on the part of government policy to achieve ecological sustainability.

We are now in a position to answer the second of our above questions – that is, what sustainability precepts must we follow to prevent the decline in both the quantity and quality of natural capital stocks? While there are many possible precepts, the four fundamental rules-of-thumb requiring adherence are:

1. The rate of renewable resource extraction should not exceed the regeneration rate of renewable resource stocks.
2. The depletion of non-renewable resources should be offset by using some of the depletion proceeds to cultivate renewable resource substitutes [15,54–55].
3. The rate of high entropy waste generation should not exceed the ecosphere’s waste assimilative capacity.
4. Native vegetation and critical ecosystems must be preserved, rehabilitated, and/or restored. In addition, future exploitation of natural capital should be confined to areas already significantly modified by previous human activities.

3.4 Human development

Engaging in a coevolutionary process consistent with achieving sustainable development necessitates more than an adherence to the above-listed sustainability precepts. It also requires a basic understanding of the critical factors applicable to human development. We have already seen that human well-being depends acutely on the psychic enjoyment of life. However, despite having a good sense of what contributes directly towards net psychic income, it is important to consider the extent to which each contributing factor is likely to advance the human condition. Although this will differ from culture to culture and between each individual in any particular society, a greater understanding can be arrived at by considering Maslow’s [56] hierarchy of human needs [57]. Beginning with the lowest form of human need, the hierarchy is classified below in accordance with Maslow’s ranking of lower to higher-order needs:

- **Physiological needs** – this category of need includes one’s basic requirement for food, clothing, and shelter.
• **Safety needs** – this includes the need for physical and mental security; freedom from fear, anxiety and chaos; and the need for stability, dependency, and protection. It also includes the need for a comprehensive and overarching philosophy that organises one’s view of the universe into a satisfactory, coherent, and meaningful whole. Satisfying safety needs necessitates such things as: (a) minimum level of income and an appropriate welfare safety net – overall, a strict adherence to the principle of intragenerational equity and justice; (b) establishment of institutions based around the need for social coherence and stability; and (c) ecological sustainability and the continuation of the evolutionary process to ensure physiological needs are safely sustained in the future.

• **The need for belongingness and love** – this includes the need for affectionate relationships with people in general hunger; the hunger for contact and intimacy; the desire for a sense of place in one’s group, family, and society; and the urgent need to overcome or avoid the pangs of loneliness, of ostracism, of rejection, and of rootlessness. A true and fully encompassing sense of belongingness and love also necessitates a strong sense of identity with posterity. Hence, satisfying the need for belongingness and love demands a corresponding adherence to the principle of intergenerational equity and justice.

• **The need for esteem** – this includes the need for a stable and high evaluation of oneself, for self-respect, and the esteem of others. It essentially involves: (a) the desire for strength, achievement, adequacy, mastery and competence; (b) the need for independence and freedom; (c) the desire for recognition, attention, importance, dignity, and appreciation; and a sense of personal contribution to society at large.

• **Self-actualisation needs** – the need for self actualisation relates to an individual’s ultimate desire for self-fulfilment, that is, one’s desire to become fully actualised in what he or she is capable of becoming. At the pinnacle of the hierarchy of human needs, Maslow considers self-actualisation needs to be the most “creative and rewarding phase of the human development process”.

By organising human needs into a hierarchy of relative prepotency, Maslow’s needs hierarchy not only reflects the multi-dimensionality of the human existence, it paints a picture of the human personality as an integrated whole in which every part, level, and dimension is interdependent. Most importantly, however, the needs hierarchy indicates that once basic physiological needs have been satisfied, desires originating from a higher level of existence begin to emerge. As they do, an individual’s desires are no longer dominated by the need for food, clothing, and shelter, but by the need to satisfy emerging psychological needs. It is at this point that a healthy human existence requires the emerging higher-order needs to be satisfied along with basic physiological needs – what Weisskopf [58] refers to as a healthy *existential balance*.

It is important to recognise that should the lower-order needs of the majority of a nation’s citizens be satisfied, the socio-economic process need not operate in a manner consistent with the adequate satisfaction of emerging higher-order needs. In other words, it is possible for the socio-economic process to continue its emphasis on physiological need satisfaction at the expense of psychological need satisfaction. Why might this be so when it perceptibly results in many people experiencing an unhealthy existential imbalance? A couple of points need to be made here. First, and unlike psychological need satisfaction, physiological need satisfaction (such as being well-fed) has no
enduring qualities. Hence, satisfying lower-order needs requires one to frequently engage in what is required to satisfy them (such as eating often). Second, if higher-order or psychological needs are being inadequately satisfied, an equilibrium – albeit an unhealthy one – can be obtained by engaging in more physiological need-satisfying activities (such as increased production and consumption). Because physiological need satisfaction quickly evaporates, the desire for more production and consumption significantly reduces one’s ability and the time available to fully satisfy higher-order needs. In doing so, it further increases the desire for higher rates of production and consumption that usually manifests itself in the form of a physical expansion of the macroeconomic subsystem. Consequently, an illusionary need for continued growth has the potential to become self-perpetuating. In a coevolutionary world characterised by path-dependency, a growth addiction can arise even though it may be contrary to the betterment of the human condition. This growth addiction is commonly referred to as ‘consumerism’ or the ‘treadmill of production’ [59].

What does this all mean in terms of the human developmental process? To begin with, it is self-evident that need satisfaction aimed continuously at increasing the supply of means along one level that neglects needs on a different level is likely to disturb the balance of human existence [60]. Since human development or the improvement in the total quality of life demands a balanced system of need satisfaction, the accumulation of human-made capital should only continue if, having largely satisfied lower-order needs, it does not come at the expense of satisfying higher-order needs. Finally, it would seem that human development demands, at the very least, a deep respect for the continuation of the evolutionary process plus as a widespread concern for posterity and intragenerational inequities and injustices. Clearly, this entails having to invoke and uphold various universal rights and privileges, two of which immediately stand out. The first is the eradication of absolute poverty. Not only does poverty alleviation ensure the satisfaction of basic physiological needs, but also constitutes a prerequisite for the attainment of the higher-order needs necessary for a balanced and healthy human existence.

The second is the right to paid employment. Few would suggest that unemployed people in countries with an adequate social security system are deprived of their ability to satisfy basic, lower-order needs. However, unemployment often deprives people of their capacity to satisfy safety and esteem needs. In almost all instances, unemployed people are starved of their potential to satisfy self-actualisation needs. Indeed, for many long-term unemployed people, self-actualisation needs are grotesquely suppressed. This often leads to disillusionment, depression, and an increased likelihood of committing a serious crime [61]. Unemployment also results in a major loss of valuable skills and a subsequent depreciation of a nation’s productive capacity [62]. Undoubtedly, full employment must be viewed as an obligatory macroeconomic objective for any nation wanting to achieve a comprehensive form of sustainable development.

3.5 Economic and uneconomic growth

In view of what has been said so far, two very important questions arise that simply cannot be ignored. They are: “How big can the macroeconomic subsystem grow before the throughput of matter-energy required to maintain it can no longer be ecologically sustained?” Moreover: “How big should the macroeconomic subsystem grow before the economic welfare it generates starts to decline and growth itself becomes uneconomic?” I
believe the latter question is as important as the first if only because an economic limit to growth is likely to be arrived at sooner than a biophysical limit and, in the case of many nations, has probably been reached [8–12].

It is at this point that the two elemental categories of net psychic income (uncancelled benefits) and lost natural capital services (uncancelled costs) prove invaluable. Both can be presented diagrammatically to demonstrate the impact of a growing macroeconomy. Consider Figure 3 where, for the moment, it is assumed that there is no technological progress.

**Figure 3** The changing sustainable economic welfare from a growing macroeconomy

Panel 3a.

Uncanc. Benefits (UB)  
Uncanc. Costs (UC)  
and  
Sust. Eco. Welfare (SEW)

Panel 3b.

Sust. Eco. Welfare (SEW)

The uncancelled benefit (UB) curve in Panel 3a represents the net psychic income generated as a national economy expands. The characteristic shape of the UB curve is attributable to the law of diminishing marginal benefits which, barring technological improvements, is equally applicable to the total stock of wealth as it is to individual items. The cost of a growing macroeconomy is represented in Panel 3a by way of an uncancelled cost (UC) curve. It represents the natural capital services lost in the process of transforming natural capital and the low entropy it provides into human-made capital.
The shape of the UC curve is attributable to the law of increasing marginal costs. Why does this law apply to a macroeconomic system? First, it is customary to extract the more readily available and higher quality resources first and be left with the more complicated task of having to extract lower quality resources later. Second, the cost of the undesirable ecological feedbacks associated with each incremental disruption of natural capital increases as the macroeconomy expands relative to a finite natural environment. Note that the UC curve is vertical at a physical economic scale of $S_S$. This is because $S_S$ denotes the maximum sustainable scale – what is, for given levels of human know-how, the largest macroeconomic scale that a nation can physically sustain while still adhering to the four sustainability precepts (see Appendix and [15] for a formal explanation as to why there are biophysical limits on the growth of physical output and, therefore, of real GDP).

Since economic welfare is the difference between the benefits and costs of the socio-economic process, the vertical distance between the UB and UC curves represents the sustainable economic welfare applicable to various macroeconomic scales. Sustainable economic welfare is also illustrated by way of the SEW curve in Panel 3b. In this particular case, a nation’s sustainable economic welfare is maximised by operating at the macroeconomic scale of $S^*$ (i.e., where sustainable economic welfare equals SEW*). For this reason, $S^*$ constitutes the optimal macroeconomic scale although, in a coevolutionary world characterised by disequilibria, such a point would not precisely exist nor be precisely attained. Importantly, when technological progress is assumed to be fixed – that is, when the UB and UC curves are stationary – growth is only desirable in the early stages of a nation’s developmental process. Continued physical expansion of the economic subsystem beyond the optimal scale is antithetic to the sustainable development goal because it eventually leads to a decline in sustainable economic welfare.

3.6 Technological progress and sustainable economic welfare

The role played by technological progress cannot, of course, be ignored. Technological progress can increase the net psychic income gained and decrease the natural capital services sacrificed when maintaining a given macroeconomic scale. This is because technological progress can beneficially shift the UB curve upwards and the UC curve downwards and to the right. It can also bring about a larger optimal macroeconomic scale. To explain how, the two elemental categories of net psychic income and lost natural capital services can be arranged to arrive at a measure of ecological economic efficiency (EEE). Consider the following EEE ratio [7,p.84]:

$$
\text{EEE} = \frac{\text{net psychic income}}{\text{lost natural capital services}}
$$

(1)

For a given physical scale of the economy, an increase in the EEE ratio indicates an improvement in the efficiency with which natural capital is transformed into human-made capital. A multitude of factors can be shown to contribute to an increase in the EEE ratio. To demonstrate how, the EEE ratio is decomposed to reveal four eco-efficiency ratios. The EEE ratio thus becomes the following identity:
Starting from Ratio 1 and progressing through Ratio 4, each eco-efficiency ratio cancels the ensuing ratio out. This leaves the basic EEE ratio on the left-hand side. The order in which the four eco-efficiency ratios are presented is in keeping with the conclusions drawn from the linear throughput representation of the socio-economic process – i.e., net psychic income is enjoyed as a consequence of human-made capital (Ratio 1); human-made capital requires, the continued throughput of matter-energy (Ratio 2); the throughput of matter-energy is made possible thanks to the three instrumental services provided by natural capital (Ratio 3); and, in exploiting natural capital, the three instrumental services provided by natural capital are, to some degree, sacrificed (Ratio 4). Each component ratio represents a different form of efficiency and will now, along with its implications, be individually explained and discussed.

Ratio 1 is a measure of the service efficiency of human-made capital. It increases whenever a given physical magnitude of human-made capital yields a higher level of net psychic income. An increase in Ratio 1 causes the UB curve to shift upwards and can be achieved by improving the technical design of newly produced goods and by improving the manner in which human beings organise themselves in the course of producing and maintaining the stock of human-made capital (thereby reducing such things as the disutility of labour and the cost of commuting and unemployment). A beneficial shift in the UB curve can also be achieved by distributing the stock of human-made capital more equitably. Often overlooked, the redistribution of income from the low marginal service or psychic income uses of the rich to the higher marginal service uses of the poor can lead to an overall increase in the net psychic income enjoyed by society as a whole [63]. There is, however, a limit on the capacity for redistribution to increase Ratio 1 because an excessive approach to redistribution adversely dilutes the incentive structure built into a market-based system.

Figure 4 illustrates what happens to sustainable economic welfare when the UB curve shifts upwards. Because an increase in Ratio 1 augments the net psychic income yielded by a given amount of human-made capital, the UB curve shifts up to UB. The UC curve does not move since the uncancelled cost of creating and maintaining a given stock of human-made capital remains unchanged. Moreover, the maximum sustainable scale remains at Ss. However, sustainable economic welfare is no longer maximised at the prevailing macroeconomic scale of Ss. It is now desirable to expand the physical scale of the macroeconomy to S*, where sustainable economic welfare increases to SEW*.
Changes in Ratios 2, 3, and 4 cause the UC curve to shift. Ratio 2 is a measure of the *maintenance efficiency* of human-made capital. It increases whenever a given physical magnitude of human-made capital can be maintained by a lessened rate of throughput. This can be achieved by developing new technologies that reduce the requirement for resource input either through: (a) more efficient use of resources in production; (b) increased rates of product recycling; (c) greater product durability, or (d) improved operational efficiency. An increase in Ratio 2 causes the UC to shift downwards and to the right for the following reasons. First, it enables any given macroeconomic scale to be sustained by a reduced rate of resource throughput. Second, a lower rate of throughput means less natural capital requires exploitation that, in turn, means fewer lost natural capital services.

Ratio 3 is a measure of the *growth efficiency* or productivity of natural capital. This form of efficiency is increased whenever a given amount of natural capital is able to sustainably yield a greater quantity of low entropy resources and assimilate more of the high entropy waste generated by economic activity. Better management of natural resource systems and the preservation of critical ecosystems can lead to a more productive stock of natural capital. How does an increase in Ratio 3 lead to a downward and rightward shift of the UC curve? An increase in the productivity of natural capital reduces the quantity of natural capital that must be exploited to sustain the macroeconomy at a given physical scale. This allows a macroeconomy of a given physical scale to be sustained at the expense of fewer natural capital services.

Ratio 4 is a measure of the *exploitative efficiency* of natural capital. If Ratio 4 increases, fewer natural capital services are lost in exploiting a given quantity of natural capital. This, again, allows a macroeconomy of a given physical scale to be sustained at the expense of fewer natural capital services and, thus, to a downward and rightward shift of the UC curve. Increases in Ratio 4 can be obtained through the development and
execution of more ecologically sensitive extractive techniques, such as the use of underground rather than open-cut or strip mining practices.

Figure 5 illustrates what happens to sustainable economic welfare when there is a shift of the UC curve. Because an increase in Ratios 2, 3, and 4 reduces the uncancelled cost of producing and maintaining a given macroeconomic scale, the UC curve shifts down and out to UC'. However, the UB curve remains stationary since an increase in any one of these efficiency ratios does not augment the net psychic income generated by a given stock of human-made capital. Unlike a shift in the UB curve, a shift in the UC curve results in an increase in the maximum sustainable macroeconomic scale (S_S to S_S').

The logic behind this is quite simple. If there are now fewer natural capital services sacrificed in maintaining what was previously the maximum sustainable macroeconomic scale, a larger macroeconomic subsystem can now be ecologically sustained from the same loss of natural capital services. Prior to increases in the maintenance efficiency of human-made capital or the growth and exploitative efficiencies of natural capital, sustainable economic welfare is maximised by operating at a macroeconomic scale of S_S. Upon an increase in Ratios 2, 3, and/or 4, it is desirable to expand the physical scale of the macroeconomy to S_S'.

**Figure 5** A change in sustainable economic welfare brought about by increases in the maintenance efficiency of human-made capital (Ratio 2), and the growth and exploitative efficiencies of natural capital (Ratios 3 and 4)

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3.7 *Efficiency-increasing versus throughput-increasing technological progress*

Not all technological progress results in a shift in either the UB or UC curves. Some forms of technological progress simply allow more natural capital to be exploited which, in turn, permits the matter-energy passing through the macroeconomic subsystem to be increased. Technological progress of this kind can be called *throughput-increasing* technological progress. Examples of throughput-increasing technological progress include the development of a novel resource exploration method that leads to the discovery of a new oil deposit, a new resource extraction technique that allows a previously inaccessible mineral deposit to be exploited, and the development of a new
use for a previously unwanted resource. The application of throughput-increasing technological progress brings to bear, at least in the short-run, a larger physical scale of a nation’s macroeconomy. Unlike efficiency-increasing technological progress (technological progress that increases any one of the four efficiency ratios at the prevailing macroeconomic scale), the throughput-increasing variety is not always desirable. This is because the application of throughput-increasing technology merely results in a movement along the UB and UC curves which, as Figure 3 shows, is only desirable in the early phase of a nation’s developmental process. Eventually, its continued application leads to a decline in sustainable economic welfare and a macroeconomic scale in excess of the optimum.

3.8 Limits to technological progress and beneficial shifts of the UB and UC curves

There is considerable debate surrounding how much and for how long human beings can rely on efficiency-increasing technological progress to increase the four efficiency ratios and shift the UB and UC curves. Due to the thermodynamic and biophysical constraints outlined in Section 3.3, there are many observers who correctly point out that the ability to increase Ratios 2, 3, and 4 is ultimately limited. Ratio 2, for instance, is limited by the first and second laws of thermodynamics (e.g., as mentioned earlier, nothing is eternally durable, 100% recycling is impossible, and 100% production efficiency is unobtainable). Ratio 3 is limited by the inability to forever increase the productivity of a given amount of natural capital, while Ratio 4 is limited by the fact that at least some of the environment’s instrumental functions are lost as a consequence of its exploitation. In view of these limitations, it is clear that an upper limit exists on the maximum sustainable scale of macroeconomic systems. In other words, there is an inevitable biophysical limit to growth. It is because of this that ecological economists believe the transition to a steady-state economy is a long-run necessity [7–8,37,46–47].

Of course, until such time as the limits to any increases in Ratios 2–4 are reached, growth of the macroeconomy is permissible. However, evidence suggests that any efficiency gains are likely to be both modest and sporadic [14]. As a consequence, the permissible growth rate of industrialised economies in the foreseeable future will be very small. It is this that has prompted ecological economists to call for the immediate transition to a low-growth economy.

For some countries, however, a higher rate of growth is permissible and a necessary course of action. For others, there may be the need for an immediate macroeconomic reduction. A higher growth rate is possible for a small number of nations whose current rate of resource throughput is substantially less than the maximum sustainable rate [64]. Whether it is desirable for these countries to rapidly expand the physical scale of their macroeconomies depends on whether they are approaching or have reached the optimal macroeconomic scale. Should they have already done so, growth fuelled by an increase in the rate of throughput will simply push the macroeconomy beyond its optimal scale and lower sustainable economic welfare. Growth, while permissible, would in this instance be undesirable. As for less-developed countries that are able to sustain higher rates of growth in the short-term, their macroeconomies will no doubt be well short of the optimum. Rapid growth in the short-term will be both permissible and desirable.

We then move to the category of nations whom, at present, are enjoying a rate resource throughput far in excess of the maximum sustainable rate. To operate
sustainably, such countries will be forced to reduce the current rate of throughput. Should the extent of any throughput reductions outweigh probable future efficiency gains (increases in Ratios 2–4), these countries face the prospect of a macroeconomic reduction. Since this is likely to cause considerable hardship, it may be preferable to peg the rate of deceleration in resource throughput to that of the increasing rate of efficiency-increasing technological progress. By doing this, a steady-state economy is initially experienced. Then, with the rate of throughput finally reduced to the maximum sustainable rate, a period of low growth can be enjoyed until the limits to efficiency-increasing technological progress are ultimately reached. Unfortunately, a calibrated transitional process of this nature would be of little comfort to many Third World countries urgently requiring high rates of growth to both alleviate poverty and accumulate sufficient quantities of human-made capital to facilitate their future development in an inevitable steady-state environment. These countries will clearly need the assistance of richer Northern countries in the form of foreign aid and the transfer of natural resources and technology.

While there are limits to increases in Ratios 2–4, what about Ratio 1? This is a more complex issue because service, as a psychic rather than physical magnitude, can theoretically grow forever. Having said this, there is a probable limit on humankind’s capacity to experience service. Thus, regardless of how well physical goods are designed, a given quantity of human-made capital is unlikely to yield increasing levels of net psychic income.

For argument sake, let’s assume that Ratio 1 can be augmented indefinitely or that a limit to its increase exists somewhere well beyond the immediate future. In view of the fast approaching limits to Ratios 2–4, all but impoverished nations are best advised to focus on qualitative improvement (development), not quantitative expansion (growth), since as Figure 4 showed, the former can clearly be achieved without the need for the latter. More importantly, and contrary to popular opinion, the long-run necessity of a steady-state economy need in no way impede a nation’s desire to achieve the sustainable development goal.

4 Empirical evidence on the sustainable development performance of nations

Having argued that the maximum sustainable scale need not be desirable and that a nation should operate somewhere approaching the optimal scale, how well are countries performing in terms of meeting the sustainable development goal? Furthermore, is there any evidence that countries are fast approaching or have reached the economic and biophysical limits to growth? An assessment of this kind necessitates a set of performance indicators capable of answering the following questions:

- Is the physical scale of a nation’s macroeconomy growing?
- Is the sustainable economic welfare being generated by the socio-economic process increasing and, should it be falling, does this mean a nation’s macroeconomy has exceeded its optimal macroeconomic scale?
- In view of the complementarity of natural capital and human-made capital, what is happening to a nation’s stock of natural capital? If it is declining then: (a) what is the nation’s ‘true’ income given that income ought to reflect the maximum amount a nation can consume without reducing the stock of income-generating capital? And (b) has the nation’s macroeconomy exceeded its maximum sustainable scale?
Is a nation improving the efficiency with which it transforms natural capital and the low entropy it provides into human-made capital? In other words, are the four efficiency ratios and the EEE ratio increasing or decreasing?

To find the answers to these questions, it is necessary to compile accounts for each of the five elemental categories previously discussed in relation to the linear throughput model. While such a task has only been undertaken for Australia, measures of sustainable economic welfare have been calculated for a number of other countries. These measures have been variously labelled the Index of Sustainable Economic Welfare (ISEW) and the Genuine Progress Indicator (GPI). Figure 6 compares the real GDP and the ISEW of six industrialised countries. It shows that, despite real GDP continuing to rise in each case, sustainable economic welfare has, at some point, begun to decline. Thus, according to Figure 6, the macroeconomies of all six nations appear to have surpassed their optimal scale. Similar results have been obtained for many countries not included in Figure 6 [65–66].

**Figure 6**  

Source: [67]
In the case of Australia, four of the five recommended accounts have been compiled for the period 1966–67 to 1994–95 [8,68]. The following judgements can be made about Australia’s sustainable development performance:

- The Australian macroeconomy grew in all but one financial year over the study period.
- After an initial rise in per capita sustainable economic welfare between 1966–67 and 1973–74, it fell in almost every year between 1973–74 and 1994–95 (see Figure 7). Overall, per capita sustainable economic welfare was lower in 1994–95 than in 1973–74. This suggests that the Australian macroeconomy has also exceeded its optimal scale.

**Figure 7** Per capita sustainable economic welfare and per capita real GDP for Australia, 1966–67 to 1994–95

- The EEE ratio for Australia peaked in the early 1970s and declined in most years thereafter. Not unlike per capita sustainable economic welfare, the EEE ratio was lower in 1994–95 than it was in 1973–74. Australia’s overall transformation of natural capital into human-made capital over the study period was very inefficient.
- While the service efficiency of Australia’s human-made capital (Ratio 1) increased over the period 1966–67 to 1972–73, it remained relatively steady up to 1981–82 and effectively declined thereafter. By 1994–95, the service efficiency ratio was less than what it was in 1966–67 [8]. Why was this the case? Quite simply, the increase in the quantity and quality of human-made capital was offset by sharp increases in such psychic disbenefits as unemployment, commuting costs, noise pollution, crime, and a widening gap between the rich and poor.

*Source:* [8]
Australia's maintenance efficiency ratio – a ratio of the human-made capital maintained per petajoule of energy consumed (ratio 2) – rose from 1966–67 to a peak in 1970–71 [8]. It then declined very gradually to a low in 1989–90. By 1993–94, Australia's maintenance efficiency ratio had marginally recovered, however, it was still lower than the initial 1966–67 figure. This evidence plus the large overall increase in total energy consumption between 1966–67 to 1993–94 indicates that most technological innovation in Australia over the last 30 years has been of the throughput-increasing rather than efficiency-increasing variety.

Australia's natural capital declined between 1966–67 and 1994–95 [8]. While Australia's stocks of renewable natural capital increased slightly, its augmentation was insufficient to offset the diminution of non-renewable resource stocks. This suggests that little if any of the proceeds earned from the sale of non-renewable resource depletion were set aside to cultivate renewable resource substitutes. Australia has therefore been liquidating its natural capital to finance much of its consumption. Furthermore, Australia has been wrongly classifying it as income. A better measure of Australia's national income would, at the very minimum, require the user cost of non-renewable resource depletion to be deducted from its real GDP. As for the productivity of Australia's natural capital (Ratio 3), the ratio of resource throughput to natural capital increased between 1966–67 and 1994–95 [8]. This implies that Australia's natural capital is more productive. Such a suggestion is misleading for a number of reasons. First, much of Australia's energy input came from non-renewable resources. Second, the actual stock of non-renewable natural capital steadily declined. Thus, the increase in the ratio was largely a consequence of Australia's rapid depletion of its non-renewable resource stocks. This, of course, cannot be sustained [69].

Australia's exploitative efficiency ratio (Ratio 4) declined in every year between 1966–67 and 1994–95 [8]. This result indicates that the opportunity cost of exploiting natural capital in terms of lost natural capital services increased continuously over the study period. The decline in the exploitative efficiency ratio was considerable. While the result probably overstates the true increase in the opportunity cost, it does reflect Australia's poor record in preserving remnant vegetation, its heavy reliance on non-renewable resources, and its lack of reinvestment into renewable resource substitutes.

Given the above evidence, Australia does not appear to be moving toward the sustainable development goal. The same can be said of the six industrialised nations featured in Figure 6, although the evidence with respect to these countries is far less conclusive. Despite some concerns about the accuracy of sustainable economic welfare estimates [70], the industrialised world should seriously contemplate the abandonment of its high-growth predilection, begin the transition towards a steady-state economy, and embrace the more desirable notions of sufficiency, equity, and natural capital maintenance.
5 Can't countries simply shift away from goods to services?

There is a widespread belief that the problem of ecological and biophysical limits to growth can be averted by: (a) shifting the emphasis of socio-economic activity away from the production of goods and towards the provision of services, and (b) by engaging in a higher concentration of 'greener' activities (e.g., tree planting and weed control). A couple of things need to be said about this so-called 'dematerialisation' escape hatch. First, as much as goods and services are two distinct magnitudes, they are in no way independent magnitudes [71]. As Figure 2 illustrated, goods (human-made capital) are the physical objects that yield the service (psychic income). Service is the benefit that flows from goods as they are either consumed or worn out through use. Clearly, all services have a physical dimension as indicated by the fact that accounting services, for example, are not provided by an imaginary accountant in an imaginary office working on an imaginary computer. What's more, green activities, despite helping to increase Ratios 2-4, also involve the use and wearing out of human-made capital. It is on this basis that Costanza [72] and Ayres and Ayres [73] have shown there is very little difference in resource use intensity across industries. The disparity virtually disappears if one attributes to the so-called 'service industries' the resources required to produce the human-made capital necessary for such industries to function. There is, therefore, no reason to believe that a shift in economic activity towards what are deemed to be 'service industries' or 'green activities' will continue to keep biophysical limits to growth at arms length.

6 Ecological sustainability, the steady-state economy, and full employment

Let us recapitulate with what has so far been posited. First, ecological sustainability or, more specifically, sustainable development requires: (a) achievement of the full employment objective since, without it, it is inconceivable that the higher- and lower-order needs of each and every citizen could be adequately satisfied; and (b) an abandonment of the growth objective and, thus, a transition towards a steady-state economy. Yet, and as was pointed out at the beginning of the paper, many would argue that the full employment objective is not obtainable without an annual growth rate of the macroeconomy in the vicinity of at least 2% to 3%. On the surface at least, two of the critical means to achieving sustainable development appear to be utterly incompatible with each other. Why is this so? More importantly, is it possible for policy and/or institutional changes to bring about their congruence?

An answer to the first question can be found by perusing any undergraduate textbook or popular macroeconomics journal. With little difficulty, references to the terms 'full employment level of output' and 'potential output' are common. Both terms mean the same thing and can be considered the level at which national output or real GDP would be if all resources were fully employed [74]. Although mainstream economists do not specify what is meant by fully employed resources, they essentially imply the full utilisation of the incoming resource flow (the material cause of production) plus the full employment of the labour and producer goods component of the stock of human-made capital (the efficient or value-adding cause of production). Interestingly, mainstream economists never spell out what is meant by a fully employed unit of labour. Is it a person engaged for 30, 35, 40, or 50 hours per week in a paid form of employment?
Perhaps more, perhaps less? This is an important question because someone working 35 hours in a week may be deemed to be underemployed if the answer is 40 hours, but fully employed if it is 35 hours! Unfortunately, this issue has yet to be adequately addressed.

The above aside, it is a fact-of-life that unemployment is in some way related to real GDP. For example, if the current level of real GDP is insufficient to generate full employment (i.e., the prevailing level of real GDP is less than potential real GDP), full employment can only be obtained if, ceteris paribus, real GDP is increased sufficiently to bridge what is commonly referred to as the ‘unemployment gap’. However, there are many factors other than real GDP that affect unemployment. Thus, when one is referring to potential real GDP, they are implying a level of real GDP that ensures full employment under a particular set of circumstances. This fact is not altogether ignored by mainstream economists who frequently state that any particular full employment level of real GDP is specific to a given quantity of human-made capital embodying a particular level of technology. What mainstream economists tend to overlook is the fact that it is also policy- and institution-specific. It goes without saying that mainstream economists routinely ignore the limits that the rate of resource throughput places on the full employment level of output [75].

Once it is recognised that the full employment level of real GDP is as policy- and institution-specific as the prevailing level of real GDP, it becomes abundantly clear that closing the unemployment gap no longer requires efforts directed almost exclusively towards increasing real GDP. Thoughts immediately arise to the possibilities of bringing the full employment level of output back towards the prevailing level of real GDP or, if the optimal macroeconomic scale has been exceeded, something considerably lower again (e.g., Australia and the countries featured in Figure 6). It is, therefore, the failure of mainstream economists to fully acknowledge the policy- and institution-specific nature of the full employment level of output that goes a long way towards explaining the perceived incompatibility of the steady-state economy and the full employment objective. They simply haven’t given much if any thought to lowering the full employment level of output which, naturally, leads to one very false conclusion – growth in real GDP is necessary to obtain full employment.

Of course, understanding why the perceived conflict between the steady-state economy and the full employment objective exists does not, by itself, indicate how the full employment level of output can be reduced to the prevailing level of real GDP – something that is necessary to answer the second of the above questions. As I pointed out in the introduction, this issue will not be addressed in this paper. It will hopefully be addressed in due course by future contributors to IJEWE.

7 Ecological sustainability and the restructuring of the socio-economic process

The consequences of moving towards ecological sustainability are not confined to the potential impact on unemployment. Because of the inevitable restructuring of the socio-economic process, a host of ancillary issues also emerge. For example, in order to make the transition to a steady-state economy and achieve sustainable development, it will be necessary for most nations to undertake the following:
• Reduce the rate of resource throughput to satisfy the four sustainability precepts earlier outlined.

• Utilise the incoming resource flow far more efficiently, that is:
  a Add more value to the matter-energy used in production to increase Ratio 1 and shift the UB curve upwards.
  b Reduce the matter-energy wasted in the transformation of low entropy resources into physical goods to increase Ratio 2 and shift the UC curve downwards.

• Increase the durability, recyclability, and operational efficiency of human-made capital to increase Ratio 2 and shift the UC curve downwards.

• Discover better ways to organise production activities to: (a) increase productivity and augment Ratios 1 and 2; (b) reduce unemployment; and (c) render work more rewarding and purposeful.

• Increase the levels of investment in natural capital to satisfy sustainability precept No.2 and augment the productivity of existing natural capital to increase Ratio 3 and shift the UC curve downwards.

• Develop more sensitive exploitative resource-extraction techniques to increase Ratio 4 and shift the UC curve downwards.

• Increase workplace flexibility to both facilitate job-sharing and extend the opportunity for people to pursue high-order needs satisfying activities (i.e., increase their income-leisure options).

From this less-than-exhaustive list, it can be seen that a transition to a steady-state economy will result in the gradual elimination of resource-intensive industries. This, in turn, will have an enormous impact on the overall structure of industries within the macroeconomy as well as the types of jobs available and the skills required to perform them proficiently. The need for efficiency-increasing rather than throughput-increasing technological progress will also increase the future demand for, and development of, 'green' technologies. Competitive advantage, at least within the domestic macroeconomy, will become increasingly dependent on a firm’s capacity to be resource-efficient and to produce durable, recyclable, and high value-added goods [76]. Given, also, the importance of greater workplace flexibility, the corporate management strategies of tomorrow are unlikely to resemble much of what they are today. Exactly what these management strategies should entail and in what form the firms, workplaces, jobs, and technologies of the future will take will hopefully become more transparent as they are detailed, debated, and discussed by future contributors to IJEWE. As the Editor of IJEWE, I eagerly look forward to the process and the journey that lies ahead.

References and Notes


10 A good example is [5].


17 To understand what is meant by low and high entropy matter-energy, the importance of the first and second laws of thermodynamics must be revealed. The first law of thermodynamics is the law of conservation of energy and matter. It declares that energy and matter can never be created or destroyed. The second law is the Entropy Law. It declares that whenever energy is used in physical transformation processes, the amount of usable or 'available' energy always declines. While the first law ensures the maintenance of a given quantity of energy and matter, the Entropy Law determines which is usable. This is critical since, from a physical viewpoint, it is not the total quantity of matter-energy that is of primary concern, but the amount that exists in a readily available form. The best way to illustrate the relevance of these two laws is to provide a simple example. Consider a piece of coal. When it is burned, the matter-energy embodied within the coal is transformed into heat and ash. While the first law ensures the total amount of matter-energy in the heat and ashes equals that previously embodied in the piece of coal, the second law ensures the usable quantity of matter-energy does not. In other words, the dispersed heat and ashes can no longer be used in a way similar to the original piece of coal. To make matters worse, any attempt to reconcentrate the dispersed matter-energy, which requires the input of additional energy, results in more usable energy being expended than that reconcentrated. Hence, all physical transformation processes involve an irrevocable loss of available energy or what is sometimes referred to as a 'net entropy deficit'. This enables one to understand the use of the term low entropy and to distinguish it from high entropy. Low entropy refers to a highly ordered physical structure embodying energy and matter in a readily available form, such as a piece of coal. Conversely, high entropy refers to a highly disordered and degraded physical structure embodying energy and matter that is, by itself, in an unusable or unavailable from, such as heat and ash. By
definition, the matter-energy used in socio-economic processes can be considered low entropy resources whereas unusable by-products can be considered high entropy wastes.


21 Production essentially involves the rearrangement of matter-energy while consumption involves its disarrangement.


25 Dissipative structures are dynamic systems that draw in low entropy matter-energy from their parent system. In doing so, they exploit their capacity to change their physical form, to grow, and, potentially at least, to develop. Provided a dissipative structure is fulfilling its thermodynamic potential, it will tend toward a state of increasing order. But it can do so only at the expense of a much greater degree of increasing disorder of the parent system upon which it depends.

26 In the natural world, information exists as genetic information coded in the DNA molecule. In the anthropocentric world, information exists as knowledge encoded in various institutions and organisations.


29 Many definitions of sustainable development have appeared since the term was first made popular by the World Commission for Environment and Development (WCED) in 1987. For the remainder of this paper, the following will be considered sustainable development: “A nation is achieving sustainable development if it undergoes a pattern of development that improves the total quality of life of every citizen, both now and into the future, without the rate of resource use exceeding the regenerative and waste assimilative capacities of the natural environment. It is also a nation that ensures the survival of the biosphere and all its evolving processes while also recognising, to some extent, the intrinsic value of sentient non-human beings”. (see Lawn, P. (forthcoming) ‘The policy-guiding value of sustainable development indicators: an introductory essay’, *International Journal of Environment and Sustainable Development*.)


32 A holon is a term made popular by Arthur Koestler, see [30], p.303.


There are two things worthy of note here. First, uncanceled costs are often undervalued because many natural capital values escape market valuation. Second, uncanceled costs should reflect the highest of two classes of opportunity costs – the first being the cost of transforming an extracted unit of low entropy into physical goods in terms of alternative goods forgone (e.g., if an extracted unit of low entropy resource X is used to produce good A, it cannot be used to produce goods B, C, or D, etc.); the second in terms of the reduced capacity of natural capital to provide a future flow of low entropy resources that is required to produce physical goods in the future (e.g., if the extraction of a unit of low entropy resource X reduces the capacity of natural capital to provide a continuous flow of a unit of X over time, a unit of X will be unavailable to produce goods of any type in the future).


The technical efficiency of production (E) can be written as the ratio of energy-matter embodied in physical goods (Q) to the energy-matter embodied in the low entropy resources used to produce them (R) – i.e., $E = Q/R$. While the value of E can be reduced by technological progress, E must be something less than a value of one.


It is the self-organisational capacity of the Earth to maintain the conditions fit for life that has led Lovelock to develop his ‘Gaian hypothesis’ – an hypothesis based on the notion that the Earth, or Gaia, behaves like an immense quasi-organism, see Lovelock, J. (1988) Ages of Gaia: A Biography of our Living Planet, New York: Norton & Company.


It has been estimated that for every one plant species lost, approximately fifteen animal species will follow, see Norton, B. (1986) ‘On the inherent danger of undervaluing species’, in B. Norton (Ed.) The Preservation of Species, Princeton: Princeton University Press, p.117.


Of course, the mere preservation or ‘locking up’ of large and small ecosystems will not, by itself, ensure biodiversity maintenance. Given the interdependent relationships between systems of all types, individual ecosystems are not entirely self-supporting [48]. Their continued existence and the well-being of the biodiversity they contain is conditional upon the exchanges of both matter-energy with and between neighbouring and far-distant systems. This applies to systems of all kinds, whether they be relatively pristine, moderately disturbed, or
totally refined. Above all else, maintaining biodiversity requires the exploitation of natural capital to be conducted on the principle of respecting the holistic integrity of geographical land and water resource units.


57 It should be pointed out that Max-Neef, while agreeing with Malsow’s notion that all human needs are inter-related, does not believe in the existence of a needs hierarchy. Except for basic subsistence needs, Max-Neef believes in the presence of a horizontal spectrum rather than vertical hierarchy of human needs, see Max-Neef, M. (1991) Human Scale Development, New York: Apex Press.


61 Evidence provided by the Australian Bureau of Statistics shows an alarmingly high rate of mental disorders amongst unemployed people relative to the remaining population. See ABS (1997) Mental Health and Well-being: Profile of Adults, Canberra: AGPS, Catalogue No. 4326.0.


64 One method of determining if a nation’s current rate of resource throughput is more or less than the maximum sustainable rate is to compare its biocapacity with its ecological footprint. A country’s ecological footprint is the equivalent area of land required to generate the renewable resources capable of sustaining socio-economic activity at the current level. Nations with a biocapacity well in excess of their ecological footprint include Iceland, New Zealand, Australia, Peru, Brazil, Finland, Canada, and Colombia. A small number of nations have a negligible ecological surplus, while all others suffer from small to very large ecological deficits. For more on the ecological footprint and a summary of biocapacity-footprint comparisons for different countries see Wackernagel, M., Onisto, L., Bello, P., Callejas Linares, A., Susana Lopez Falfan, S., Mendez Garcia, J., Suarez Guerrero, A. I. and Suarez Guerrero, Ma.G. (1999) ‘National natural capital accounting with the ecological footprint concept’, Ecological Economics, Vol. 29, No. 3, pp.375–390.


68 Because the compilation of a throughput account was a more difficult proposition, the annual consumption of energy was used as a proxy measure of resource throughput. Due to a lack of space and the extensive and unique nature of the study, a full explanation of the individual accounts, the items they comprise, data sources, and the methods of calculation can be found in [8].
A better indicator of the productivity of natural capital is a ratio of renewable energy consumption to the total renewable resource stock. This ratio has increased only marginally over the study period [8].


**Appendix**

Why does a limit on the sustainable quantity of resource input and waste output impose a constraint on the growth of real output and, therefore, real GDP? Before answering this question, it is important to make a distinction between the maximum potential real output level if an ecologically sustainable rather than an unsustainable pathway is chosen. The latter option results in a greater output level but, of course, it is only feasible in the short run. While the output level associated with the former option is less, it can at least be sustained indefinitely.

Let us now contemplate aggregate production possibilities in light of an aggregate production function that obeys the first and second laws of thermodynamics. Consider the so-called Bergstrom production function (BPF) below [77]:

\[ Q(\beta, K, R) = \left[ 1 - \exp(-\beta K/R) \right] R \]  \hspace{1cm} (A1)

where:

- \( Q \) = real output measured in terms of the matter-energy (available work) embodied in the output produced
- \( K \) = human-made capital and includes labour as well as producer goods such as plant, machinery, and equipment.
- \( R \) = low entropy resource input measured in terms of the matter-energy (available work) embodied in the resources used to produce \( Q \)
- \( \beta \) = technology parameter indicating the state of production technology.
Equation (A1) satisfies the three necessary properties of a production function as dictated by the first and second laws of thermodynamics. They are: (a) the technical efficiency of the production process \( E = Q / R \) must be less than a value of one; (b) the technical efficiency of the production process must rise asymptotically to the thermodynamic limit of \( E = 1 \) as the ratio of human-made capital to resource input \( (\beta K / R) \) increases; and (c) low entropy resources must be treated as the only true input of the production process. Human-made capital, on the other hand, must be treated as a low entropy resource transforming production agent that, itself, needs low entropy resource input to be produced and maintained. The third property is satisfied by denoting real output as a multiple of \( R \).

Figure A is an isoquant map generated by a BPF. Included in Figure A are four isoquants \( (I_1 \text{ through to } I_4) \) representing the different resource/human-made capital combinations required to produce four different output levels \( (Q_1 \text{ through to } Q_4) \). For each isoquant and output level there is a unique resource asymptote representing the minimum low entropy resource requirement \( (R_{\text{min1}} \text{ through to } R_{\text{min4}}) \). The resource asymptote is determined by the quantity of resource input where \( E = 1 \). Unlike standard production functions, an isoquant map generated by a BPF precludes all thermodynamically infeasible resource/human-made capital combinations (i.e., combinations that lie to the left of the relevant resource asymptote).

Figure A  
In isoquant map generated by a Bergstrom production function
Imagine that $R_{\text{min}}$ is the maximum sustainable input quantity of low entropy resources (i.e., $R > R_{\text{min}}$) exceeds the regenerative capacity of the natural environment). Assume, also, that $R_{\text{min}} = 1,000$ units of embodied matter-energy. Figure B shows that the quantity of matter-energy embodied in physical goods produced must be less than 1,000 units. Only an augmentation of the combined technology/human-made capital factor can increase the matter-energy embodied in physical goods towards the thermodynamic limit of 1,000 units. Clearly, there is a limit on the maximum quantity of physical goods that can be produced from a sustainable throughput of matter-energy. One might argue that more goods can be produced by reducing the matter-energy embodied in each unit of output. Nonetheless, each good would have to be smaller in size and there is surely a limit on the capacity for size reduction (i.e., there is a minimum viable size for such goods as automobiles, houses, clothes, etc.).

**Figure B** Aggregate production possibilities from a limited input of resources

\[
\beta \cdot \frac{K}{R} \quad E = 1
\]

\[
R_{\text{min}} = 1,000 \quad I_1 (Q_1 < 1,000)
\]

It is often argued that human-made capital and the technology embodied within it can serve as an adequate substitute for declining natural capital. This argument is already called into question given, as previously mentioned, human-made capital requires the low entropy that natural capital provides in order for the former to exist. One way of determining if one form of capital can substitute for another is to calculate the elasticity of substitution between the two factors. A value of one for the elasticity of substitution implies that increases in human-made capital can offset the decline in natural capital sufficiently to sustain real output at the current level. Should the elasticity of substitution
be greater than one, increases in human-made capital can, even in the presence of declining natural capital, lead to a higher quantity of future output. When the elasticity of substitution is less than one, no amount of additional human-made capital can sufficiently offset the decline in natural capital to sustain real output in the long-run. In this instance, a continuing decline in natural capital means less real output.

The aim now is to derive the elasticity of substitution (\(\sigma\)) from the BPF in order to gain greater insight into the range of feasible substitution possibilities. If we let \(Z = \beta.K\) and substitute it into (A1) one obtains:

\[
Q(Z, R) = \left[1 - \exp\left(-\frac{Z}{R}\right)\right].R
\]  

(A2)

The elasticity of substitution is given by the following:

\[
\sigma = \frac{\frac{d(Z/R)}{d(MRTS_{RZ})}}{MRTS_{RZ}} \times \frac{MRTS_{RZ}}{Z/R}
\]  

(A3)

where \(MRTS_{RZ}\) denotes the marginal rate of technical substitution between low entropy resource input and the human-made capital/technology factor, and is:

\[
MRTS_{RZ} = \frac{Q_R}{Q_Z}
\]  

(A4)

where:

- \(Q_R\) = the marginal product of low entropy resource input
- \(Q_Z\) = the marginal product of the human-made capital/technology factor.

To continue, it is necessary to derive \(Q_R\) and \(Q_Z\). They are respectively:

\[
Q_R = \frac{\partial Q}{\partial R}
= 1 - (1 + Z/R).e^{-Z/R}
\]  

(A5)

and

\[
Q_Z = \frac{\partial Q}{\partial Z}
= e^{-Z/R}
\]  

(A6)

By substituting (A6) and (A5) into (A4) one obtains:

\[
MRTS_{RZ} = \frac{1 - (1 + Z/R).e^{-Z/R}}{e^{-Z/R}}
\]  

(A7)

\[
= e^{Z/R} - 1 - \frac{Z}{R}
\]  

(A8)

If, for simplification, we let \(\mu = Z/R\), then:

\[
MRTS_{RZ} = e^\mu - 1 - \mu
\]  

(A9)

\[
\therefore \frac{d(MRTS_{RZ})}{d(Z/R)} = e^\mu - 1
\]  

(A10)

and
\[
\frac{d(Z/R)}{d(MRTS_{RZ})} = \frac{1}{e^\mu - 1}
\]  

(A11)

Substituting (A9) and (A11) into (A3) yields:

\[
\sigma = \frac{e^\mu - 1 - \mu}{(e^\mu - 1) \mu}
\]

(A12)

where, for \( \mu > \approx 10^{\frac{8}{8}} \), \( \sigma \) is less than one.

Furthermore:

\[
\lim_{\mu \to \infty} \sigma = 0
\]

(A13)

Both (A12) and (A13) convey some important information. Not only is there a binding complementary relationship between natural and human-made capital for all relevant values of \( \mu \), but the degree of complementarity increases as the human-made capital/resource ratio rises (i.e., \( \sigma \to 0 \)). Does this suggest that, in the presence of declining natural capital, technological advances cannot ensure a sustained real output level? Eventually, yes, since an elasticity of substitution of less than one implies the inadequate long-run substitutability of human-made capital for natural capital. In the short-run, however, and until the thermodynamic limit of \( E = 1 \) has effectively been reached, the answer is no. Nevertheless, it is a mistake to believe that the short-run potential for additional human-made capital to sustain real output is an example of substitution of one for the other. It is what I have elsewhere referred to as ‘implicit substitution’ – the illusion of substitutability that is created when improved human know-how embodied in human-made capital reduces the high entropy waste generated during the production process [42]. At no stage does this constitute human-made capital substituting or ‘taking the place of’ natural capital.