Understanding systems and their complex interrelationships: a prerequisite to solving environmental problems

N. Voulvoulis
Centre for Environmental Policy, Imperial College London, London SW7 2AZ, U.K, n.voulvoulis@imperial.ac.uk,

Abstract

One of the most profound causes of environmental problems is the way in which traditional production and consumption processes have been so entirely linear. While in the past such processes were perhaps considered "efficient", when considering the whole life costs of production it is hard to demonstrate a real benefit for these practices. Similarly the introduction of environmental management systems and clean production in industry in recent years, driven by more preventive approaches, mainly seek to minimise waste and increase resource efficiency, thus overlooking opportunities that lie across sectors, or in bridging both ends of the chain.

Methods

This paper reflects on the changes in mindsets required in value chains and business models, with a renewed focus on re-assessing what the real problems are from a systems perspective, in order for symbiotic systems to be utilised successfully. The question is not solely how to reduce waste, but how to create value from it.

Results

The need to understand environmental problems from a more systems-based perspective led to emerging concepts such as "industrial symbiosis", which indicate many areas of cooperation and synergy, resource efficiency (in materials, energy, logistics and human resources) in production and optimization of services and products.

Conclusions

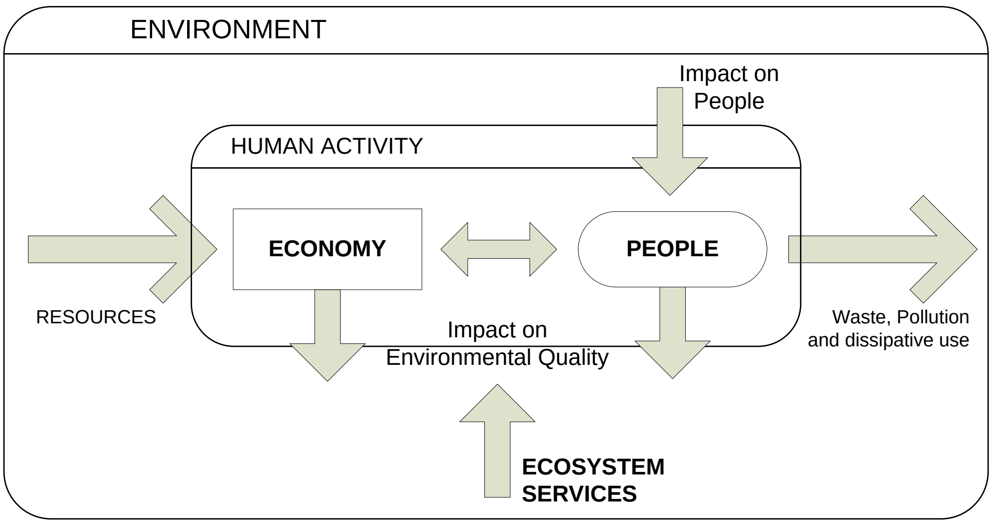
The drive to a society which is more literate and aware of sustainability may in turn drive industrial practices, government policies and individual behaviours that support sustainability and the use of environmental resources in this context. The emergence of this holistic worldview creates the potential for the rapid development of a sustainable societal system.

Keywords: environmental problem; holistic solutions; closing the loop; sustainability; resources management; systems thinking

Introduction

Significant improvements and progress made through science and engineering in the last century, increased efficiency in production and reduced impacts of our activities to the environment mainly due to economic drivers [1]. Such drivers often provided the context for scientific progress, and had a profound influence on both the realization of benefits to the society and the treatment of its negative impacts to the environment as externalities. Traditional economics rely heavily on the production function, a concept basic to the determination of the allocation and growth of economic output, conventionally measured as marketed output, i.e. GDP, in national accounts [2]. The traditional economic approach is almost exclusively neoclassical, depending on the validity of adding up the welfare of households or people such that the aggregate social welfare function is stable and predictable over time. Neoclassical economists claim that their work is value-free [3], purely descriptive [4,5], or even scientific (being peer-reviewed and reproducible) but it is based on an approach which has persistently ignored the conclusions and insights of other disciplines [6].

This decision making context, driven by the desire to determine the allocation and growth of economic output- conventionally measured as GDP in national accounts-, has played a significant role in making production and consumption processes almost entirely linear (Figure 1). While in the past such processes were perhaps considered to be efficient, consideration of the whole life costs of production and consumption puts a new perspective on the real net benefits derived from many of these traditional practices.



Translated into two economic paradigms:

ECOLOGICAL: "*There is no wealth but life*"- nature can provide, and NEO-CLASSICAL: "*Supply and demand*" – the market will provide

Figure 1: Production and consumption impacts to the environment

Environmental management systems and clean production applications in recent years have increased the environmental performance of industrial establishments and sectors and also affected the economic performances and corporate prestige in a positive way. However, such initiatives are often constrained within the borders of firms or sectors and are driven by more preventive approaches, which mainly seek - for each production process - to minimise the generation of waste and increase resource efficiency. This has the drawback of overlooking opportunities that lie across sectors, or that could link both ends of the chain.

This paper therefore reflects on emerging scenarios and calculations that demonstrate that any benefits delivered from resource efficiency alone will not address the demands of ever-growing production and consumption for raw materials and energy. These scenarios, however, dictate the need for managing all environmental resources more sustainably. The paper therefore assesses the need for raw materials to be viewed as an integral part of wider sustainable resource management, in line with the need for re-assessing the potential and necessity for extraction and utilization of natural capital, with a renewed focus on its the role from a systems perspective.

The need for a systems perspective

Sustainability necessitates a more integrated and interdisciplinary approach to resource management that takes into account interrelationships between resources, people and the environment [37]. The emergence of new threats such as climate change and resource scarcity will drive further changes in resource management. Growing climate unpredictability will need to be more satisfactorily accounted for, as will potential increases in water scarcity, energy generation and associated costs for resources extraction and utilisation.

Our current understanding of the wider processes that govern natural resources is still limited, because scientific disciplines use different concepts and languages to describe and explain complex ecological systems [7]. This problematic focus on individual components rather than on the wider systems has hindered the development of more effective and integrated solutions to managing the environmental, and indeed economic and social, problems associated with resource management [8].

These limitations are imposed by the complexity of the world in which we live, and the associated difficulty in understanding environmental problems and addressing often ill-structured resource management challenges. The perception of what constitutes an environmental problem varies between individuals and societies, and although it may be the scientists who search for answers, it is often the decision makers who ask the questions and therefore define the problems. Defining an environmental problem can be very complicated [9]. Most environmental problems are intricate and immensely complex. Yet we are often unable to comprehend such complex systems and so tend to simplify them and as a result think linearly [10]. This prevents us from a deeper understanding of the consequences of natural destruction. This also often leads us to underestimate the extent of the problem. Overall, our cognitive limitations to understanding environmental degradation seriously compromise our emotional engagement and our willingness to act [10].

Because of the current limited understanding of wider processes, advancements in individual fields and disciplines have not been matched with major improvements in understanding of the complex interrelationships among them. Achieving such a 'systems mindset' with an emphasis on interdisciplinary and holistic thinking is a prerequisite to addressing resource management challenges and solving environmental problems.

The implications for the role of science and knowledge in dealing with complex policy problems in environmental management should be addressed through participatory processes, organized to cross these different boundaries, with particular attention given to collaborative knowledge-sharing and production between all actors involved: scientists, policy makers and stakeholders [11]. Interdisciplinary science needs to be the foundation for this and at the core of significant political decisions. Active, hands-on/minds-on experiences, as well as research and problem-solving opportunities, build an understanding of what it means to know science. Doing science develops our ability to ask questions, collect information, organize and test our ideas, problem-solve and apply what we learn. Even more, science is a platform for building confidence, developing communication skills, and making sense of the world around us. The world is not fragmented into discrete subjects, and science to understand our interactions with the environment cannot be isolated from everything else in our lives — it needs to cross into all subjects, if it is to address the 'whole' problems.

The nexus of water, energy and materials is slowly becoming recognised as a system that needs to be examined, but solutions have so far not been nearly integrated enough to deliver overall benefits across the sectors, especially in light of the many emerging challenges facing resources management. Rising global demand for energy and materials will also increase our impact on water resources, a trend exacerbated by these facts: that mining activities are increasingly taking place in water scarce regions, that climate change presents further challenges in terms of water scarcity, and that globally declining ore grades for many major commodities are likely to increase water demands for most future mines [12]. Meeting the growing demand for commodities will of course also bring additional demand for energy used in extraction, processing and transport, while it is additionally evident that material constraints could have an impact on the sustained growth of the renewable energy sector [13-15].

While it has been often accepted that it is the responsibility of governments to impose solutions upon resource users in the form of regulation in order to achieve sustainable resource use, some government policies have been shown to accelerate resource destruction. At the same time some resource users have seen the benefits of investing in sustainable practices [7]. Achieving this sustainability, however, requires our many ecological/environmental, economic and social issues to be accounted for (Figure 2). A better understanding of demand and pressure on the existing resources, followed by appropriate pricing that is inclusive of all environmental costs, can light up the way for new opportunities for resource recovery through waste management.

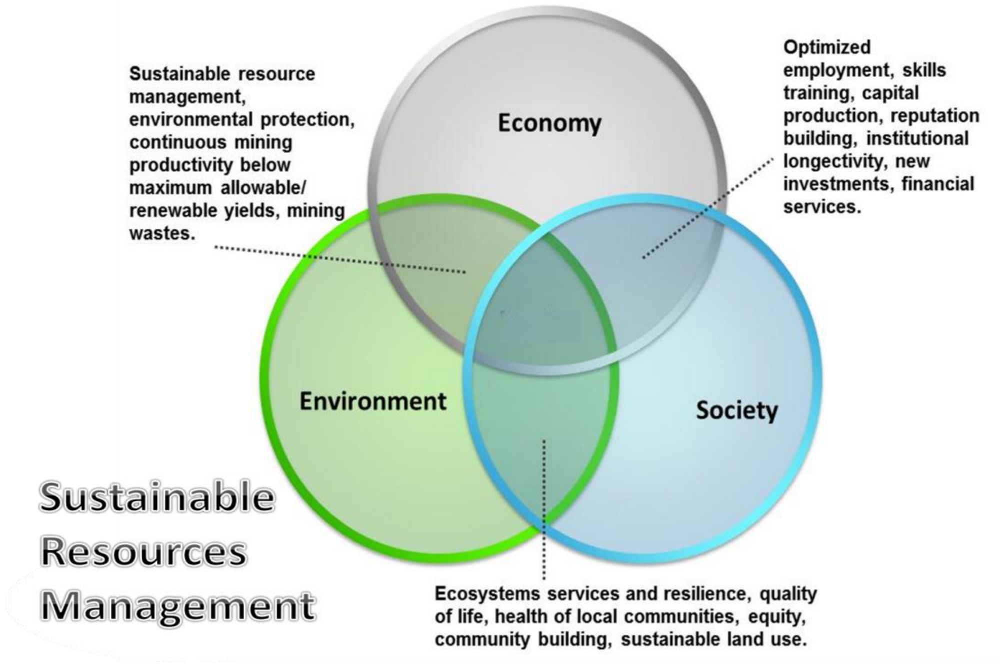


Figure 2: Sustainable resources management

It is essential to use appropriate pricing that is inclusive of all environmental costs and environmental externalities when making decisions and developing policies relating to the use of raw materials (e.g. from the mining sector) versus recycled materials from the waste sector. The carrying capacity of the natural environment is an unprized input to resource production, and it is increasingly accepted that resource users should be made to pay for the environmental impacts they cause [16]. While several methods for the monetary valuation of environmental impacts have been developed [17], the internalisation of environmental costs has yet to become fully mainstream in practice [18].

In addition, in the light of increasing concerns regarding material security, shortages and environmental pollution, realistic frameworks have emerged for processing waste as a resource in many parts of the world [19-21]. More broadly, waste recycling and reuse can provide a viable opportunity to augment traditional resource supplies, at the same time reducing the need for waste disposal [22].

The role of '*waste*' in the context of resources management

In the traditional modern economy, natural resources are mined and extracted, turned into products and finally discarded, with the traditional development model driven by heavy industrial growth and resource-intensive infrastructure. This remains a fundamentally open, linear system, and one that is likely to cause unsustainable pressures on the environment [23]. Rather than releasing high quality wastes back into the environment while simultaneously paying to extract it as minerals through traditional mining of raw materials, it is more sustainable and energy efficient to close the loop (Figure 3). As a result, resource reuse can help to close the loop between supply and waste disposal, providing a sustainable alternative to extraction of virgin stocks. Given the two-fold need to protect the environment and recognise the importance of natural capital, while at the same time enhancing our economic prosperity and improving living standards of developing countries and the world's poor, achieving more from less by closing the resource loops is of paramount importance.

Figure 3: Closing the loop: sustainable resources management

Properly accounting for natural capital in resources management first requires a more comprehensive understanding of the use and disposal of materials and their waste by-products, including those produced through resource extraction, material processing, product design and manufacturing, , and of how products are consumed and move towards their end-of-life cycle [24]. Economies are largely dependent on linear systems where resources are extracted from virgin stocks before ending up as discarded waste after proceeding through a supply chain which itself produces waste at every stage [25]. While the debate surrounding 'peak minerals' and the potential threat posed by resource scarcity is ongoing [26-30], it is nevertheless essential to address inefficiencies of this system, especially when social and environmental constraints are taken into account in addition to physical ones [31]. At the same time, mined materials (such as platinum group elements) are increasingly used in a range of environmentally-related technologies, as for example in chemical process catalysts, catalytic converters for vehicle exhaust control, hydrogen fuel cells, electronic components, and a variety of specialty medical uses, among others. This growth trend is expected to continue increasing in the future especially in light of emerging environmental and technological challenges. Despite ongoing arguments on the availability of abundant geologic resources, it is still ethically responsible to manage properly all associated environmental, economic and social impacts associated with any increases in production [32].

Continuing technological advancements and the changing economic climate are likely to promote the exploitation of alternative non-virgin stocks from waste. Information on the scale and distribution of such stocks is currently limited, and individual components of the supply chain are too often viewed in isolation [33]. Material Flow Analysis (MFA) is one tool that can be utilised to address this challenge, providing an improved insight into how an economic system interacts with natural resource and material flows, thereby informing environmental policy and decision making [34].

The alumina industry worldwide has reduced the volume of waste produced by about fifty percent, with valuable raw materials being recovered and the risk of storage failure significantly reduced. For example, dry disposal produces a paste for stacking and drying instead of a water-like suspension to be stored in a dam or pond and other options, demonstrating improvements in waste management practices driven by several factors, such as public perception, water recovery, the necessity to earn the right to operate, and even by common sense accounting [35]. Similarly, there have been efforts to mitigate some of the negative effects of increased mining and use of copper. Recent progress in microbiological and biotechnological aspects of microorganisms in contact with copper could lead to more thermo-tolerant, copper ion-resistant microorganisms that could improve copper leaching and lessen copper groundwater contamination, and copper ion-resistant bacteria associated with plants might be useful in biostabilization and phytoremediation of copper-contaminated environments [36].

To address sustainable development successfully we cannot view any one process, product or effect of the supply chain in isolation. It is essential that all steps in the supply chain are drawn together in a generic framework that gives a holistic view of its performance and progress. A rigorous mass and energy balance appraisal with a clear understanding of inputs, outputs and boundaries is recommended to start moving towards a more sustainable society. It will be very difficult to manage material flows in a society where there is no information available on the quantity and quality of the materials leaving and entering the society at all stages of the supply chain. Material flow accounting provides a framework for establishing opportunities to close the loop, and identifying opportunities for industrial symbiosis, the concept of a closed loop value chain where manufacturers are able to capture additional value during production. In symbiotic conditions, consumption and production ecosystems become closed loops, eliminating the waste of outputs throughout the product lifecycle. In these systems the idea of ‘waste’ disappears, to be replaced with the term ‘resources’ and ‘outputs’ that can be used to feed into other manufacturing processes, and with a renewed focus on value creation rather than material throughput.

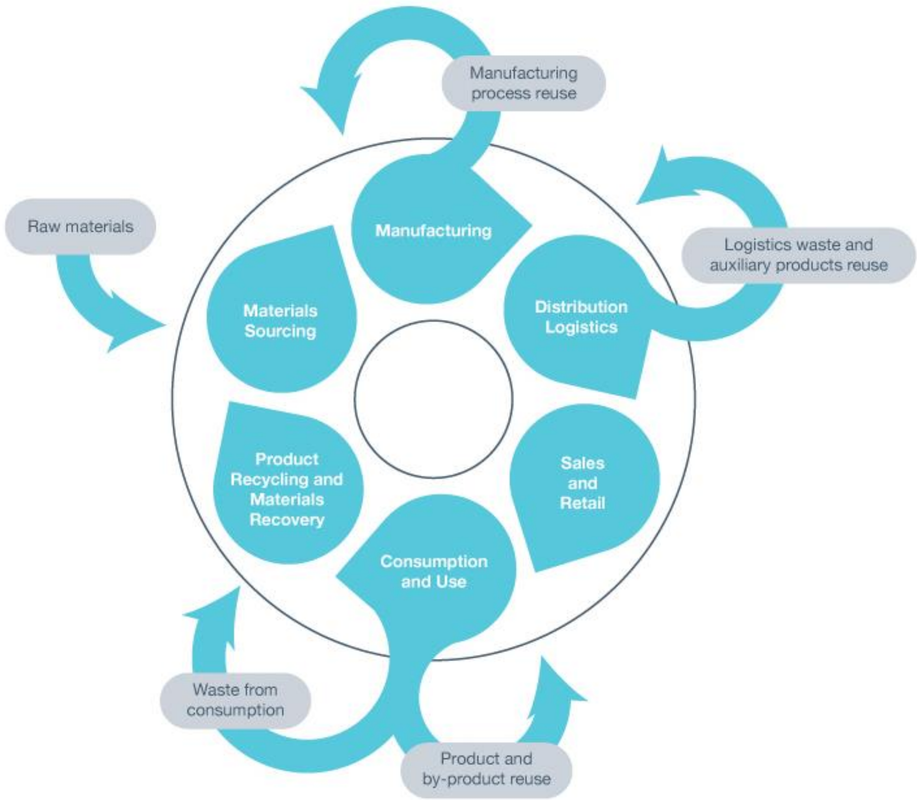


Figure 4: Industrial symbiosis as a closed loop value chain, where manufacturers are able to capture additional value during production.

Discussion

Looking back over the last two and a half centuries since the industrial revolution and especially since the second world war, there has been a change from the industrial societies of the 'dark satanic mills' and smogs where risks of pollution were more localised and immediately perceptible, to a globalised, 'risk conscious' and even 'risk averse' society, at least in the developed world, that is no longer simply concerned with 'making nature useful but with problems resulting from techno-economic development itself' [37]. Such risks are now known to be more complex and to have global impacts, although they are often hidden and undetectable through the senses [38]. Many of the risks may remain poorly understood or unknown [39]

Identifying and building sustainable resource management systems is one of the most critical issues that today's society is trying to address. Recent trends with regard to mineral resources have presented many new challenges for resource management. While there are research questions in these areas, e.g., how to harvest and/or extract the resources and how to account for environmental impacts, there are also differences, e.g., the length of time associated with a growth and harvesting or extraction cycle, and whether or not the resource is renewable. Research in all four areas is at different levels of advancement in terms of the methodology currently developed and the acceptance of implementable plans and policies [40]. Owing to population growth and rises in incomes, per capita resource use has been increasing sharply [41]. At the same time, there is a need to achieve more with less by improving the living standards of the poor while improving the sustainability of resource use and shrinking our ecological footprint. While technological advancements and clean production approaches have vastly improved environmental management and material and energy efficiency in production and consumption [42], these new challenges threaten to overwhelm our capacity to adapt through technological improvements alone.

This more holistic and sustainable use of resources is based in a systems approach using diverse disciplines to develop a coherent theory from which new methodologies and tools have been emerging. The last few years have seen a shift away from the development of policy in reaction to high profile events, first towards attempts to control of releases to single environmental media, and now to the present position of moving toward integrated management of all environmental media. This development has moved towards environmental holism, including recognition of the ecological value of resources management in the whole life cycle [43].

As a society, we must develop and refine our ability to recognize systems, determine the appropriate scale of "wholeness," and sufficiently learn/understand the underlying components/connections. Given the possible far-reaching implications that climate change and evolving anthropogenic pressures will have on natural resources and ecosystems, and given the uncertainties surrounding the effects of how multiple, complex stressors will interact, it is evident that there is an urgent need for environmental policy and management to adapt in the future, so that both vital resources and ecosystems are equally protected. Moreover, acknowledging the critical role of socio-economic policy instruments and necessary investments, only an adaptive systems approach can offer a way to broaden the approaches, the stakeholder base (policy makers/regulators, scientific community and the public) and the innovation brought to environmental quality management. By considering all parts of the environmental quality system, such an approach, while not discarding the appropriate use of command and control regulation, is expanding the means for environmental protection so that innovation and improvement- rather than control and protection- become the major functions of environmental quality management. This indicates the need to for an integrated approach to managing resources effectively and efficiently.

One of the greatest challenges in achieving a sustainable society is to create a society that is more literate and aware of sustainability and is moved away from the unsustainable and unequal wealth creation with deleterious effects on the environment. This may in turn drive industrial practices, government policy and individual behaviour that support sustainability and the use of environmental resources in this context. Necessary for this, is the development of scientific research that is participatory, ethical and anticipatory with regard to potential impacts on health and the environment and that is guided by the principles of openness and transparency. Accountability is also required, such that researchers and research organisations remain accountable for the social, environmental and human health impacts that their research may impose on present and future generations. The emergence of this holistic worldview creates the potential for the rapid development of a sustainable societal system.

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