



Industrial Ecology

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First Edition, 2012

ISBN 978-81-323-3073-8

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Published by:

Research World

4735/22 Prakashdeep Bldg,

Ansari Road, Darya Ganj,

Delhi - 110002

Email: info@wtbooks.com

Table of Contents

Chapter 1 - Industrial Ecology

Chapter 2 - Eco-Costs

Chapter 3 - Eco-Costs Value Ratio

Chapter 4 - Cradle to Cradle Design

Chapter 5 - Eco-Industrial Park & Eco-Efficiency

Chapter 6 - Life Cycle Assessment

Chapter 7 - Extended Producer Responsibility

Chapter 8 - Ecological Economics

Chapter 9 - EIOLCA

Chapter 10 - Energetics

Chapter 11 - Energy Quality

Chapter 12 - History of Industrial Ecology

Chapter 13 - Zero Waste

Chapter 14 - Waste Hierarchy & Waste Minimization

Chapter 15 - Material Flow Accounting & Material Flow Analysis

Chapter 16 - Full Cost Accounting

Chapter 17 - Industrial Symbiosis & Integrated Chain Management

Chapter 1

Industrial Ecology

Industrial Ecology (IE) is the study of material and energy flows through industrial systems. The global industrial economy can be modeled as a network of industrial processes that extract resources from the Earth and transform those resources into commodities which can be bought and sold to meet the needs of humanity. Industrial ecology seeks to quantify the material flows and document the industrial processes that make modern society function. Industrial ecologists are often concerned with the impacts that industrial activities have on the environment, with use of the planet's supply of natural resources, and with problems of waste disposal. Industrial ecology is a young but growing multidisciplinary field of research which combines aspects of engineering, economics, sociology, toxicology and the natural sciences.

Industrial Ecology has been defined as a "systems-based, multidisciplinary discourse that seeks to understand emergent behaviour of complex integrated human/natural systems". The field approaches issues of sustainability by examining problems from multiple perspectives, usually involving aspects of sociology, the environment, economy and technology. The name comes from the idea that we should use the analogy of natural systems as an aid in understanding how to design sustainable industrial systems.

Overview



Example of Industrial Symbiosis. Waste steam from a waste incinerator (right) is piped to an ethanol plant (left) where it is used as input to their production process.

Industrial ecology is concerned with the shifting of industrial process from linear (open loop) systems, in which resource and capital investments move through the system to become waste, to a closed loop system where wastes can become inputs for new processes.

Much of the research focuses on the following areas:

- material and energy flow studies ("industrial metabolism")

- dematerialization and decarbonization
- technological change and the environment
- life-cycle planning, design and assessment
- design for the environment ("eco-design")
- extended producer responsibility ("product stewardship")
- eco-industrial parks ("industrial symbiosis")
- product-oriented environmental policy
- eco-efficiency

Industrial ecology seeks to understand the way in which industrial systems (for example a factory, an ecoregion, or national or global economy) interact with the biosphere. Natural ecosystems provide a metaphor for understanding how different parts of industrial systems interact with one another, in an "ecosystem" based on resources and infrastructural capital rather than on natural capital. It seeks to exploit the idea that natural systems do not have waste in them to inspire sustainable design.

Along with more general energy conservation and material conservation goals, and redefining commodity markets and product stewardship relations strictly as a service economy, industrial ecology is one of the four objectives of Natural Capitalism. This strategy discourages forms of amoral purchasing arising from ignorance of what goes on at a distance and implies a political economy that values natural capital highly and relies on more instructional capital to design and maintain each unique industrial ecology.

History



A training meeting with factory workers in a stainless steel ecodesign company from Rio de Janeiro, Brazil. Its the diffusion of industrial ecology knowledge in action

Industrial ecology was popularized in 1989 in a *Scientific American* article by Robert Frosch and Nicholas E. Gallopoulos. Frosch and Gallopoulos' vision was "why would not our industrial system behave like an ecosystem, where the wastes of a species may be resource to another species? Why would not the outputs of an industry be the inputs of another, thus reducing use of raw materials, pollution, and saving on waste treatment?" A notable example resides in a Danish industrial park in the city of Kalundborg. Here several linkages of byproducts and waste heat can be found between numerous entities such as a large power plant, an oil refinery, a pharmaceutical plant, a plasterboard factory, an enzyme manufacturer, a waste company and the city itself.

The scientific field Industrial Ecology has grown quickly in recent years. The Journal of Industrial Ecology (since 1997), the International Society for Industrial Ecology (since 2001), and the journal Progress in Industrial Ecology (since 2004) give Industrial Ecology a strong and dynamic position in the international scientific community. Industrial Ecology principles are also emerging in various policy realms such as the concept of the Circular Economy that is being promoted in China. Although the definition of the Circular Economy has yet to be formalized, generally the focus is on strategies such as creating a circular flow of materials, and cascading energy flows. An example of this would be using waste heat from one process to run another process that requires a lower temperature. The hope is that strategy such as this will create a more efficient economy with fewer pollutants and other unwanted by products.

Principles

One of the central principles of Industrial Ecology is the view that societal and technological systems are bounded within the biosphere, and do not exist outside of it. Ecology is used as a *metaphor* due to the observation that natural systems reuse materials and have a largely closed loop cycling of nutrients. Industrial Ecology approaches problems with the hypothesis that by using similar principles as *natural systems*, *industrial systems* can be improved to reduce their impact on the natural environment as well. The table shows the general metaphor.

Biosphere	Technosphere
• Environment	• Market
• Organism	• Company
• Natural Product	• Industrial Product
• Natural Selection	• Competition
• Ecosystem	• Eco-Industrial Park

- Ecological Niche
- Anabolism / Catabolism
- Mutation and Selection
- Succession
- Adaptation
- Food Web
- Market Niche
- Manufacturing / Waste Management
- Design for Environment
- Economic Growth
- Innovation
- Product Life Cycle

The Kalundborg industrial park is located in Denmark. This industrial park is special because companies reuse each others' waste (which then becomes by-products). For example, the Energy E2 Asnæs Power Station produces gypsum as a by product of the electricity generation process; this gypsum becomes a resource for the BPB Gyproc A/S which produces plasterboards. This is one example of a system inspired by the biosphere-technosphere metaphor: in ecosystems, the waste from one organism is used as inputs to other organisms; in industrial systems, waste from a company is used as a resource by others.

Apart from the direct benefit of incorporating waste into the loop, the use of an eco-industrial park can be a means of making renewable energy generating plants, like Solar PV, more economical and environmentally friendly. In essence, this assists the growth of the renewable energy industry and the environmental benefits that come with replacing fossil-fuels.

IE examines societal issues and their relationship with both technical systems and the environment. Through this *holistic view*, IE recognizes that solving problems must involve understanding the connections that exist between these systems, various aspects cannot be viewed in isolation. Often changes in one part of the overall system can propagate and cause changes in another part. Thus, you can only understand a problem if you look at its parts in relation to the whole. Based on this framework, IE looks at environmental issues with a *systems thinking* approach.

Take a city for instance. A city can be divided into commercial areas, residential areas, offices, services, infrastructures, etc. These are all sub-systems of the 'big city' system. Problems can emerge in one sub-system, but the solution has to be global. Let's say the price of housing is rising dramatically because there is too high a demand for housing. One solution would be to build new houses, but this will lead to more people living in the city, leading to the need of more infrastructure like roads, schools, more supermarkets, etc. This system is a simplified interpretation of reality whose behaviors can be 'predicted'.

In many cases, the systems IE deals with are complex systems. Complexity makes it difficult to understand the behavior of the system and may lead to rebound effects. Due to unforeseen behavioral change of users or consumers, a measure taken to improve environmental performance does not lead to any improvement or may even worsen the situation. For instance, in big cities, traffic can become problematic. Let's imagine the government wants to reduce air pollution and makes a policy stating that only cars with an even license plate number can drive on Tuesdays and Thursdays. Odd license plate numbers can drive on Wednesdays and Fridays. Finally, the other days, both cars are allowed on the roads. The first effect could be that people buy a second car, with a specific demand for license plate numbers, so they can drive every day. The rebound effect is that, the days when all cars are allowed to drive, some inhabitants now use both cars (whereas they only had one car to use before the policy). The policy did obviously not lead to environmental improvement but even made air pollution worse.

Moreover, *life cycle thinking* is also a very important principle in industrial ecology. It implies that all environmental impacts caused by a product, system, or project during its life cycle are taken into account. In this context life cycle includes

- Raw material extraction
- Material processing
- Manufacture
- Use
- Maintenance
- Disposal

The transport necessary between these stages is also taken into account as well as, if relevant, extra stages such as reuse, remanufacture, and recycle. Adopting a life cycle approach is essential to avoid shifting environmental impacts from one life cycle stage to another. This is commonly referred to as problem shifting. For instance, during the re-design of a product, one can choose to reduce its weight, thereby decreasing use of resources. However, it is possible that the lighter materials used in the new product will be more difficult to dispose of. The environmental impacts of the product gained during the extraction phase are shifted to the disposal phase. Overall environmental improvements are thus null.

A final and important principle of IE is its *integrated approach* or *multidisciplinarity*. IE takes into account three different disciplines: social sciences (including economics), technical sciences and environmental sciences. The challenge is to merge them into a single approach.

Tools

People	Planet	Profit	Modeling
<ul style="list-style-type: none"> Stakeholder analysis 			
<ul style="list-style-type: none"> Strength Weakness Opportunities Threats Analysis (SWOT Analysis) 	<ul style="list-style-type: none"> Environmental impact assessment (EIA) Input-output analysis (IOA) 	<ul style="list-style-type: none"> Cost benefit analysis (CBA) 	
<ul style="list-style-type: none"> Ecolabelling 		<ul style="list-style-type: none"> Full cost accounting (FCA) 	<ul style="list-style-type: none"> Stock and flow analysis
<ul style="list-style-type: none"> ISO 14000 	<ul style="list-style-type: none"> Life cycle analysis (LCA) 		
<ul style="list-style-type: none"> Environmental management system (EMS) 	<ul style="list-style-type: none"> Material flow analysis (MFA) 	<ul style="list-style-type: none"> Life cycle costing (LCC) 	<ul style="list-style-type: none"> Agent based modeling
<ul style="list-style-type: none"> Integrated chain management (ICM) 	<ul style="list-style-type: none"> Substance flow analysis (SFA) 		
<ul style="list-style-type: none"> Technology assessment 	<ul style="list-style-type: none"> MET Matrix 		

Future directions

The ecosystem metaphor popularized by Frosch and Gallopoulos has been a valuable creative tool for helping researchers look for novel solutions to difficult problems. Recently, it has been pointed out that this metaphor is based largely on a model of classical ecology, and that advancements in understanding ecology based on complexity science have been made by researchers such as C. S. Holling, James J. Kay, and others. For industrial ecology, this may mean a shift from a more mechanistic view of systems, to one where sustainability is viewed as an emergent property of a complex system. To explore this further, several researchers are working with agent based modeling techniques.

Exergy analysis is performed in the field of industrial ecology to use energy more efficiently. The term *exergy* was coined by Zoran Rant in 1956, but the concept was developed by J. Willard Gibbs. In recent decades, utilization of exergy has spread outside of physics and engineering to the fields of industrial ecology, ecological economics, systems ecology, and energetics.

Recently, there has been work advocating for large scale photovoltaic production facilities in an industrial ecology setting. These facilities not only reduce their environmental impact but also decrease the costs of photovoltaic productions to as little as \$1 per Watt by economy of scale.

Chapter 2

Eco-Costs

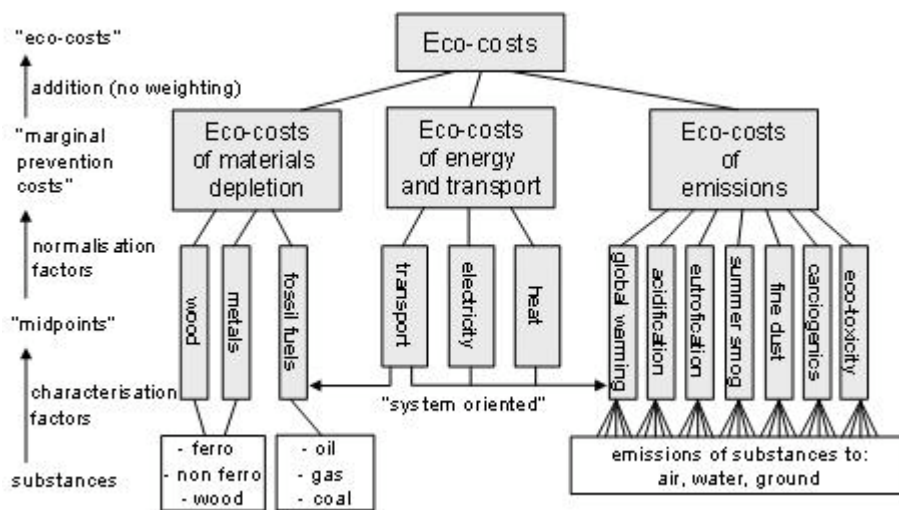


Fig 1: Calculation structure of the eco-costs 2007.

Eco-costs are a measure to express the amount of environmental burden of a product on the basis of prevention of that burden. They are the costs which should be made to reduce the environmental pollution and materials depletion in our world to a level which is in line with the carrying capacity of our earth.

For example: for each 1000 kg CO₂ emission, one should invest € 135,- in offshore windmill parks (or other CO₂ reduction systems at that price or less). When this is done consequently, the total CO₂ emissions in the world will be reduced by 65% compared to the emissions in 2008. As a result global warming will stabilise. In short: "the eco-costs of 1000kg CO₂ are € 135,-".

Similar calculations can be made on the environmental burden of acidification, eutrophication, summer smog, fine dust, eco-toxicity, and the use of metals, fossil fuels and land (nature). As such, the eco-costs are virtual costs, since they are not yet integrated in the real life costs of current production chains (Life Cycle Costs). The eco-costs should be regarded as hidden obligations.

The eco-costs of a product are the sum of all eco-costs of emissions and use of materials and energy during the life cycle "from cradle to cradle". The widely accepted method to

make such a calculation is called Life Cycle Assessment (LCA), which is basically a mass and energy balance, defined in the 14040 and ISO 14044.

The practical use of eco-costs is to compare the sustainability of several product types with the same functionality. The advantage of eco-costs is that they are expressed in a standardized monetary value (€) which appears to be easily understood ‘by instinct’. Also the calculation is transparent and relatively easy, compared to damage based models which have the disadvantage of extremely complex calculations with subjective weighting of the various aspects contributing to the overall environmental burden .

The system of eco-costs is part of the bigger model of the EVR

Background information

The eco-costs system has been introduced in 1999 and published in 2000-2004 in the International Journal of LCA, and in the Journal of Cleaner Production. In 2007 the system was updated.

The method of the eco-costs is based on the sum of the marginal prevention costs (end of pipe as well as system integrated) for toxic emissions, material depletion, energy consumption and transport, and conversion of land. For a visual display of the system see figure 1.

The classical way to calculate a “single indicator” in LCA is based on the damage of the emissions. Pollutants are grouped in “classes”, multiplied by a “characterisation” factor to account for their relative importance within a class, and totalised to the level of their “midpoint” effect (global warming, acidification, nutrification, etc.). The classical problem is then to determine the relative importance of each midpoint effect. This is done by “normalisation” (= comparison with the pollution in a country or a region) and “weighting” (= giving each midpoint a weight, to take the relative importance into account) by an expert panel.

The calculation of the eco-costs is based on classification and characterisation tables as well (combining tables from IPCC, the Universities of Leiden and the University of Michigan), however has a different approach to the normalisation and weighting steps. Normalisation is done by calculating the marginal prevention costs for a region (i.e. the European Union), to reduce the pollution to the “no observable adverse effect level” (often the threshold level of a toxic substance). The weighting step is not required in the eco-costs system, since the total result is the sum of the eco-costs of all midpoints. The advantage of such a calculation is that the marginal prevention costs are related to the cost of the most expensive Best Available Technology which is required to meet the target, and the corresponding level of future Tradable Emission Rights. Example: For reduction of CO₂ emissions to a sustainable level, the marginal prevention costs is the cost of replacement of coal fired power plants by windmill parks at the sea.

The eco-costs have been calculated for the situation in the European Union. It might be argued that the eco-costs are also an indication of the marginal prevention costs for other

parts of the globe, under the condition of a level playing field for production companies. A group of universities in Japan is developing a set of data for Japan as well.

Eco-costs 2007

The method of the eco-costs 2007 comprises tables of over 3000 emissions, and has been made operational by special database for Simapro, based on LCIs from Ecoinvent v2 and Idemat 2008 (over 5000 materials and processes), and a database for CES (Cambridge Engineering Selector).

For emissions of toxic substances, the following set of multipliers is used in the eco-costs 2007 system:

- prevention of acidification 7.55 €/kg SO_x equivalent
- prevention of eutrophication 3.60 €/kg phosphate equivalent
- prevention of ecotoxicity 802 €/kg Zn equivalent
- prevention of carcinogens 33 €/kg PAH equivalent
- prevention of summer smog (respiratory diseases) 8.90 €/kg C₂H₄ equivalent
- prevention of fine dust 27.4 €/kg fine dust PM_{2.5}
- prevention of global warming (GWP 100) 0.135 €/kg CO₂ equivalent

The eco-costs of abiotic depletion is 0.7 €/kg for fossil fuels. The eco-costs of material depletion of tropical hardwood are based on the change of biodiversity before and after harvesting.

The characterisation tables which are applied in the eco-costs 2007 system:

- IPPC 2007, 100 years, for greenhouse gasses
- CML-2, for acidification, eutrophication and summer smog (respiratory diseases)
- IMPACT 2002+, for aquatic eco-toxicity (inc. heavy metals), fine dust and carcinogens

Prevention costs versus Damage costs

Prevention measures will decrease the costs of the damage, related to environmental pollution (e.g. damage costs related to human health problems in terms of QALYs). The savings which are a result of the prevention measures are of the same order of magnitude as the costs of prevention. So the total effect of prevention measures on our society is that it results in a better environment at virtually no extra costs, since costs of prevention and costs of savings will level out.

Discussion

There are many “single indicators” for LCA. Basically they fall in three categories:

- single issue

- damage based
- prevention based

The best known “single issue” indicator is the carbon footprint: the total emissions of kg CO₂, or kg CO₂ *equivalent* (taking methane and some other greenhouse gasses into account as well). The advantage of a single issue indicator is, that its calculation is simple and transparent, without any complex assumptions. It is easy as well to communicate to the public. The disadvantage is that it ignores the problems caused by other pollutants and it is not suitable for cradle to cradle calculations (because materials depletion is not taken into account).

The most common single indicators are damage based. This stems from the period of the 1990ties, when LCA was developed to make people aware of the damage of production and consumption. The advantage of damage based single indicators is, that they make people aware of the fact that they should consume less, and make companies aware that they should produce cleaner. The disadvantage is that these damage based systems are very complex, not transparent for others than who make the computer calculations, need many assumptions, and suffer from the subjective weighting procedure at the end. Communication of the result is not easy, since the result is expressed in “points” (attempts to express the results in money were never very successful, because of methodological flaws).

Prevention based indicators, like the system of the eco-costs, are relatively new. The advantage, in comparison to the damage based systems, is that the calculations are relatively easy and transparent, and that the results can be explained in terms of money and in measures to be taken. The system is focused on the decision taking processes of architects, business people, designers and engineers. The disadvantage is that the system is not focused on the fact that people should consume less.

Chapter 3

Eco-Costs Value Ratio

The **EVR model** is a Life Cycle Assessment based method to analyse consumption patterns, business strategies and design options in terms of eco-efficient value creation. Next to this it is used to compare products and service systems (e.g. benchmarking).

The eco-costs/value ratio (EVR) is an indicator to reveal sustainable and unsustainable consumption patterns of people. The eco-costs is an indicator for the environmental pollution of the products people buy, the value is the price they pay for it in our free market economy. Example: When somebody spends 1000 euro per month on housing (in Europe: EVR approx. 0,3) it is less harmful for the environment than when 1000 euro is spend on diesel (in Europe: EVR approx. 1,0). See section 3.1.

The EVR is also relevant for business strategies, because companies are facing the slow but inevitable internalization of environmental costs. At the moment the costs of products don't take into account the environmental damage caused by these products. This "pollution is for free" mentality is less and less accepted by communities.

The EVR makes companies aware of the relative importance of the environmental pollution of their products, and the relative risk they run that future production costs will increase because of this internalization of environmental costs. By using the EVR, companies can make decisions for their product portfolio: abandon products with low value and high environmental costs and stimulate products with high value and low environmental costs. See sections 2.3 and 3.2.

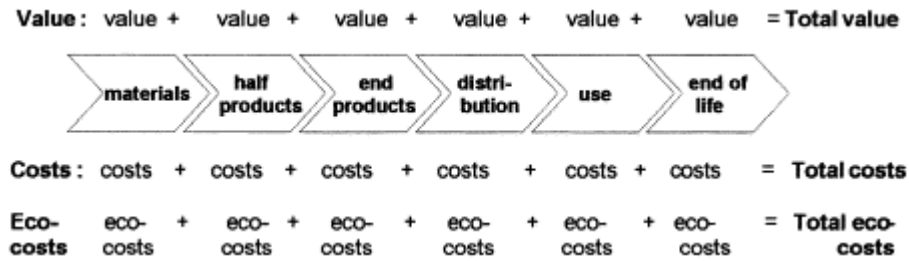


Figure 1: The basic idea of combining the economic and ecological chain: ‘the EVR chain’.

Background information

The EVR model has been introduced in 1998 and published in 2000-2004 in the International Journal of LCA, and in the Journal of Cleaner Production. In 2007 the system was updated. The concept of EVR is based on eco-costs. In 2010 a book named "LCA-based assessment of sustainability: the Eco-costs/Value Ratio (EVR)" was published containing the most important articles about the EVR.

Working principle

The model

$EVR = \text{Eco-costs}/\text{value}$. The basic idea of the EVR model is to link the ‘value chain’ to the ecological product chain. In the value chain, the added value (in terms of money) and the added costs are determined for each step of the product ‘from cradle to grave’. Similarly, the ecological impact of each step in the product chain is expressed in terms of money, the so-called ‘eco-costs’. See figure 1

Eco-costs

Eco-costs express the amount of environmental burden of a product on basis of prevention of that burden. They are the marginal prevention costs (money) which should be made to reduce the environmental pollution and materials depletion in our world to a level which is in line with the carrying capacity of our earth.

As such, the eco-costs are virtual costs, since they are not yet integrated in the real life costs of current production chains (Life Cycle Costs). The eco-costs should be regarded as hidden obligations.

For example: for each 1000 kg CO₂ emission, one should invest € 135,- in offshore windmill parks (or other CO₂ reduction systems at that price or less). When this is done consequently, the total CO₂ emissions in the world will be reduced by 65% compared to the emissions in 2008. As a result global warming will stabilise. In short: "the eco-costs of 1000kg CO₂ are € 135,-". Similar calculations can be made on the environmental

burden of acidification, eutrication, summer smog, fine dust, eco-toxicity, and the use of metals, fossil fuels and land (nature).

At this moment eco-costs are used to assess the environmental performance of different materials, processes and End of Life methods.

EVR of products

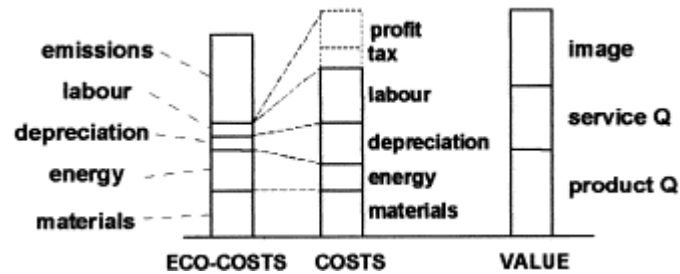


Figure 2: The decomposition of 'virtual eco-costs', costs and value of a product.

The EVR combines eco-cost and value to see whether a product will be successful. The product should have low environmental impact in its lifecycle (low eco-costs) and an attractive value for consumers. The value here is the market value (perceived customer value, also called fair price). Figure 2 depicts the three dimensions of a product: the value, the costs and the eco-costs.

It is a trend in society that heavy pollution of industry is not accepted anymore by the inhabitants of a country. This results in stricter regulations by countries (e.g. tradable emission rights, enforcement of best available technologies, eco-taxes, etc.). Eco-costs will then become part of the internal production costs. This internalizing of eco-costs might be a threat to a company, but it might also be an opportunity: "When my product has less eco-burden than that of my competitor, my product can withstand stricter regulations of the government. So this characteristic of low eco-costs of my product is a competitive edge." To analyse the short term and the long term market prospects of a product or a product service combination (Product Service System, PSS), each product or PSS can be positioned in the portfolio matrix of Figure 3. The basic idea of the product portfolio matrix is the notion that a product, service or PSS is characterized by:

- its short term market potential: high value/costs ratio
- its long term market requirement: low eco-costs.

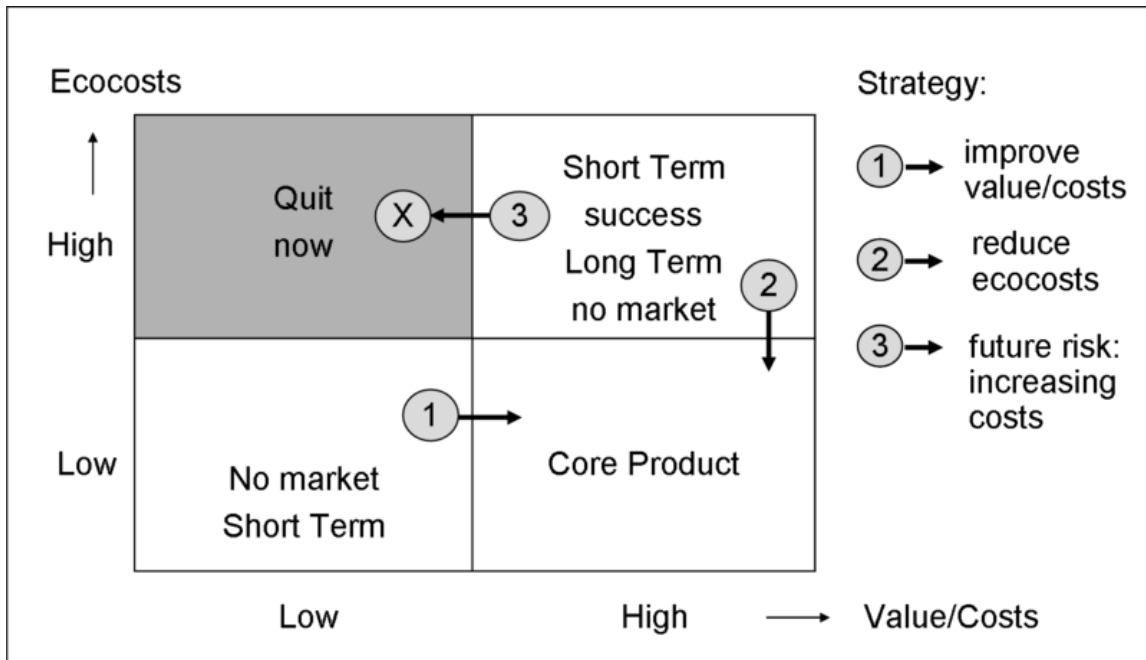


Figure 3: Product portfolio matrix for EVR product strategy of companies.

In terms of product strategy, the matrix results in 3 strategic directions:

1. enhance the value/costs ratio of a green design to create a bigger market
2. lower the eco-costs of current successful products to make it fit for future markets
3. abandon products with a low value/ costs ratio (not much profit, small market) and high eco-costs

For many ‘green designs’, the usual problem is that they have a low current value/costs ratio. In most of the cases the production costs are higher than the production costs of the classic solution, in some cases even the (perceived) quality is poor. There are two ways to do something about it:

- a. enhance the (perceived) quality of the product
- b. attach to the product a service (create a PSS) in a way that the value of the bundle of the product and the service is more than the value of its components.

For a product which has a good present value/costs ratio, but high eco-costs, the product and the production process have to be redesigned to lower the eco-costs. This road towards sustainability is often far more promising than the strategy of enhancing the value/costs ratio of a green design.

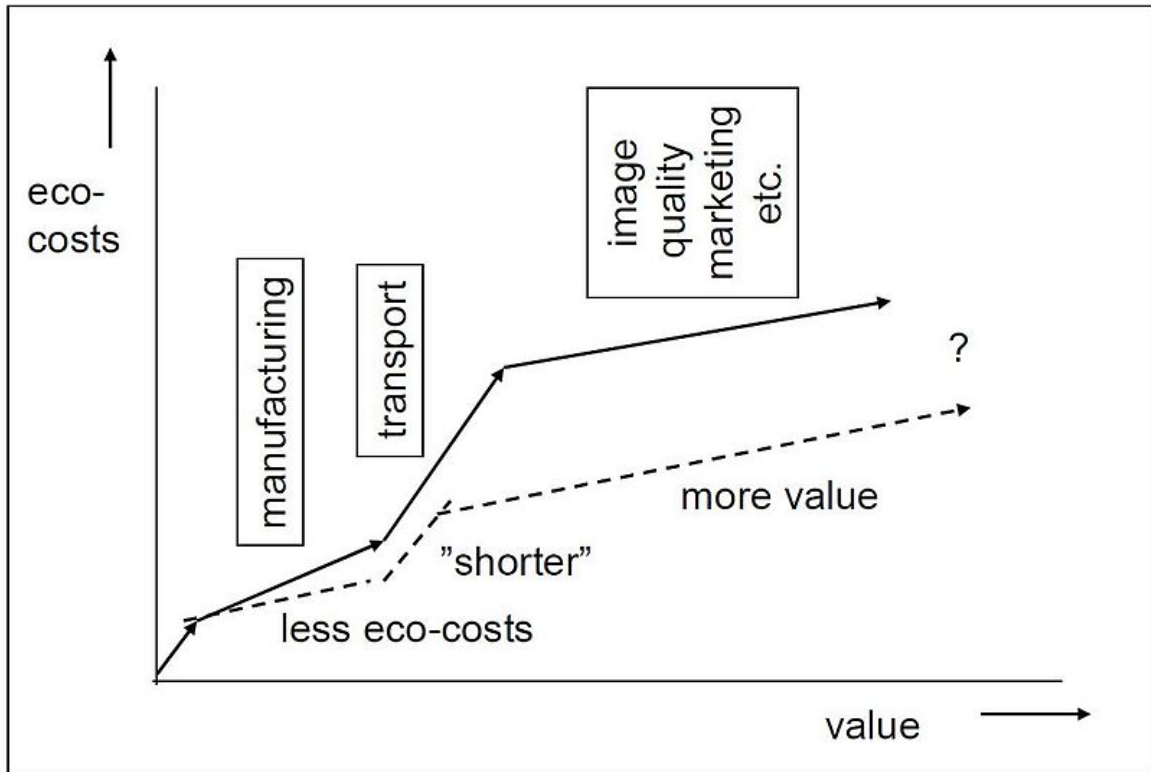


Figure 4: Design strategies to enhance the EVR of a product.

The reason is that the economies of scale for production and distribution are available and that the new product is marketed to an existing client base which is used to the brand name, the quality standards, the service system, etc.

Note: The most common fear of business managers is that their new green products end up with a deteriorated value/costs ratio, and hence will have a cumbersome position in the market. The stability of the governmental policy plays an important role here. When governmental regulations which level the playing field are postponed or even abandoned, proactive companies with sound product strategies are harmed. This can cause severe damage to the transition process and may lead to reluctance of players to move proactively in the future.

The most successful design options are depicted in Figure 4. The best design strategy is:

- to increase value where value is high
- to decrease the eco-costs where the eco-costs are high

Use

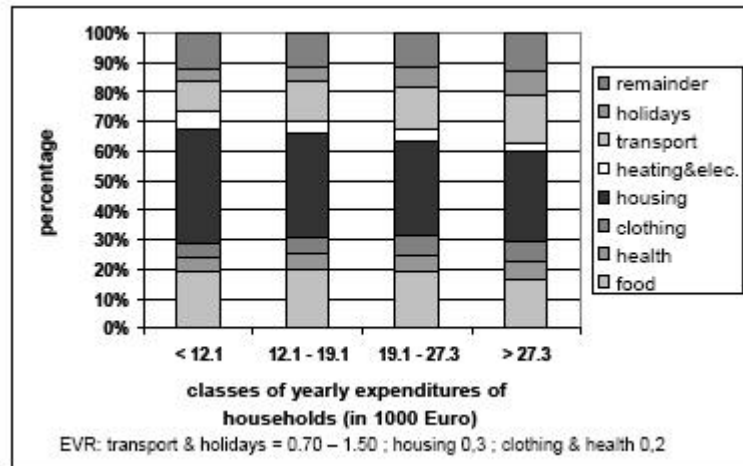


Figure 5. The consumer's side: preference of expenditures in Dutch households.

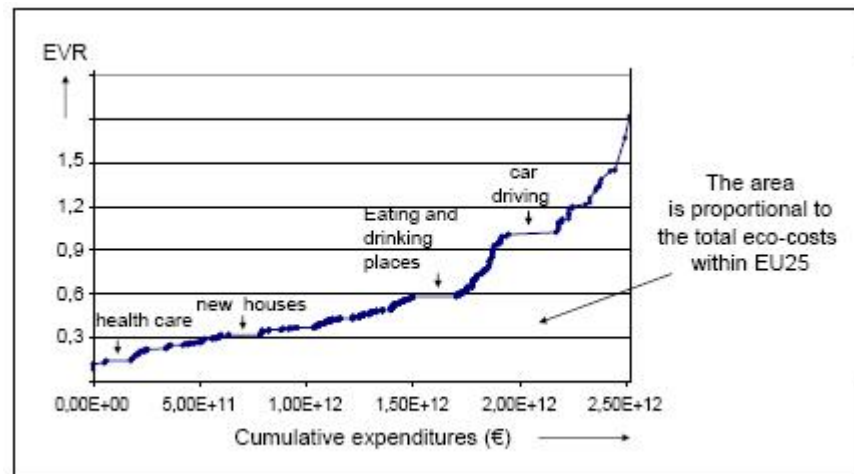


Figure 6. The EVR and the total expenditures of all consumers in the EU25 (from IIPRO)

EVR & de-linking

In economics, de-linking (also known as decoupling) is often used in the context of economic production and environmental quality. In this context, it refers to the ability of an economy to grow without corresponding increases in environmental pressure. In many economies increasing production (GDP) would involve increased pressure on the environment. An economy that is able to sustain GDP growth, without also experiencing a worsening of environmental conditions, is said to be de-linked.

There is a consumer's side of the de-linking of economy and ecology. Under the assumption that most of the households spend in their life what they earn in their life, the total EVR of the spending of households is the key towards sustainability. Only when this

total EVR of the spending gets lower, the eco-costs related to the total spending can be reduced even at a higher level of spending. There are two ways of achieving this:

- At the production side: the improvement of eco-efficiency ('lowering EVR') of products and services by the industry
- At the consumer's side: the change of lifestyle of customers in the direction of 'low EVR' products.

At the production side, our society is heading in the right direction: gradually, industrial production is achieving higher levels of the value/costs ratio and is at the same time becoming cleaner. At the consumer's side, however, our society is suffering from the fact that the consumers preferences are heading in the wrong direction: towards products and services with an unfavourable EVR (like driving in SUVs, more kilometres, intercontinental flights for holidays). These unfavourable preferences can be concluded from Figure 5.

Figure 5 shows that people in the Netherlands (and probably in the other EC countries as well) spend relatively more money on cars and holidays when they have more money available. Other studies show that people tend to have intercontinental holidays at the moment they can afford it. This shift in consumer spending will become a big problem in the near future, since the EVR of e.g. housing and health care is much lower than the EVR of transport and (inter)continental holidays by plane. Figure 6 shows the EVR (= ecocosts/price) on the Y-axis as a function of the cumulative expenditures of all products and services of all citizens in the EU 25 on the X-axis. The data is from the EIPRO study of the European Commission (EIPRO = environmental impact of products).

The area underneath the curve is proportional to the total eco-costs of the EU25. Basically there are two strategies to reduce the area under the curve: - ask industry to reduce the eco-costs of their products (this will shift the curve downward) - try to reduce expenditures of consumers in high end of the curve, and let them spend this money at the low end of the curve (this will shift the middle part of the curve to the right). The question is now how designers and engineers can contribute to this required shift towards sustainability and what this means to product portfolio strategies of companies. The solution is Eco-efficient Value Creation.

Eco-efficient Value Creation

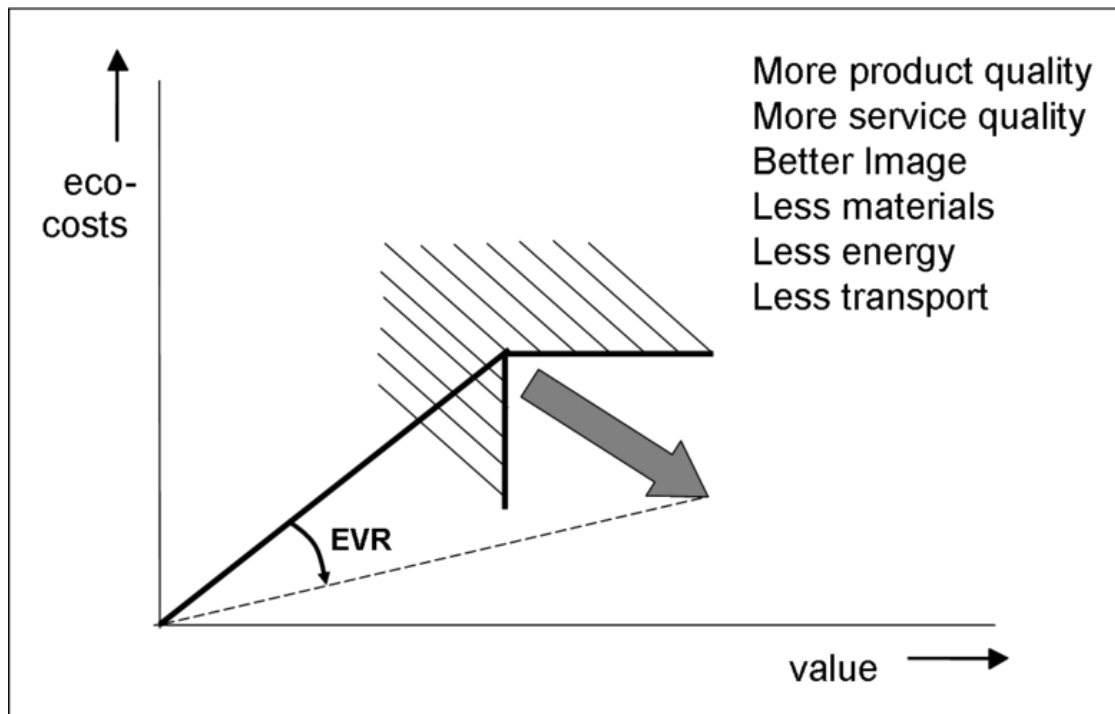


Figure 7: The double objective for design & engineering: less eco-costs, more value.

The way towards sustainability requires a double aim in product innovation, see Figure 7:

- lower eco-costs, and at the same time
- higher value (a higher market price).

We call this: Eco-efficient Value Creation. The reason we need value creation for eco-efficient products is threefold:

1. the higher price in the market is required to cover the higher production cost of green products (note that a higher price is only accepted by the consumer when the perceived value is higher, otherwise the consumer will not buy the product)
2. the higher price prevents the rebound effect
3. lowering the EVR appears the key to a sustainable development at the level of countries (Figure 6)

Below, an example of eco-efficient value creation is given:

The first example is the introduction of the Lexus RX 400h in the USA:

- the customer value has increased, by emphasising its combined power and comfort (from the advertisement in the US: ".....While it may have a V6 engine

- under the hood, the extra boost from the electric-drive motor gives the vehicle the acceleration power of a V8..... and the noise levels in Lexus hybrid vehicles have been reduced even more")
- the eco-costs of driving are lower, since its excellent overall fuel economy

Note that the acceleration of a car is an interesting issue in terms of value. High acceleration is associated with expensive sports cars (Porsche, Ferrari). But people who buy these fast cars hardly use it. For these people acceleration is more part of the image of the product than it is part of the product qualities they use on a daily basis.

Environmental Benchmarking in LCA

Life Cycle Assessment (LCA) is the generally accepted method to compare two (or more) alternative products or services. A prerequisite for such a comparison is that the functionality ('functional unit') and the quality of the alternatives are the same (you cannot compare apples and oranges in the classical LCA). In cases of product design and architecture, however, this prerequisite seems to be a fundamental flaw in the application of LCA: the designer or architect is aiming at a better quality (in the broad sense of the word: including intangible aspects like beauty and image), so the new design never has the same quality. In some cases the functionality of the design is not the same, since the design solution is limited by a maximum budget, in some cases the functionality is the same, but the higher quality results in a higher price. In all these cases a single indicator in LCA (like the eco-costs) is not suitable for environmental benchmarking. In these cases however, it does make sense to compare the design alternatives on the basis of the eco-costs/value ratio (EVR), where the value is the perceived customer value (the fair price). See section 3.1 on EVR & Delinking.

Example 1. Different types of armchairs differ in terms of comfort, aesthetics, etc. rather than in terms of functionality. A classical LCA (with a single indicator like eco-costs, carbon footprint, etc.) does not make sense here. Selection on the basis of EVR, however, is the key to a sustainable consumption pattern. The chair with the lowest EVR is the best solution in terms of sustainability.

Example 2. In LCA, the comparison of a new building and a renovated building is in the majority of cases not possible, since, in practice, both solutions differ in almost all quality aspects (tangible as well as intangible). However, the solution with lowest EVR is the best in terms of sustainable consumption.

Note that the renovated building is the best solution in most of the cases, because it has the lowest EVR in the production phase. However, in some cases the renovated building is not the best solution, because of unfavourable energy consumption (high EVR) in the use phase.

Chapter 4

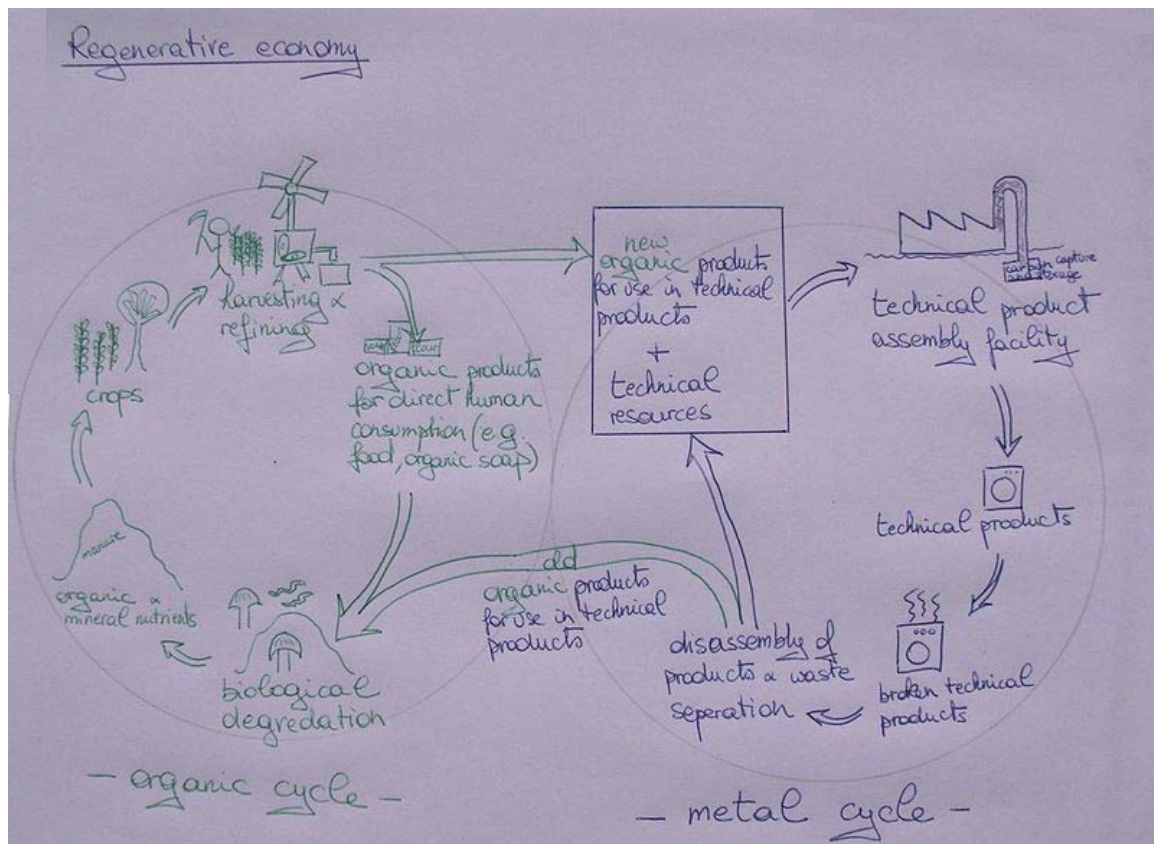
Cradle to Cradle Design

Cradle to Cradle Design (sometimes abbreviated to **C2C**, or **Cradle 2 Cradle**, or in some circles referred to as regenerative) is a biomimetic approach to the design of systems. It models human industry on nature's processes in which materials are viewed as nutrients circulating in healthy, safe metabolisms. It suggests that industry must protect and enrich ecosystems and nature's biological metabolism while also maintaining safe, productive technical metabolism for the high-quality use and circulation of organic and synthetic materials. Put simply, it is a holistic economic, industrial and social framework that seeks to create systems that are not just efficient but essentially waste free. The model in its broadest sense is not limited to industrial design and manufacturing; it can be applied to many different aspects of human civilization such as urban environments, buildings, economics and social systems.

The term 'C2C Certification' is a protected term of the McDonough Braungart Design Chemistry (MBDC) consultants. It is a proprietary system of certification. The phrase "Cradle to Cradle" itself was coined by Walter R. Stahel in the 1970s, and the current model is based on a system of "lifecycle development" initiated by Michael Braungart and colleagues at the Environmental Protection Encouragement Agency (EPEA) in the 1990s and explored through the publication *A Technical Framework for Life-Cycle Assessment*. In partnership with Braungart, William McDonough released the publication *Cradle to Cradle: Remaking the Way We Make Things* in 2002, which is an effective manifesto for Cradle to Cradle Design that gives specific details of how to achieve the model. The model has been implemented by a number of companies, organisations and governments around the world, predominantly in the European Union, China and the United States. Cradle to Cradle has also been the subject matter of many documentary films, including the critically acclaimed *Waste=Food*.

Introduction

In the Cradle to Cradle model, all materials used in industrial or commercial processes—such as metals, fibers, dyes—are seen to fall into one of two categories: "technical" or "biological" nutrients. *Technical nutrients* are strictly limited to non-toxic, non-harmful synthetic materials that have no negative effects on the natural environment; they can be used in continuous cycles as the same product without losing their integrity or quality. In this manner these materials can be used over and over again instead of being "downcycled" into lesser products, ultimately becoming waste. *Biological Nutrients* are organic materials that, once used, can be disposed of in any natural environment and decompose into the soil, providing food for small life forms without affecting the natural environment. This is dependent on the ecology of the region; for example, organic material from one country or landmass may be harmful to the ecology of another country or landmass.



Biological and technical cycle

The two types of materials each follow their own cycle in the regenerative economy envisioned by Keunen and Huizing.

Structure

The certification criteria in MBDC's C2C certification process are:

- 'Material Health', which involves identifying the chemical composition of the materials that make up the product. Particularly hazardous materials (e.g. heavy metals, pigments, halogen compounds etc.) have to be reported whatever the concentration, and other materials reported where they exceed 100 ppm. For wood, the forest source is required. The risk for each material is assessed against criteria and eventually ranked on a scale with green being materials of low risk, yellow being those with moderate risk but are acceptable to continue to use, and red for materials that have high risk and need to be phased out. Grey for materials with incomplete data. The method uses the term 'risk' in the sense of hazard (as opposed to consequence and likelihood).
- The next assessment is of 'Material Reutilization' which is about recovery and recycling at the end of product life.
- The third assessment is of energy required for production, which for the highest level of certification needs to be based at least 50% on solar for all parts and subassemblies.
- Fourth is water, particularly usage and discharge quality.
- The fifth area is 'social responsibility' which refers to fair labour practices.

The certification is available at several levels: basic, silver, gold, platinum, with more stringent requirements at each.

Health

Currently, many human beings come into contact or consume, directly or indirectly, many harmful materials and chemicals on a daily basis. In addition, countless other forms of plant and animal life are also exposed. C2C seeks to remove dangerous *technical nutrients* (synthetic materials such as mutagenic materials, heavy metals and other dangerous chemicals) from current life cycles. If the materials we come into contact with and are exposed to on a daily basis are not toxic and do not have long term health effects, then the health of the overall system can be better maintained. For example, a fabric factory can eliminate all harmful *technical nutrients* by carefully reconsidering what chemicals they use in their dyes to achieve the colours they need and attempt to do so with fewer base chemicals.

Economics

The use of a C2C model often lowers the financial cost of systems. For example, in the redesign of the Ford River Rouge Complex, the planting of native grasses on assembly plant roofs retains and cleanses rain water. It also moderates the internal temperature of the building in order to save energy. The roof is part of an \$18 million rainwater treatment system designed to clean 20 billion gallons (76,000,000 m³) of rainwater annually. This saved Ford \$50 million that would otherwise have been spent on

mechanical treatment facilities. If products are designed according to C2C design principles, they can be manufactured and sold for less than alternative designs. They eliminate the need for waste disposal such as landfills.

Definitions

- **Cradle to Cradle** phrase; essentially a play on the "Cradle to Grave" phrase, implying that the C2C model is sustainable and considerate of life in general.
- **Technical nutrients** are basically inorganic or synthetic materials manufactured by humans—such as plastics and metals--that can be used many times over without any loss in quality, staying in a continuous cycle.
- **Biological nutrients** and materials are organic materials that can decompose into the natural environment, soil, water, etc. without affecting it in a negative way, providing food for bacteria and microbiological life.
- **Materials** are usually referred to as the building blocks of other materials, such as the dyes used in colouring fibers or rubbers used in the sole of a shoe.
- **Downcycling** is a term used to describe what is conventionally known as recycling, which is seen as "downcycling" materials into lesser products, a plastic computer housing becomes a plastic cup, which then becomes a park bench, eventually becoming waste.
- **Waste = Food** is a basic concept of organic waste materials becoming food for bugs, insects and other small forms of life who can feed on it, decompose it and return it to the natural environment which we then indirectly use for food ourselves.

Existing synthetic materials

The question of how to deal with the countless existing *technical nutrients* (synthetic materials) that cannot be recycled or reintroduced to the natural environment is dealt with in C2C design. The materials that can be reused and retain their quality can be used within the technical nutrient cycles while other materials are far more difficult to deal with, such as plastics in the Pacific Ocean.

Hypothetical examples

One effective example is a shoe that is designed and mass produced using the C2C model. The sole might be made of "biological nutrients" while the upper parts might be made of "technical nutrients." The shoe is mass produced at a manufacturing plant that utilises its waste material by putting it back into the cycle; an example of this is using off-cuts from the rubber soles to make more soles instead of merely disposing of them (this is dependent on the technical materials not losing their quality as they are reused). Once the shoes have been manufactured, they are distributed to retail outlets where the customer buys the shoe at a fraction of the price they would normally pay for a shoe of comparable aspects; the customer is only paying for the use of the materials in the shoe for the period of time that they will be using the shoe. When they outgrow the shoe or it is damaged, they return it to the manufacturer. When the manufacturer separates the sole from the

upper parts (separating the technical and biological nutrients), the biological nutrients are returned to the natural environment while the technical nutrients are used to create the sole of another shoe.

Another example of C2C design is a disposable cup, bottle, or wrapper made entirely out of biological materials. When the user is finished with the item, it can be disposed of and returned to the natural environment; the cost of disposal of waste such as landfill and recycling is eliminated. The user could also potentially return the item for a refund so it can be used again.

Ford's Model U is a design concept of a car, made completely from cradle-to-cradle materials. It also uses hydrogen propulsion.

Finished products

- Cradle-to-cradle shoes have been made through the Nike Considered project.
- The Edag light car
- Rohner Textile AG Climatex-textile
- Biofoam; a cradle-to-cradle alternative to expanded polystyrene
- Sewage sludge processing plants are facilities that create fertiliser from sewage sludge. This approach is green retrofit for the current (inefficient) system of organic waste disposal; as composting toilets are a better approach in the long run.

Implementation

The C2C model can be applied to almost any system in modern society: urban environments, buildings, manufacturing, social systems. 5 steps are outlined in *Cradle to Cradle - Remaking the way we make things*:

- Get "free of" known culprits
- Follow informed personal preferences
- Create "passive positive" lists - lists of materials used categorised according to their safety level

The X List - substances that must be phased out, such as teratogenic, mutagenic, carcinogenic.

The Gray List - problematic substances that are not so urgently in need of phasing out

The P List - the "positive" list, substances actively defined as safe for use

- Activate the positive list
- Reinvent - the redesign of the former system

Products that adhere to all steps can generally be granted a certification. Two certifications used for cradle-to-cradle products include Leadership in Energy and

Environmental Design (LEED) and BRE Environmental Assessment Method (BREEAM).

C2C principles were first applied to systems in the early 1990s by Braungart's Hamburger Umweltinstitut (HUI) and The Environmental Institute in Brazil for biomass nutrient recycling of effluent to produce agricultural products and clean water as a byproduct.

Nowadays, the C2C principles are being actively promoted by the Environmental Protection and Encouragement Agency; which is another organisation directed by Michael Braungart.

In 2007, MBDC and the EPEA formed a strategic partnership with global materials consultancy Material ConneXion to help promote and disseminate C2C design principles by providing greater global access to C2C material information, certification and product development.

As of January 2008, Material ConneXion's Materials Libraries in New York, Milan, Cologne, Bangkok and Daegu, Korea started to feature C2C assessed and certified materials and, in collaboration with MBDC and EPEA, the company now offers C2C Certification, and C2C product development.

While the C2C model has influenced the construction or redevelopment of many smaller buildings, several large companies, organisations and governments have also implemented the C2C model and its ideas and concepts:

Major Implementations

- The Lyle Center for Regenerative Studies incorporates cradle to cradle systems throughout the center. The use of the term C2C is replaced with Regenerative.
- The Chinese Government is constructing many cities like Huangbaiyu based on C2C principles, utilising the rooftops for agriculture.
- The Ford River Rouge Complex redevelopment. Cleaning 20 billion gallons (76,000,000 m³) of rainwater annually.
- The Netherlands Institute of Ecology (NIOO-KNAW) will make its laboratory and office complex completely cradle to cradle compliant
- Several private houses and communal buildings in the Netherlands

Coordination with other models

The Cradle to Cradle model can be viewed as a framework that considers systems as a whole or holistically. It can be applied to many aspects of human society, and is related to Life cycle assessment. See for instance the LCA based model of the Eco-costs, which has been designed to cope with analyses of recycle systems. The Cradle to Cradle model in some implementations is closely linked with the Car-free movement, such as in the case of large scale building projects or the construction or redevelopment of urban environments. It is closely linked with passive solar design in the building industry and

with permaculture in agriculture within or near urban environments. An earthship is a perfect example where different re-use models are used, cradle to cradle and permaculture.

Criticism

Criticism has been advanced on the fact that McDonough and Braungart keep C2C consultancy and certification in their inner circle. The authors argue that this lack of competition prevents the model fulfilling its potential. They plead for a public-private partnership overseeing the C2C concept, thus enabling competition and growth of practical applications and services.

Experts in the field of environment protection have questioned the practicability of the concept. Friedrich Schmidt-Bleek, head of the German Wuppertal Institute called his assertion, that the "old" environmental movement had hindered innovation with its pessimist approach "pseudo-psychological humbug".

Schmidt-Bleek believes it to be completely out of the question that the concept can be realized on a bigger scale.

Moreover, several Life Cycle Assessment (LCA) practitioners, eco-design engineers and recycling experts tell their doubts about the technical implementation of the Cradle-to-Cradle concept.

Indeed, some claims (from some C2C representatives) pretend that C2C-certified products can be either compostable, or indefinitely recyclable with very minimal quality losses. According to several experts, this assertion should be re-discussed, especially because recycling conditions are much more complicated than what is defined and marketed by the C2C certification. In addition to this recycling issue, the fact that transportation criteria are not part of the certification's demand is also a potential source of discussions.

Some claim that C2C certification may not be entirely sufficient in all eco-design approaches. Quantitative methodologies (LCAs) and more adapted tools (regarding the product type which is considered) could be used in tandem.

It is safe to say that every production step or resource-transformation step needs a certain amount of energy (Newton's second law). Cradle to cradle approach does not consider this energy requirement nor where or how the energy is created to do so.

Chapter 5

Eco-Industrial Park & Eco-Efficiency

Eco-Industrial Park



View of the Kalundborg Eco-industrial Park

An **eco-industrial park** (EIP) is an industrial park in which businesses cooperate with each other and with the local community in an attempt to reduce waste and pollution, efficiently share resources (such as information, materials, water, energy, infrastructure, and natural resources), and help achieve sustainable development, with the intention of increasing economic gains and improving environmental quality. An EIP may also be planned, designed, and built in such a way that it makes it easier for businesses to cooperate, and that results in a more financially sound, environmentally friendly project for the developer.

The Eco-industrial Park Handbook states that "An Eco-Industrial Park is a community of manufacturing and service businesses located together on a common property. Members seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues."

Based on the concepts of industrial ecology, collaborative strategies not only include by-product synergy ("waste-to-feed" exchanges), but can also take the form of wastewater cascading, shared logistics and shipping & receiving facilities, shared parking, green technology purchasing blocks, multi-partner green building retrofit, district energy systems, and local education & resource centres. This is an application of a systems approach, in which designs and processes/activities are integrated to address multiple objectives.

EIPs can be developed as greenfield land projects, where the eco-industrial intent is present throughout the planning, design and site construction phases, or developed through retrofits and new strategies in existing industrial developments.

Examples



Example of Industrial Symbiosis. Waste steam from a waste incinerator (right) is piped to an ethanol plant (left) where it is used as input to their production process.

"Industrial symbiosis" is a related but more limited concept in which companies in a region collaborate to utilize each other's by-products and otherwise share resources. In Kalundborg, Denmark a symbiosis network links a 1500MW coal fired power plant with the community and other companies. Surplus heat from this power plant is used to heat 3500 local homes in addition to a nearby fish farm, whose sludge is then sold as a fertilizer. Steam from the power plant is sold to Novo Nordisk, a pharmaceutical and enzyme manufacturer, in addition to a Statoil plant. This reuse of heat reduces the amount thermal pollution discharged to a nearby fjord. Additionally, a by-product from the power plant's sulfur dioxide scrubber contains gypsum, which is sold to a wallboard

manufacturer. Almost all of the manufacturer's gypsum needs are met this way, which reduces the amount of open-pit mining needed. Furthermore, fly ash and clinker from the power plant is utilized for road building and cement production.

The industrial symbiosis at Kalundborg was not created as a top-down initiative, but instead evolved gradually. As environmental regulations became stricter, firms were motivated reduce the cost of compliance, and turn their by-products into economic products.

In Canada, eco-industrial parks exist across the country and have enjoyed some success. The best known example is Burnside Park, in Halifax, Nova Scotia. With support from Dalhousie University's Eco-Efficiency Centre, the more than 1,500 businesses have been improving their environmental performance and developing profitable partnerships. Subsequently, two greenfield industrial developments have been started in Alberta: TaigaNova Eco-Industrial Park is in the heart of the Athabasca oil sands, while Innovista Eco-Industrial Park is a gateway to the Rocky Mountains ~300km west of Edmonton.

Other usage

EIPs also refer to industrial parks where a "green" approach has been taken towards the infrastructure and development of the site. This can include green infrastructure related to Renewable Energy Systems; stormwater, groundwater and wastewater management; road surfaces; and transportation demand management. Green building practices can also be encouraged or mandated

EIPs are often used as a stimulus for economic diversification in the community or region where they are located. Anchor tenants, such as bio-based product manufacturers or waste-to-energy facilities, etc., can attract complementary businesses as suppliers, scavengers/recyclers, service providers, downstream users and other businesses that could benefit from eco-industrial strategies.

Suggested usage

It is suggested that EIPs be used as a means of growing the renewable energy sector. In the case of a Solar Photovoltaic (PV) Manufacturing plant, an EIP can increase the manufacturing efficiency to make it more economical, while reducing the environmental impact of producing the solar cells. In essence, this assists the growth of the renewable energy industry and the environmental benefits that come with replacing fossil-fuels.

Eco-Efficiency

The term **eco-efficiency** was coined by the World Business Council for Sustainable Development (WBCSD) in its 1992 publication "Changing Course". It is based on the concept of creating more goods and services while using fewer resources and creating less waste and pollution.

The 1992 Earth Summit endorsed eco-efficiency as a means for companies to implement Agenda 21 in the private sector, and the term has become synonymous with a management philosophy geared towards sustainability.

According to the WBCSD definition, eco-efficiency is achieved through the delivery of "competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the Earth's estimated carrying capacity."

This concept describes a vision for the production of economically valuable goods and services while reducing the ecological impacts of production. In other words eco-efficiency means producing more with less.

According to the WBCSD, critical aspects of eco-efficiency are:

- A reduction in the material intensity of goods or services;
- A reduction in the energy intensity of goods or services;
- Reduced dispersion of toxic materials;
- Improved recyclability;
- Maximum use of renewable resources;
- Greater durability of products;
- Increased service intensity of goods and services.

The reduction in ecological impacts translates into an increase in resource productivity, which in turn can create a competitive advantage.

Strategies that have been linked to eco-efficiency include "Factor 4" and "Factor 10", which call for specific reductions in resource use, "natural capitalism", which incorporates eco-efficiency as part of a broader strategy, and the "cradle-to-cradle" movement, which claims to go beyond eco-efficiency in abolishing the very idea of waste. According to Boulanger, all versions of eco-efficiency share four key characteristics:

- Confidence in technological innovation as the main solution to un-sustainability;
- Reliance on business as the principal actor of transformation. The emphasis is on firms designing new products, shifting to new production processes, and investing in R&D, etc., more than on the retailer or the consumer, let alone the citizen.
- Trust in markets (if they are functioning well);
- "Growthphilia": there is nothing wrong with growth as such. Moreover, with "cradle-to-cradle", growth is conducive to sustainability per se.

Chapter 6

Life Cycle Assessment

A **life cycle assessment (LCA)**, also known as **life cycle analysis**, **ecobalance**, and **cradle-to-grave analysis**) is a technique to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). LCA's can help avoid a narrow outlook on environmental concerns by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help you make a more informed decision.

Goals and purpose of LCA

The goal of LCA is to compare the full range of environmental effects assignable to products and services in order to improve processes, support policy and provide a sound basis for informed decisions.

The term 'life cycle' refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product's existence.

There are two main types of LCA. Attributional LCAs seek to establish the burdens associated with the production and use of a product, or with a specific service or process, at a point in time (typically the recent past). Consequential LCAs seek to identify the environmental consequences of a decision or a proposed change in a system under study (oriented to the future), which means that market and economic implications of a decision may have to be taken into account. Social LCA is under development as a different

approach to life cycle thinking intended to assess social implications or potential impacts. Social LCA should be considered as an approach that is complementary to environmental LCA.

The procedures of life cycle assessment (LCA) are part of the ISO 14000 environmental management standards: in ISO 14040:2006 and 14044:2006. (ISO 14044 replaced earlier versions of ISO 14041 to ISO 14043.)

Four main phases

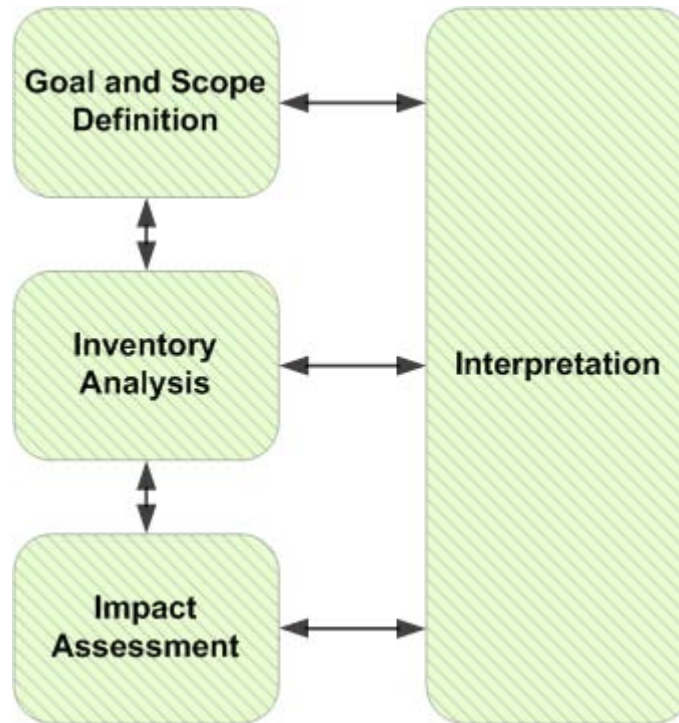


Illustration of LCA phases.

According to the ISO 14040 and 14044 standards, a Life Cycle Assessment is carried out in four distinct phases as illustrated in the figure shown to the right. The phases are often interdependent in that the results of one phase will inform how other phases are completed.

Goal and scope

An LCA starts with an explicit statement of the goal and scope of the study, which sets out the context of the study and explains how and to whom the results are to be communicated. This is a key step and the ISO standards require that the goal and scope of an LCA be clearly defined and consistent with the intended application. The goal and scope document therefore includes technical details that guide subsequent work:

- the functional unit, which defines what precisely is being studied and quantifies the service delivered by the product system, providing a reference to which the inputs and outputs can be related;
- the system boundaries;
- any assumptions and limitations;
- the allocation methods used to partition the environmental load of a process when several products or functions share the same process; and
- the impact categories chosen.

Life cycle inventory

Life Cycle Inventory (LCI) analysis involves creating an inventory of flows from and to nature for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water. To develop the inventory, a flow model of the technical system is constructed using data on inputs and outputs. The flow model is typically illustrated with a flow chart that includes the activities that are going to be assessed in the relevant supply chain and gives a clear picture of the technical system boundaries. The input and output data needed for the construction of the model are collected for all activities within the system boundary, including from the supply chain (referred to as inputs from the technosphere).

The data must be related to the functional unit defined in the goal and scope definition. Data can be presented in tables and some interpretations can be made already at this stage. The results of the inventory is an LCI which provides information about all inputs and outputs in the form of elementary flow to and from the environment from all the unit processes involved in the study.

Inventory flows can number in the hundreds depending on the system boundary. For product LCAs at either the generic (i.e., representative industry averages) or brand-specific level, that data is typically collected through survey questionnaires. At an industry level, care has to be taken to ensure that questionnaires are completed by a representative sample of producers, leaning toward neither the best nor the worst, and fully representing any regional differences due to energy use, material sourcing or other factors. The questionnaires cover the full range of inputs and outputs, typically aiming to account for 99% of the mass of a product, 99% of the energy used in its production and any environmentally sensitive flows, even if they fall within the 1% level of inputs.

One area where data access is likely to be difficult is flows from the technosphere. Those completing a questionnaire will be able to specify how much of a given input they use from supply chain sources, but they will not usually have access to data concerning inputs and outputs for those production processes. The entity undertaking the LCA must then turn to secondary sources if it does not already have that data from its own previous studies. National databases or data sets that come with LCA-practitioner tools, or that can be readily accessed, are the usual sources for that information. Care must then be taken to ensure that the secondary data source properly reflects regional or national conditions.

Life cycle impact assessment

Inventory analysis is followed by impact assessment. This phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results. Classical Life Cycle Impact Assessment (LCIA) consists of the following mandatory elements:

- selection of impact categories, category indicators, and characterization models;
- the classification stage, where the inventory parameters are sorted and assigned to specific impact categories; and
- impact measurement, where the categorized LCI flows are characterized, using one of many possible LCIA methodologies, into common equivalence units that are then summed to provide an overall impact category total.

In many LCAs, characterization concludes the LCIA analysis; this is also the last compulsory stage according to ISO 14044:2006. However, in addition to the above mandatory LCIA steps, other optional LCIA elements – normalization, grouping, and weighting – may be conducted depending on the goal and scope of the LCA study. In normalization, the results of the impact categories from the study are usually compared with the total impacts in the region of interest, the U.S. for example. Grouping consists of sorting and possibly ranking the impact categories. During weighting, the different environmental impacts are weighted relative to each other so that they can then be summed to get a single number for the total environmental impact. ISO 14044:2006 generally advises against weighting, stating that “weighting, shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public”. This advice is often ignored, resulting in comparisons that can reflect a high degree of subjectivity as a result of weighting.

Interpretation

Life Cycle Interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the life cycle inventory and/or the life cycle impact assessment. The results from the inventory analysis and impact assessment are summarized during the interpretation phase. The outcome of the interpretation phase is a set of conclusions and recommendations for the study. According to ISO 14040:2006, the interpretation should include:

- identification of significant issues based on the results of the LCI and LCIA phases of an LCA;
- evaluation of the study considering completeness, sensitivity and consistency checks; and
- conclusions, limitations and recommendations.

A key purpose of performing life cycle interpretation is to determine the level of confidence in the final results and communicate them in a fair, complete, and accurate manner. Interpreting the results of an LCA is not as simple as 3 is better than 2, therefore

Alternative A is the best choice! Interpreting the results of an LCA starts with understanding the accuracy of the results, and ensuring they meet the goal of the study. This is accomplished by identifying the data elements that contribute significantly to each impact category, evaluating the sensitivity of these significant data elements, assessing the completeness and consistency of the study, and drawing conclusions and recommendations based on a clear understanding of how the LCA was conducted and the results were developed.

LCA tools and uses

There are two basic types of LCA tools:

- dedicated software packages intended for practitioners; and
- tools with the LCA in the background intended for people who want LCA-based results without have to actually develop the LCA data and impact measures.

In the former category, the two principal tools are GaBi Software, developed by PE International, and SimaPro, developed by PRé Consultants, In the second category, different tools operate at different levels. At the product level, the U.S. National Institute of Standards and Technology (NIST) makes its BEES (Building for Environmental and Economic Sustainability) tool freely available. At the whole building design level, different tools are available in different parts of the world. For example, the ATHENA® Impact Estimator for Buildings is capable of modeling 95% of the building stock in North America, Envest has been developed by the Building Research Establishment to meet UK needs, and EcoQuantum is available in the Netherlands. At a building assembly level (e.g., exterior walls) the free ATHENA® EcoCalculator for Assemblies is an example of a tool that serves North America and the Whole Building Design Guide is an example of a tool applicable to the UK.

Based on a survey of LCA practitioners carried out in 2006 LCA is mostly used to support business strategy (18%) and R&D (18%), as input to product or process design (15%), in education (13%) and for labeling or product declarations (11%).

Major corporations all over the world are either undertaking LCA in house or commissioning studies, while governments support the development of national databases to support LCA. Of particular note is the growing use of LCA for ISO Type III labels called Environmental Product Declarations, defined as "quantified environmental data for a product with pre-set categories of parameters based on the ISO 14040 series of standards, but not excluding additional environmental information".. These third-party certified LCA-based labels provide an increasingly important basis for assessing the relative environmental merits of competing products.

Data analysis

A life cycle analysis is only as valid as its data; therefore, it is crucial that data used for the completion of a life cycle analysis is accurate and current. When comparing different

life cycle analyses with one another, it is crucial that equivalent data is available for both products or processes in question. If one product has a much higher availability of data, it cannot be justly compared to another product which has less detailed data.

There are two basic types of LCA data – unit process data and environmental input-output data (EIO), where the latter is based on national economic input-output data. Unit process data is derived from direct surveys of companies or plants producing the product of interest, carried out at a unit process level defined by the system boundaries for the study.

The validity of data should always be a concern with life cycle analyses. Since we are living in a global world and economy, new processes, manufacturing methods, and materials are introduced to various processes and products. Therefore, it is important to have current data when performing a LCA. If data from 5 to 10 years in the past is used, the LCA will not be accurate, because the quantitative analysis will not reflect the current methods utilized in the process or product. Therefore, drawing conclusions from a report using such data will be ineffective, since the data is unavailable. Some products, whose processes have not changed in 5 to 10 years (if there are any) will be exempt from this. When analyzing electronics, such as cell phones or computers, for example, the most current data is necessary. Since new computer and cell phone models are created every few months, the results of a life cycle analysis of a 3-year-old computer system will often not be applicable to current systems.

The life cycle considered usually consists of a number of stages including: materials extraction, processing and manufacturing, product use, and product disposal. If the most environmentally harmful of these stages can be determined, then impact on the environment can be efficiently reduced by focusing on making changes for that particular phase. For example, the most energy-intensive life phase of an airplane or car is during use due to fuel consumption. One of the most effective ways to increase fuel efficiency is to decrease vehicle weight, and thus, car and airplane manufacturers can decrease environmental impact in a significant way by replacing aluminum with lighter materials such as carbon fiber reinforced fibers. The reduction during the use phase should be more than enough to balance additional raw material or manufacturing cost.

Variants

Cradle-to-grave

Cradle-to-grave is the full Life Cycle Assessment from resource extraction ('cradle') to use phase and disposal phase ('grave'). For example, trees produce paper, which can be recycled into low-energy production cellulose (fiberised paper) insulation, then used as an energy-saving device in the ceiling of a home for 40 years, saving 2,000 times the fossil-fuel energy used in its production. After 40 years the cellulose fibers are replaced and the old fibers are disposed of, possibly incinerated. All inputs and outputs are considered for all the phases of the life cycle.

Cradle-to-gate

Cradle-to-gate is an assessment of a *partial* product life cycle from resource extraction ('cradle') to the factory gate (i.e., before it is transported to the consumer). The use phase and disposal phase of the product are omitted in this case. Cradle-to-gate assessments are sometimes the basis for environmental product declarations (EPD) termed business-to-business EDPs.

Cradle-to-Cradle or Open Loop Production

Cradle-to-cradle is a specific kind of cradle-to-grave assessment, where the end-of-life disposal step for the product is a recycling process. It is a method used to minimize the environmental impact of products by employing sustainable production, operation, and disposal practices and aims to incorporate social responsibility into product development. From the recycling process originate new, identical products (e.g., asphalt pavement from discarded asphalt pavement, glass bottles from collected glass bottles), or different products (e.g., glass wool insulation from collected glass bottles).

Allocation of burden for products in open loop production systems presents considerable challenges for LCA. Various methods, such as the avoided burden approach have been proposed to deal with the issues involved.

Gate-to-gate

Gate-to-gate is a partial LCA looking at only one value-added process in the entire production chain. Gate-to-gate modules may also later be linked in their appropriate production chain to form a complete cradle-to-gate evaluation.

Well-to-wheel

Well-to-wheel is the specific LCA used for transport fuels and vehicles. The analysis is often broken down into stages entitled "well-to-station", or "well-to-tank", and "station-to-wheel" or "tank-to-wheel", or "plug-to-wheel". The first stage, which incorporates the feedstock or fuel production and processing and fuel delivery or energy transmission, and is called the "upstream" stage, while the stage that deals with vehicle operation itself is sometimes called the "downstream" stage. The well-to-wheel analysis is commonly used to assess total energy consumption, or energy conversion efficiency and emissions impact of marine vessels, aircrafts and motor vehicle emissions, including their carbon footprint, and the fuels used in each of these transport modes.

The well-to-wheel variant has a significant input on a model developed by the Argonne National Laboratory. The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model was developed to evaluate the impacts of new fuels and vehicle technologies. The model evaluates the impacts of fuel use using a well-to-wheel evaluation while a traditional cradle-to-grave approach is used to determine the impacts from the vehicle itself. The model reports energy use, greenhouse gas emissions, and six

additional pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NO_x), particulate matter with size smaller than 10 micron (PM₁₀), particulate matter with size smaller than 2.5 micron (PM_{2.5}), and sulfur oxides (SO_x).

Economic input–output life cycle assessment

Economic input–output LCA (EIO-LCA) involves use of aggregate sector-level data on how much environmental impact can be attributed to each sector of the economy and how much each sector purchases from other sectors. Such analysis can account for long chains (for example, building an automobile requires energy, but producing energy requires vehicles, and building those vehicles requires energy, etc.), which somewhat alleviates the scoping problem of process LCA; however, EIO-LCA relies on sector-level averages that may or may not be representative of the specific subset of the sector relevant to a particular product and therefore is not suitable for evaluating the environmental impacts of products. Additionally the translation of economic quantities into environmental impacts is not validated.

Ecologically-based LCA

While a conventional LCA uses many of the same approaches and strategies as an Eco-LCA, the latter considers a much broader range of ecological impacts. It was designed to provide a guide to wise management of human activities by understanding the direct and indirect impacts on ecological resources and surrounding ecosystems. Developed by Ohio State University Center for resilience, Eco-LCA is a methodology that quantitatively takes into account regulating and supporting services during the life cycle of economic goods and products. In this approach services are categorized in four main groups: supporting, regulating provisioning and cultural services.

Life cycle energy analysis

Life cycle energy analysis (LCEA) is an approach in which all energy inputs to a product are accounted for, not only direct energy inputs during manufacture, but also all energy inputs needed to produce components, materials and services needed for the manufacturing process. An earlier term for the approach was *energy analysis*.

With LCEA, the *total life cycle energy input* is established.

Energy production

It is recognized that much energy is lost in the production of energy commodities themselves, such as nuclear energy, photovoltaic electricity or high-quality petroleum products. *Net energy content is the energy content of the product minus energy input used during extraction and conversion, directly or indirectly.* A controversial early result of LCEA claimed that manufacturing solar cells requires more energy than can be recovered in using the solar cell. The result was refuted. Another new concept that flows from life cycle assessments is Energy Cannibalism. Energy Cannibalism refers to an effect where

rapid growth of an entire energy-intensive industry creates a need for energy that uses (or cannibalizes) the energy of existing power plants. Thus during rapid growth the industry as a whole produces no energy because new energy is used to fuel the embodied energy of future power plants. Work has been undertaken in the UK to determine the life cycle energy (alongside full LCA) impacts of a number of renewable technologies.

Energy recovery

If materials are incinerated during the disposal process, the energy released during burning can be harnessed and used for electricity production. This provides a low-impact energy source, especially when compared with coal and natural gas. While incineration produces more greenhouse gas emissions than landfilling, the waste plants are well-fitted with filters to minimize this negative impact. A recent study comparing energy consumption and greenhouse gas emissions from landfilling (without energy recovery) against incineration (with energy recovery) found incineration to be superior in all cases except for when landfill gas is recovered for electricity production.

LCEA criticism

A criticism of LCEA is that it attempts to eliminate monetary cost analysis, that is replace the currency by which economic decisions are made with an energy currency. It has also been argued that energy efficiency is only one consideration in deciding which alternative process to employ, and that it should not be elevated to the only criterion for determining environmental acceptability; for example, simple energy analysis does not take into account the renewability of energy flows or the toxicity of waste products; however the life cycle assessment does help companies become more familiar with environmental properties and improve their environmental system. Incorporating **Dynamic LCAs** of renewable energy technologies (using sensitivity analyses to project future improvements in renewable systems and their share of the power grid) may help mitigate this criticism.

A problem the energy analysis method cannot resolve is that different energy forms (heat, electricity, chemical energy etc.) have different quality and value even in natural sciences, as a consequence of the two main laws of thermodynamics. A thermodynamic measure of the quality of energy is exergy. According to the first law of thermodynamics, all energy inputs should be accounted with equal weight, whereas by the second law diverse energy forms should be accounted by different values.

The conflict is resolved in one of these ways:

- value difference between energy inputs is ignored,
- a value ratio is arbitrarily assigned (e.g., a joule of electricity is 2.6 times more valuable than a joule of heat or fuel input),
- the analysis is supplemented by economic (monetary) cost analysis,
- exergy instead of energy can be the metric used for the life cycle analysis.

Critiques

Life cycle assessment is a powerful tool for analyzing commensurable aspects of quantifiable systems. Not every factor, however, can be reduced to a number and inserted into a model. Rigid system boundaries make accounting for changes in the system difficult. This is sometimes referred to as the boundary critique to systems thinking. The accuracy and availability of data can also contribute to inaccuracy. For instance, data from generic processes may be based on averages, unrepresentative sampling, or outdated results. Additionally, social implications of products are generally lacking in LCAs. Comparative life-cycle analysis is often used to determine a better process or product to use. However, because of aspects like differing system boundaries, different statistical information, different product uses, etc., these studies can easily be swayed in favor of one product or process over another in one study and the opposite in another study based on varying parameters and different available data. There are guidelines to help reduce such conflicts in results but the method still provides a lot of room for the researcher to decide what is important, how the product is typically manufactured, and how it is typically used.

An in-depth review of 13 LCA studies of wood and paper products found a lack of consistency in the methods and assumptions used to track carbon during the product life cycle. A wide variety of methods and assumptions were used, leading to different and potentially contrary conclusions – particularly with regard to carbon sequestration and methane generation in landfills and with carbon accounting during forest growth and product use.

The Agroecology tool "agroecosystem analysis" offers a framework to incorporate incommensurable aspects of the life cycle of a product (such as social impacts, and soil and water implications). This tool is specifically useful in the analysis of a product made from agricultural materials such as corn ethanol or soybean biodiesel because it can account for an ecology of contexts interacting and changing through time. This analysis tool should not be used instead of life-cycle analysis, but rather, in conjunction with life-cycle analysis to produce a well-rounded assessment.

Dynamic life cycle assessment

In recent years, the literature on life cycle assessment of energy technology has begun to reflect the interactions between the current electrical grid and future energy technology. Some papers have focused on energy life cycle, while others have focused on carbon dioxide and other greenhouse gases. The essential critique given by these sources is that when considering energy technology, the growing nature of the power grid must be taken into consideration. If this is not done, a given class of energy technology may emit more carbon dioxide over its lifetime than it mitigates.

Chapter 7

Extended Producer Responsibility

Extended producer responsibility (EPR) is a strategy designed to promote the integration of environmental costs associated with goods throughout their life cycles into the market price of the products.

Definition

Also known as product stewardship, EPR uses financial incentives to encourage manufacturers to design environmentally-friendly products by holding producers liable for the costs of managing their products at end of life. This tactic attempts to relieve local governments of the costs of managing certain priority products by forcing manufacturers to internalize the cost of recycling within the product price. EPR promotes that producers (usually brand owners) have the greatest control over product design and marketing and therefore have the greatest ability and responsibility to reduce toxicity and waste.

EPR may take the form of a reuse, buy-back, or recycling program, or in energy production from waste materials. The producer may also choose to delegate this responsibility to a third party, a so-called *producer responsibility organization* (PRO), which is paid by the producer for spent-product management. In this way, EPR shifts responsibility for waste from government to private industry, obliging producers, importers and/or sellers to internalise waste management costs in their product prices and ensuring the sustainable and safe handling of the remains of their products.

A good example for producer responsibility organisations are the member organisations of PRO EUROPE. PRO EUROPE s.p.a. (PACKAGING RECOVERY ORGANISATION EUROPE), founded in 1995, is the umbrella organisation for European packaging and packaging waste recovery and recycling schemes which set themselves the task of relieving industrial companies and commercial enterprises of their individual obligation to take back used sales packaging through the operation of a scheme which fulfils these obligations on a nation-wide basis on behalf of their member

companies. The aim is to ensure the recovery and recycling of packaging waste in the most economically efficient and ecologically sound manner. In many countries, this is done through the Green Dot (symbol) trademark of which PRO EUROPE is the general licensor. The "Green Dot" has evolved into a proven concept in many countries as implementation of Producer Responsibility. Industry in twenty-five nations is now using the "Green Dot" as the financing symbol for the organisation of recovery, sorting and recycling of sales packaging.

Take-Back

In response to the growing problem of excessive waste, several countries adopted liability schemes in which manufacturers must take responsibility for their products in attempts to slow the filling of landfills and the consequential releases of toxic materials from the discarded products. Such laws, known as "take-backs," are requirements imposed on manufacturers, importers, and seller to take back their products from end users at the end of the products useful life. The goals of take-back laws are to

1. encourage companies to design products for reuse, recyclability, and materials reduction;
2. correcting market signals to the consumer by incorporating waste management costs into the product's price;
3. promoting innovation in recycling technology.

Take-backs make these goals a reality by creating incentives for companies to redesign their products by incorporating safer materials and making products easier to recycle and reuse. The greatest take-back activity has been in Europe, where government-sponsored take-back initiatives arose from concerns about scarce landfill space and potentially hazardous substances in component parts. The European Union adopted a directive on Waste Electrical and Electronic Equipment (WEEE). The purpose of this directive is to prevent the production of WEEE and also to encourage reuse and recycling of such waste. The directive requires the Member States to encourage design and production methods that take into account the future dismantling and recovery of their products. The United States, in contrast, imposes no take-back requirements at the federal level, partly because the U.S. Environmental Protection Agency (EPA) lacks the authority to enforce them on a national level.

Extended Producer Responsibility for Electronics

Extended Producer Responsibility is becoming an increasingly popular solution to the problems of E-waste. Although the United States does not currently have a national law or policy requiring producer responsibility, many states have already passed laws requiring producer responsibility and many others are currently working towards passing producer responsibility laws. Currently more than twenty states have passed such laws. Instead of communities or the government having financial and physical responsibility of recycling hazardous electronics, Extended Producer Responsibility laws across the

country are demanding manufacturers of these products to take responsibility for their reuse, recycling, and disposal.

Advantages

When producers are held directly accountable for their products end of life impact or recycling under Extended Producer Responsibility laws, there are many positive consequences. Because producers either face a financial or physical burden of recycling their electronics after use, producers are more willing to design more sustainable, less toxic, and easily recyclable electronics. They are encouraged to use less materials and design their product to last longer in order to cut costs. Extended Producer Responsibility has the potential to alter the industry standard of planned obsolescence by encouraging a longer life to reduce overall cost of production and recycling. EPR's can also affect more than just product design; because producers are so invested in the recycling process, it is likely that they will search for better ways to recycle as well as take advantage of all of the materials they can reuse. Current and future programs are supported by environmental groups, government recycling and disposal facilities, and citizens across the country.

Disadvantages

Although Producer Responsibility or Take-back laws have been successful in the past for items such as packaging and diapers, electronics are incredibly more complex and difficult to break down and safely recycle. Due to the complexity and lack of recycling techniques for electronics, Extended Producer Responsibility laws could increase the cost of electronics for consumers because producers would be adding recycling costs into the initial price tag of items. Companies would be forced to transport the waste to a recycling facility or build their own, both of which are incredibly expensive. Many organizations and researchers against EPR claim that the mandate would slow technical innovation and impede technological process. One of the major setbacks for current EPR laws is the lack of industry standards. There are no industry or national regulations or guidelines for recycling of electronics. Because most EPR laws or mandates are relatively new, benefits and outcomes in general are still fairly ambiguous.

Implementation

EPR has been implemented in many forms, which may be classified into three major approaches:

- Mandatory
- Negotiated
- Voluntary

It is perhaps because of the tendency of economic policy in market-driven economies not to interfere with consumers' preferences that the producer-centric representation is the dominant form of viewing the environmental impacts of industrial production: in statistics on energy, emissions, water, etc., impacts are almost always presented as

attributes of industries ('on-site' or 'direct' allocation) rather than as attributes of the supply chains of products for consumers. On a smaller scale, most existing schemes for corporate sustainability reporting include only impacts that arise out of operations controlled by the reporting company, and not supply-chain impacts. According to this world view, "upstream and downstream [environmental] impacts are [...] allocated to their immediate producers. The institutional setting and the different actors' spheres of influence are not reflected."

On the other hand, a number of studies have highlighted that final consumption and affluence, especially in the industrialised world, are the main drivers for the level and growth of environmental pressure. Even though these studies provide a clear incentive for complementing producer-focused environmental policy with some consideration for consumption-related aspects, demand-side measures to environmental problems are rarely exploited.

The nexus created by the different views on impacts caused by industrial production is exemplified by several contributions to the discussion about producer or consumer responsibility for greenhouse gas emissions. Emissions data are reported to the IPCC as contributions of producing industries located in a particular country rather than as embodiments in products consumed by a particular population, irrespective of productive origin. However, especially for open economies, taking into account the greenhouse gases embodied in internationally traded commodities can have a considerable influence on national greenhouse gas balance sheets. Assuming consumer responsibility, exports have to be subtracted from, and imports added to national greenhouse gas inventories. In Denmark for example, Munksgaard and Pedersen (2001) report that a significant amount of power and other energy-intensive commodities are traded across Danish borders, and that between 1966 and 1994 the Danish foreign trade balance in terms of CO₂ developed from a 7 Mt deficit to a 7 Mt surplus, compared to total emissions of approximately 60 Mt. In particular, electricity traded between Norway, Sweden and Denmark is subject to large annual fluctuations due to varying rainfall in Norway and Sweden. In wet years Denmark imports hydro-electricity whereas electricity from coal-fired power plants is exported in dry years. The official Danish emissions inventory includes a correction for electricity trade and thus applies the consumer responsibility principle.

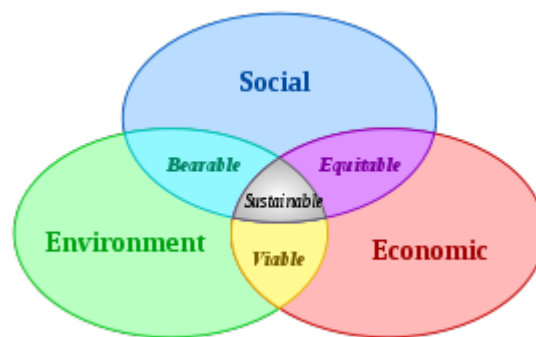
Similarly, at the company level, "when adopting the concept of eco-efficiency and the scope of an environmental management system stated in for example ISO 14001, it is insufficient to merely report on the carbon dioxide emissions limited to the judicial borders of the company".⁷ "Companies must recognise their wider responsibility and manage the entire life-cycle of their products ... Insisting on high environmental standards from suppliers and ensuring that raw materials are extracted or produced in an environmentally conscious way provides a start". A life-cycle perspective is also taken in Extended Producer Responsibility (EPR) frameworks: "Producers of products should bear a significant degree of responsibility (physical and/or financial) not only for the environmental impacts of their products downstream from the treatment and disposal of their product, but also for their upstream activities inherent in the selection of materials and in the design of products". "The major impetus for EPR came from northern

European countries in the late 1980s and early 1990s, as they were facing severe landfill shortages. [... As a result,] EPR is generally applied to post-consumer wastes which place increasing physical and financial demands on municipal waste management."

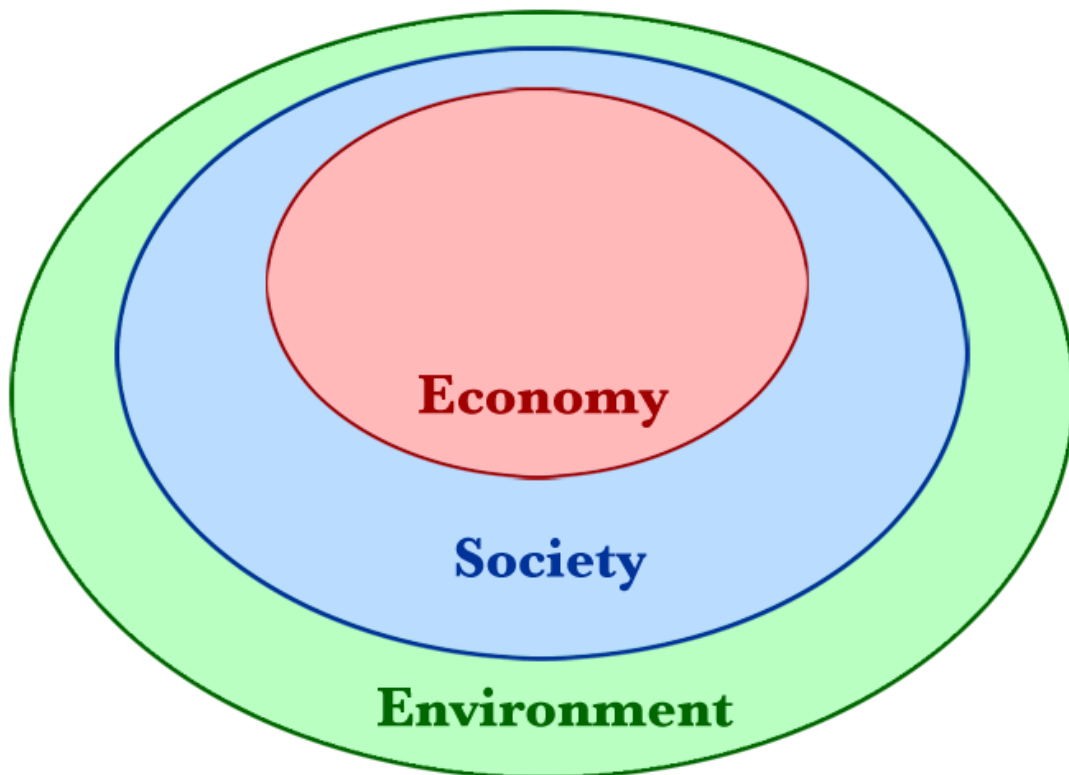
EPR has rarely been consistently quantified. Moreover, applying conventional life cycle assessment, and assigning environmental impacts to producers and consumers can lead to double-counting. Using input-output analysis, researchers have attempted for decades to account for both producers and consumers in an economy in a consistent way. Gallego and Lenzen demonstrate and discuss a method of consistently delineating producers' supply chains, into mutually exclusive and collectively exhaustive responsibilities to be shared by all agents in an economy. Their method is an approach to allocating responsibility across agents in a fully inter-connected circular system. Upstream and downstream environmental impacts are shared between all agents of a supply chain - producers and consumers.

Chapter 8

Ecological Economics



The three pillars of sustainability.



Three circles enclosed within one another showing how both economy and society are subsets of our planetary ecological system. This view is useful for correcting the misconception, sometimes drawn from the previous "three pillars" diagram that portions of social and economic systems can exist independently from the environment.

Ecological economics is a transdisciplinary field of academic research that aims to address the interdependence and coevolution of human economies and natural ecosystems over time and space. It is distinguished from environmental economics, which is the mainstream economic analysis of the environment, by its treatment of the economy as a subsystem of the ecosystem and its emphasis upon preserving natural capital. One survey of German economists found that ecological and environmental economics are different schools of economic thought, with ecological economists emphasizing "strong" sustainability and rejecting the proposition that natural capital can be substituted by human-made capital.

Ecological economics was founded in the works of Kenneth E. Boulding, Nicholas Georgescu-Roegen, Herman Daly, Robert Costanza, and others. The related field of green economics is, in general, a more politically applied form of the subject.

The identity of ecological economics as a field has been described as fragile, with no generally accepted theoretical framework and a knowledge structure which is not clearly defined. According to ecological economist Malte Faber, ecological economics is defined

by its focus on nature, justice, and time. Issues of intergenerational equity, irreversibility of environmental change, uncertainty of long-term outcomes, and sustainable development guide ecological economic analysis and valuation. Ecological economists have questioned fundamental mainstream economic approaches such as cost-benefit analysis, and the separability of economic values from scientific research, contending that economics is unavoidably normative rather than positive (empirical). Positional analysis, which attempts to incorporate time and justice issues, is proposed as an alternative.

Ecological economics includes the study of the metabolism of society, that is, the study of the flows of energy and materials that enter and exit the economic system. This subfield may also be referred to as biophysical economics, bioeconomics, and has links with the applied science of industrial symbiosis. Ecological economics is based on a conceptual model of the economy connected to, and sustained by, a flow of energy, materials, and ecosystem services. Analysts from a variety of disciplines have conducted research on the economy-environment relationship, with concern for energy and material flows and sustainability, environmental quality, and economic development.

Nature and ecology



Environmental Scientist sampling water.

A simple circular flow of income diagram is replaced in ecological economics by a more complex flow diagram reflecting the input of solar energy, which sustains natural inputs

and environmental services which are then used as units of production. Once consumed, natural inputs pass out of the economy as pollution and waste. The potential of an environment to provide services and materials is referred to as an "environment's source function", and this function is depleted as resources are consumed or pollution contaminates the resources. The "sink function" describes an environment's ability to absorb and render harmless waste and pollution: when waste output exceeds the limit of the sink function, long-term damage occurs.⁸ Some persistent pollutants, such as some organic pollutants and nuclear waste are absorbed very slowly or not at all; ecological economists emphasize minimizing "cumulative pollutants".²⁸ Pollutants affect human health and the health of the climate.

The economic value of natural capital and ecosystem services is accepted by mainstream environmental economics, but is emphasized as especially important in ecological economics. Ecological economists may begin by estimating how to maintain a stable environment before assessing the cost in dollar terms.⁹ Ecological economist Robert Costanza led an attempted valuation of the global ecosystem in 1997. Initially published in *Nature*, the article concluded on \$33 trillion with a range from \$16 trillion to \$54 trillion (in 1997, total global GDP was \$27 trillion). Half of the value went to nutrient cycling. The open oceans, continental shelves, and estuaries had the highest total value, and the highest per-hectare values went to estuaries, swamps/floodplains, and seagrass/algae beds. The work was criticized by articles in *Ecological Economics* Volume 25, Issue 1, but the critics acknowledged the positive potential for economic valuation of the global ecosystem.¹²⁹

The Earth's carrying capacity is another central question. This was first examined by Thomas Malthus, and more recently in an MIT study entitled *Limits to Growth*. Although the predictions of Malthus have not come to pass, some limit to the Earth's ability to support life are acknowledged. In addition, for real GDP per capita to increase real GDP must increase faster than population growth. Diminishing returns suggest that productivity increases will slow if major technological progress is not made. Food production may become a problem, as erosion, an impending water crisis, and soil salinity (from irrigation) reduce the productivity of agriculture. Ecological economists argue that industrial agriculture, which exacerbates these problems, is not sustainable agriculture, and are generally inclined favorably to organic farming, which also reduces the output of carbon.²⁶

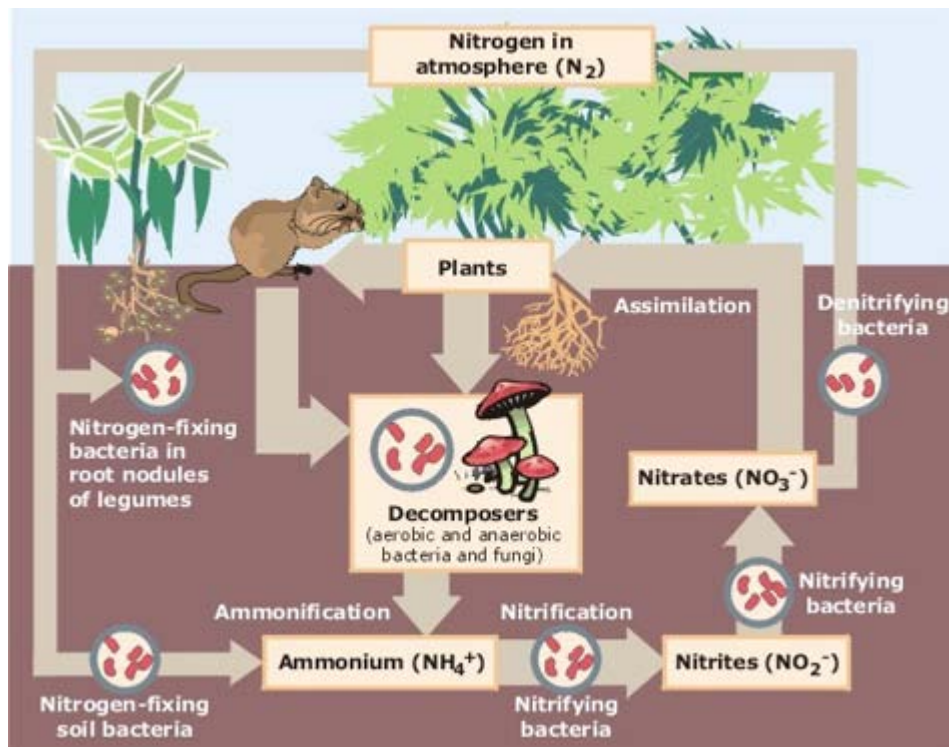
Global wild fisheries are believed to have peaked and begun a decline, with valuable habitat such as estuaries in critical condition.²⁸ The aquaculture or farming of piscivorous fish, like salmon, does not help solve the problem because they need to be fed products from other fish. Studies have shown that salmon farming has major negative impacts on wild salmon, as well as the forage fish that need to be caught to feed them.

Since animals are higher on the trophic level, they are less efficient sources of food energy. Reduced consumption of meat would reduce the demand for food, but as nations develop, they tend to adopt high-meat diets similar to that of the United States. Genetically modified food (GMF) a conventional solution to the problem, presents

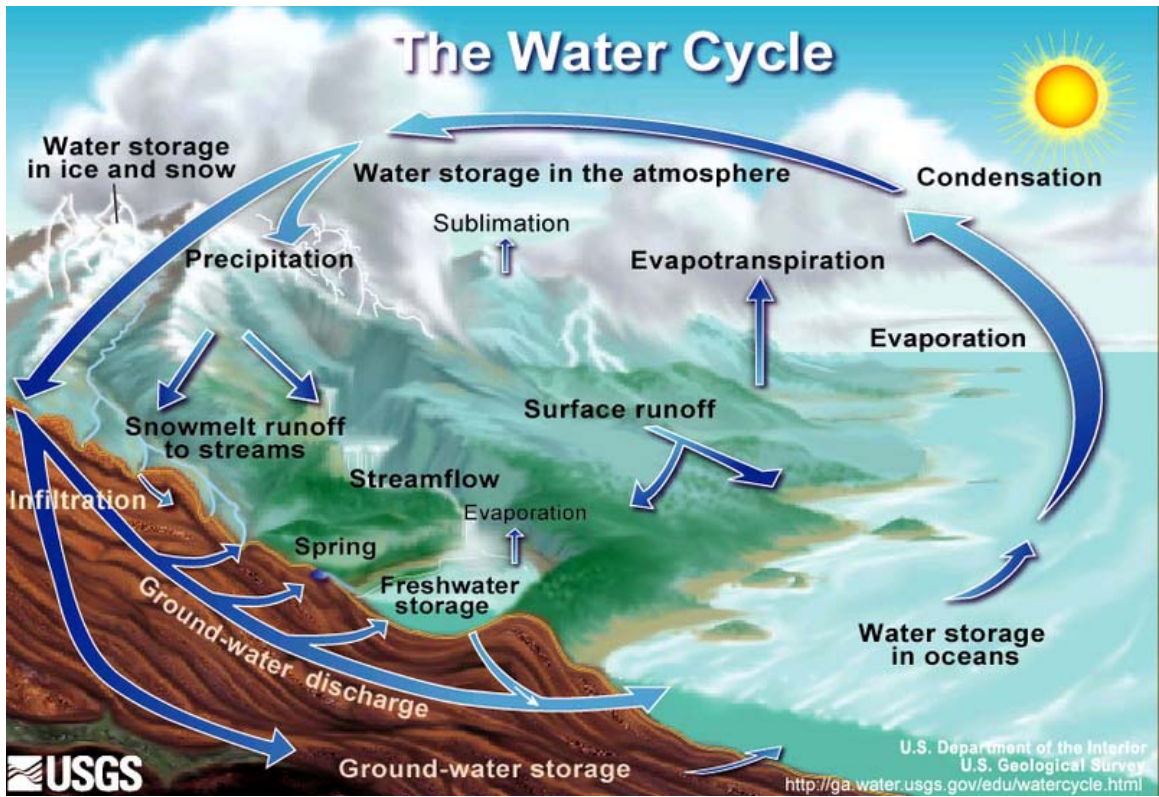
numerous problems – Bt corn produces its own *Bacillus thuringiensis*, but the pest resistance is believed to be only a matter of time.³¹ The overall effect of GMF on yields is contentious, with the USDA and FAO acknowledging that GMFs do not necessarily have higher yields and may even have reduced yields.

Global warming is now widely acknowledged as a major issue, with all national scientific academies expressing agreement on the importance of the issue. As the population growth intensifies and energy demand increases, the world faces an energy crisis. Some economists and scientists forecast a global ecological crisis if energy use is not contained – the Stern report is an example. The disagreement has sparked a vigorous debate on issue of discounting and intergenerational equity.

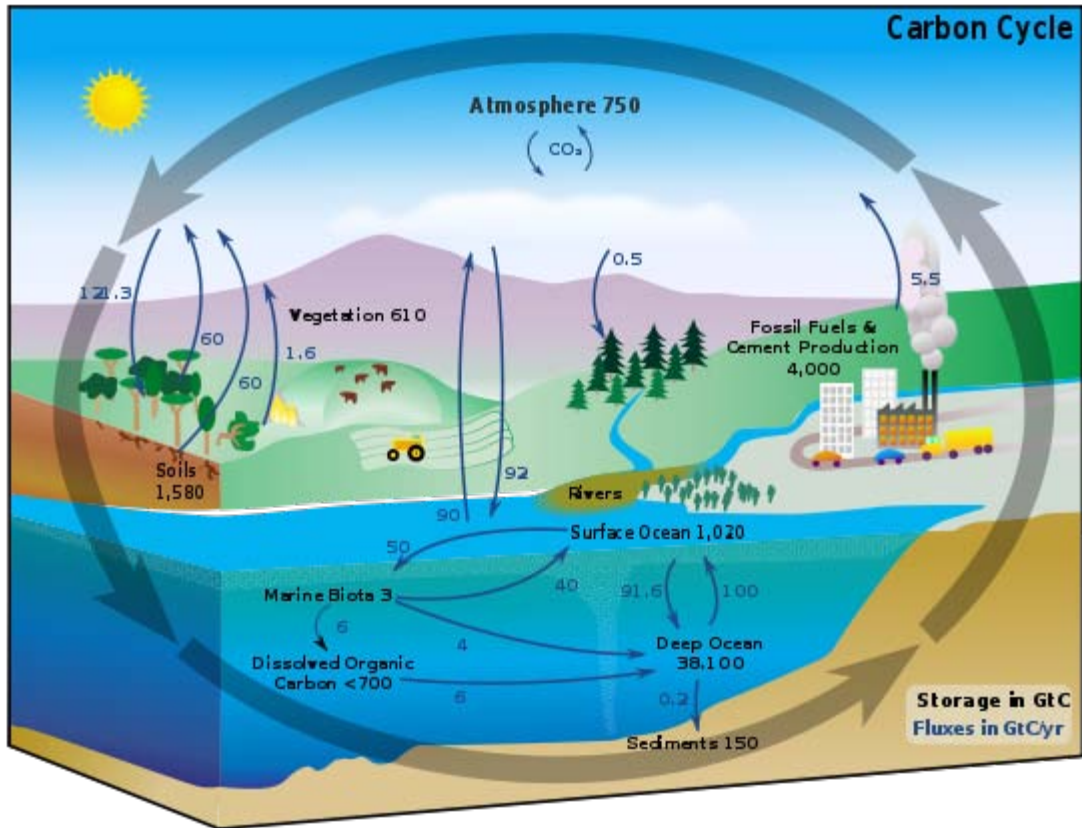
GLOBAL GEOCHEMICAL CYCLES CRITICAL FOR LIFE



Nitrogen cycle

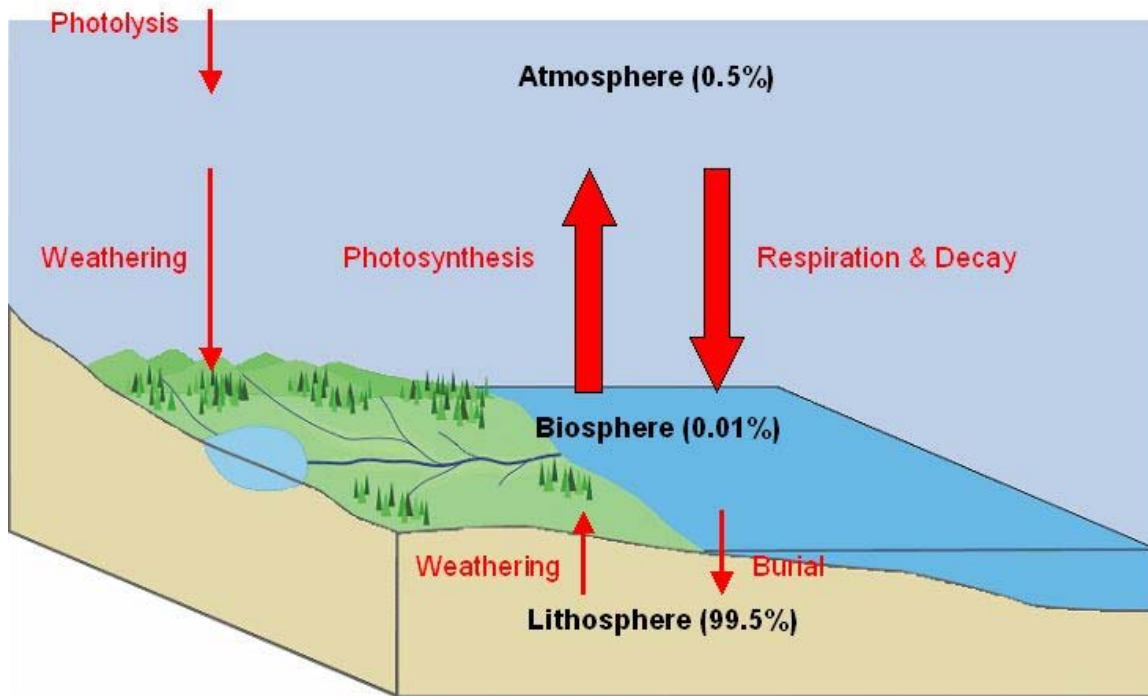


Water cycle



Carbon cycle

Oxygen Cycle Reservoirs & Flux



Oxygen cycle

Ethics

Mainstream economics has attempted to become a value-free 'hard science', but ecological economists argue that value-free economics is generally not realistic. Ecological economics is more willing to entertain alternative conceptions of utility, efficiency, and cost-benefits such as positional analysis or multi-criteria analysis. Ecological economics is typically viewed as economics for sustainable development, and may have goals similar to green politics.

Schools of thought

Various competing schools of thought exist in the field. Some are close to resource and environmental economics while others are far more heterodox in outlook. An example of the latter is the *European Society for Ecological Economics*. An example of the former is the Swedish *Beijer International Institute of Ecological Economics*.

Differentiation from mainstream schools

In ecological economics, natural capital is added to the typical capital asset analysis of land, labor, and financial capital. Ecological economics uses tools from mathematical economics, but may apply them more closely to the natural world. Whereas mainstream economists tend to be technological optimists, ecological economists are inclined to be technological pessimists. They reason that the natural world has a limited carrying capacity and that its resources may run out. Since destruction of important environmental resources could be practically irreversible and catastrophic, ecological economists are inclined to justify cautionary measures based on the precautionary principle.

The most cogent example of how the different theories treat similar assets is tropical rainforest ecosystems, most obviously the Yasuni region of Ecuador. While this area has substantial deposits of bitumen it is also one of the most diverse ecosystems on Earth and some estimates establish it has over 200 undiscovered medical substances in its genomes - most of which would be destroyed by logging the forest or mining the bitumen. Effectively, the instructional capital of the genomes is undervalued by both classical and neoclassical means which would view the rainforest primarily as a source of wood, oil/tar and perhaps food. Increasingly the carbon credit for leaving the extremely carbon-intensive ("dirty") bitumen in the ground is also valued - the government of Ecuador set a price of US\$350M for an oil lease with the intent of selling it to someone committed to never exercising it at all and instead preserving the rainforest. Bill Clinton, Paul Martin and other former world leaders have become closely involved in this project which includes lobbying for the issue of International Monetary Fund Special Drawing Rights to recognize the rainforest's value directly within the framework of the Bretton Woods institutions. If successful this would be a major victory for advocates of ecological economics as the new mainstream form of economics.

History and development

Early interest in ecology and economics dates back to the 1960s and the work by Kenneth Boulding and Herman Daly, but the first meetings occurred in the 1980s. It began with a 1982 symposium in Sweden which was attended by people who would later be instrumental in the field, including Robert Costanza, Herman Daly, Charles Hall, Ann-Mari Jansson, Bruce Hannon, H.T. Odum, and David Pimentel. Most were ecosystem ecologists or mainstream environmental economists, with the exception of Daly. In 1987, Daly and Costanza edited an issue of *Ecological Modeling* to test the waters. A book titled *Ecological Economics* by Juan Martinez-Alier was published later that year. 1989 saw the foundation of the International Society for Ecological Economics and first publication of its journal *Ecological Economics* by Elsevier. Robert Costanza was the first president of the society and first editor of the journal which is currently edited by Richard Howarth.

European conceptual founders include Nicholas Georgescu-Roegen (1971), William Kapp (1944) and Karl Polanyi (1950). Some key concepts of what is now ecological economics are evident in the writings of E.F. Schumacher, whose book *Small Is Beautiful*

– *A Study of Economics as if People Mattered* (1973) was published just a few years before the first edition of Herman Daly's comprehensive and persuasive *Steady-State Economics* (1977). Other figures include ecologists C.S. Holling, H.T. Odum and Robert Costanza, biologist Gretchen Daily and physicist Robert Ayres. CUNY geography professor David Harvey explicitly added ecological concerns to political economic literature. This parallel development in political economy has been continued by analysts such as sociologist John Bellamy Foster.

The antecedents can be traced back to the Romantics of the 19th century as well as some Enlightenment political economists of that era. Concerns over population were expressed by Thomas Malthus, while John Stuart Mill hypothesized that the "stationary state" of an economy might be something that could be considered desirable, anticipating later insights of modern ecological economists, without having had their experience of the social and ecological costs of the dramatic post-World War II industrial expansion. As Martinez-Alier explores in his book the debate on energy in economic systems can also be traced into the 19th century e.g. Nobel prize-winning chemist, Frederick Soddy (1877–1956). Soddy criticized the prevailing belief of the economy as a perpetual motion machine, capable of generating infinite wealth — a criticism echoed by his intellectual heirs in the now emergent field of ecological economics.

The Romanian economist Nicholas Georgescu-Roegen (1906–1994), who was among Daly's teachers at Vanderbilt University, provided ecological economics with a modern conceptual framework based on the material and energy flows of economic production and consumption. His *magnum opus*, *The Entropy Law and the Economic Process* (1971), has been highly influential.

Articles by Inge Ropke (2004, 2005) and Clive Spash (1999) cover the development and modern history of ecological economics and explain its differentiation from resource and environmental economics, as well as some of the controversy between American and European schools of thought. An article by Robert Costanza, David Stern, Lining He, and Chunbo Ma responded to a call by Mick Common to determine the foundational literature of ecological economics by using citation analysis to examine which books and articles have had the most influence on the development of the field.

Topics

Methodology

The primary objective of ecological economics (EE) is to ground economic thinking and practice in physical reality, especially in the laws of physics (particularly the laws of thermodynamics) and in knowledge of biological systems. It accepts as a goal the improvement of human well-being through development, and seeks to ensure achievement of this through planning for the sustainable development of ecosystems and societies. Of course the terms development and sustainable development are far from lacking controversy. Richard Norgaard argues traditional economics has hi-jacked the development terminology in his book *Development Betrayed*.

Well-being in ecological economics is also differentiated from welfare as found in mainstream economics and the 'new welfare economics' from the 1930s which informs resource and environmental economics. This entails a limited preference utilitarian conception of value i.e., Nature is valuable to our economies, that is because people will pay for its services such as clean air, clean water, encounters with wilderness, etc.

Ecological economics is distinguishable from neoclassical economics primarily by its assertion that the economy is embedded within an environmental system. Ecology deals with the energy and matter transactions of life and the Earth, and the human economy is by definition contained within this system. Ecological economists argue that neoclassical economics has ignored the environment, at best considering it to be a subset of the human economy.

The neoclassical view ignores much of what the natural sciences have taught us about the contributions of nature to the creation of wealth e.g., the planetary endowment of scarce matter and energy, along with the complex and biologically diverse ecosystems that provide goods and ecosystem services directly to human communities: micro- and macro-climate regulation, water recycling, water purification, storm water regulation, waste absorption, food and medicine production, pollination, protection from solar and cosmic radiation, the view of a starry night sky, etc.

There has then been a move to regard such things as natural capital and ecosystems functions as goods and services. However, this is far from uncontroversial within ecology or ecological economics due to the potential for narrowing down values to those found in mainstream economics and the danger of merely regarding Nature as a commodity. This has been referred to as ecologists 'selling out on Nature'. There is then a concern that ecological economics has failed to learn from the extensive literature in environmental ethics about how to structure a plural value system.

Allocation of resources

Resource and neoclassical economics focus primarily on the efficient allocation of resources, and less on two other fundamental economic problems which are central to ecological economics: distribution (equity) and the scale of the economy relative to the ecosystems upon which it is reliant. Ecological Economics also makes a clear distinction between growth (quantitative increase in economic output) and development (qualitative improvement of the quality of life) while arguing that neoclassical economics confuses the two. Ecological economists point out that, beyond modest levels, increased per-capita consumption (the typical economic measure of "standard of living") does not necessarily lead to improvement in human well-being, while this same consumption can have harmful effects on the environment and broader societal well-being.

Strong versus weak sustainability

Ecological economics challenges the conventional approach towards natural resources, claiming that it undervalues natural capital by considering it as interchangeable with human-made capital—labor and technology.

The potential for the substitution of man-made capital for natural capital is an important debate in ecological economics and the economics of sustainability. There is a continuum of views among economists between the strongly neoclassical positions of Robert Solow and Martin Weitzman, at one extreme and the 'entropy pessimists', notably Nicholas Georgescu-Roegen and Herman Daly, at the other.

Neoclassical economists tend to maintain that man-made capital can, in principle, replace all types of natural capital. This is known as the *weak sustainability* view, essentially that every technology can be improved upon or replaced by innovation, and that there is a substitute for any and all scarce materials.

At the other extreme, the *strong sustainability* view argues that the stock of natural resources and ecological functions are irreplaceable. From the premises of strong sustainability, it follows that economic policy has a fiduciary responsibility to the greater ecological world, and that sustainable development must therefore take a different approach to valuing natural resources and ecological functions.

Energy economics

A key concept of energy economics is net energy gain, which recognizes that all energy requires energy to produce. To be useful the energy return on energy invested (*EROEI*) has to be greater than one. The net energy gain from production coal, oil and gas has declined over time as the easiest to produce sources have been most heavily depleted.

Ecological economics generally rejects the view of energy economics that growth in the energy supply is related directly to well being, focusing instead on biodiversity and creativity - or natural capital and individual capital, in the terminology sometimes adopted to describe these economically. In practice, ecological economics focuses primarily on the key issues of uneconomic growth and quality of life. Ecological economists are inclined to acknowledge that much of what is important in human well-being is not analyzable from a strictly economic standpoint and suggests an interdisciplinary approach combining social and natural sciences as a means to address this.

Thermoeconomics is based on the proposition that the role of energy in biological evolution should be defined and understood through the second law of thermodynamics, but also in terms of such economic criteria as productivity, efficiency, and especially the costs and benefits (or profitability) of the various mechanisms for capturing and utilizing available energy to build biomass and do work. As a result, thermoeconomics are often

discussed in the field of ecological economics, which itself is related to the fields of sustainability and sustainable development.

Exergy analysis is performed in the field of industrial ecology to use energy more efficiently. The term *exergy*, was coined by Zoran Rant in 1956, but the concept was developed by J. Willard Gibbs. In recent decades, utilization of exergy has spread outside of physics and engineering to the fields of industrial ecology, ecological economics, systems ecology, and energetics.

Energy accounting and balance

An energy balance can be used to track energy through a system, and is a very useful tool for determining resource use and environmental impacts, using the First and Second laws of thermodynamics, to determine how much energy is needed at each point in a system, and in what form that energy is a cost in various environmental issues. The energy accounting system keeps track of energy in, energy out, and non-useful energy versus work done, and transformations within the system.

Scientists have written and speculated on different aspects of energy accounting.

Environmental services

A study was carried out by Costanza and colleagues to determine the 'price' of the services provided by the environment. This was determined by averaging values obtained from a range of studies conducted in very specific context and then transferring these without regard to that context. Dollar figures were averaged to a per hectare number for different types of ecosystem e.g. wetlands, oceans. A total was then produced which came out at 33 trillion US dollars (1997 values), more than twice the total GDP of the world at the time of the study. This study was criticized by pre-ecological and even some environmental economists - for being inconsistent with assumptions of financial capital valuation - and ecological economists - for being inconsistent with an ecological economics focus on biological and physical indicators.

The whole idea of treating ecosystems as goods and services to be valued in monetary terms remains controversial to some. A common objection is that life is precious or priceless, but this demonstrably degrades to it being worthless under the assumptions of any branch of economics. Reducing human bodies to financial values is a necessary part of every branch of economics and not always in the direct terms of insurance or wages. Economics, in principle, assumes that conflict is reduced by agreeing on voluntary contractual relations and prices instead of simply fighting or coercing or tricking others into providing goods or services. In doing so, a provider agrees to surrender time and take bodily risks and other (reputation, financial) risks. Ecosystems are no different than other bodies economically except insofar as they are far less replaceable than typical labour or commodities.

Despite these issues, many ecologists and conservation biologists are pursuing ecosystem valuation. Biodiversity measures in particular appear to be the most promising way to reconcile financial and ecological values, and there are many active efforts in this regard. The growing field of biodiversity finance began to emerge in 2008 in response to many specific proposals such as the Ecuadoran Yasuni proposal or similar ones in the Congo. US news outlets treated the stories as a "threat" to "drill a park" reflecting a previously dominant view that NGOs and governments had the primary responsibility to protect ecosystems. However Peter Barnes and other commentators have recently argued that a guardianship/trustee/commons model is far more effective and takes the decisions out of the political realm.

Commodification of other ecological relations as in carbon credit and direct payments to farmers to preserve ecosystem services are likewise examples that permit private parties to play more direct roles protecting biodiversity. The United Nations Food and Agriculture Organization achieved near-universal agreement in 2008 that such payments directly valuing ecosystem preservation and encouraging permaculture were the only practical way out of a food crisis. The holdouts were all English-speaking countries that export GMOs and promote "free trade" agreements that facilitate their own control of the world transport network: The US, UK, Canada and Australia.

Externalities

Ecological economics is founded upon the view that the neoclassical economics (NCE) assumption that environmental and community costs and benefits are mutually canceling "*externalities*" is not warranted. Juan Martinez Alier, for instance shows that the bulk of consumers are automatically excluded from having an impact upon the prices of commodities, as these consumers are future generations who have not been born yet. The assumptions behind future discounting, which assume that future goods will be cheaper than present goods, has been criticized by Fred Pearce and by the recent Stern Report (although the Stern report itself does employ discounting and has been criticized by ecological economists).

Concerning these externalities, Paul Hawken argues that the only reason why goods produced unsustainably are usually cheaper than goods produced sustainably is due to a hidden subsidy, paid by the non-monetized human environment, community or future generations. These arguments are developed further by Hawken, Amory and Hunter Lovins in "Natural Capitalism: Creating the Next Industrial Revolution".

Ecological-Economic Modeling

Mathematical modeling is a powerful tool that is used in ecological economic analysis. Various approaches and techniques include : evolutionary, input-output, neo-Austrian modeling, entropy and thermodynamic models, multi-criteria, and agent-based modeling, the environmental Kuznets curve. Systems Dynamics and GIS are tools used in spatial dynamic landscape simulation modeling.

Chapter 9

EIOLCA

Economic input-output life cycle assessment, or EIO-LCA involves use of aggregate sector-level data quantifying how much environmental impact can be directly attributed to each sector of the economy and how much each sector purchases from other sectors in producing its output. Combining such data sets can enable accounting for long chains (for example, building an automobile requires energy, but producing energy requires vehicles, and building those vehicles requires energy, etc.), which somewhat alleviates the scoping problem of traditional LCA. EIO-LCA analysis traces out the various economic transactions, resource requirements and environmental emissions (including all the various manufacturing, transportation, mining and related requirements) required for producing a particular product or service.

EIO-LCA relies on sector-level averages that may or may not be representative of the specific subset of the sector relevant to a particular product. To the extent that the good or service of interest is representative of a sector, EIOLCA can provide very fast estimates of full supply chain implications for that good or service.

Background

Economic input-output analysis was developed by Wassily Leontief (who won a Nobel Prize in 1973). It quantifies the interrelationships among sectors of an economic system, enabling identification of direct and indirect economic inputs of purchases. This concept was extended by including data about environmental and energy analysis from each sector to account for supply chain environmental implications of economic activity.

Theory

Input-output transactions tables, which track flows of purchases between sectors, are collected by the federal government in the United States. EIO works as follows: If X_{ij} represents the amount that sector j purchased from sector i in a given year and y_i is the

"final demand" for output from sector i (i.e., the amount of output purchased for consumption, as opposed to purchased by other businesses as supplies for more production), then the total output x_i from sector i includes output to consumers plus output sold to other sectors:

$$x_i = y_i + \sum_j X_{ij}$$

If we define A_{ij} as the normalized production for each sector, so that $A_{ij} = X_{ij} / x_j$, then

$$x_i = y_i + \sum_j A_{ij}x_j$$

In vector notation

$$\mathbf{x} = \mathbf{y} + \mathbf{A}\mathbf{x}$$

$$\mathbf{y} = (\mathbf{I} - \mathbf{A})\mathbf{x}$$

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$$

This result indicates that knowing only the final demand from each sector \mathbf{y} and the normalized IO matrix \mathbf{A} , one can calculate the total implied production \mathbf{x} from each sector of the economy. If data are available on a particular emissions release (or other attribute of interest) from each sector of the economy, then a matrix \mathbf{R} can be compiled to represent various releases (columns) per \$ output from each sector (rows). Total additional emissions $\Delta\mathbf{b}$ associated with additional final demand of $\Delta\mathbf{y}$ can then be calculated as:

$$\Delta\mathbf{b} = \mathbf{R}^T \Delta\mathbf{x} = \mathbf{R}^T (\mathbf{I} - \mathbf{A})^{-1} \Delta\mathbf{y}$$

This simple result enables very quick analysis, taking into account releases associated with the entire supply chain requirements needed to provide a specific final demand, on average. The equations are based on average data in the current economy, but they can be used to make predictions for marginal changes in output (such as one more unit of a particular product) if

1. average output and marginal output are assumed to be sufficiently close (i.e., the impact of *one more unit* = the impact of *the average unit*), and
2. the marginal change in final output $\Delta \mathbf{y}$ is representative of the product of interest (ex: if the product will use electricity from wind energy exclusively, then using the electricity sector, which is dominated by coal, would yield a poor estimate).

Finally, if the researcher has estimates for valuation of externality costs associated with each item in \mathbf{b} (or, alternatively, if weighting coefficients are available that represent the relative importance of each item in \mathbf{b} , using ecological indicators, for example) then the externality costs (or weights) per unit of releases could be compiled into a vector \mathbf{m} in order to calculate the scalar "environmental impact metric" m :

$$\Delta m = \mathbf{m}^T \Delta \mathbf{b} = \mathbf{m}^T \mathbf{R}^T \Delta \mathbf{x} = \mathbf{m}^T \mathbf{R}^T (\mathbf{I} - \mathbf{A})^{-1} \Delta \mathbf{y}$$

Generally there is wide uncertainty associated with estimates of \mathbf{m} , so such aggregation should be done only with care, including sensitivity analysis. Typically, researchers examine specific elements of \mathbf{b} rather than attempting to aggregate.

The big picture result is that by collecting data on average economic sector transactions \mathbf{A} and average sector emissions \mathbf{R} , it is possible to make quick predictions about the full supply chain emissions associated with a product of interest by representing the product as marginal changes in production from relevant sectors \mathbf{y} .

Software

The Economic Input Output-Life Cycle Assessment software, traces out the various economic transactions, resource requirements and environmental emissions associated with the production of a particular product or service. The model captures all the various manufacturing, transportation, mining and related requirements to produce a product or service. For example, you might wish to trace out the implications of purchasing \$ 46,000 of reinforcing steel and \$ 104,000 of concrete for a kilometer of roadway pavement. Environmental implications of these purchases can be estimated using EIO-LCA. The current (1997) model is based upon the Department of Commerce's 491 sector industry input-output model of the US economy.

Chapter 10

Energetics

Energetics is the pseudo-scientific study of energy under transformation. Because energy flows at all scales, from the quantum level to the biosphere and cosmos, energetics is a very broad discipline, encompassing for example thermodynamics, chemistry, biological energetics, biochemistry and ecological energetics. Where each branch of energetics begins and ends is a topic of constant debate. For example, Lehninger (1973, p. 21) contended that when the science of thermodynamics deals with energy exchanges of all types, it can be called energetics.

Aims

In general, energetics is concerned with seeking principles that accurately describe the useful and non-useful tendencies of energy flows and storages under transformation. 'Principles' are understood here as phenomena which behave like historical invariants under multiple observations. When some critical number of people have observed such invariance, such a principle is usually then given the status of a 'fundamental law' of science. Like in all science, whether or not a theorem or principle is considered a fundamental law appears to depend on how many people agree to such a proposition. The ultimate aim of energetics therefore is the description of fundamental laws. Philosophers of science have held that the fundamental laws of thermodynamics can be treated as the laws of energetics, (Reiser 1926, p. 432). Through the clarification of these laws energetics aims to produce reliable predictions about energy flow and storage transformations at any scale; nano to macro.

History

Energetics has a controversial history. Some authors maintain that the origins of energetics can be found in the work of the ancient Greeks, but that the mathematical formalisation began with the work of Leibniz. Liet.-Col. Richard de Villamil (1928) said that Rankine formulated the Science of Energetics in his paper *Outlines of the Science of*

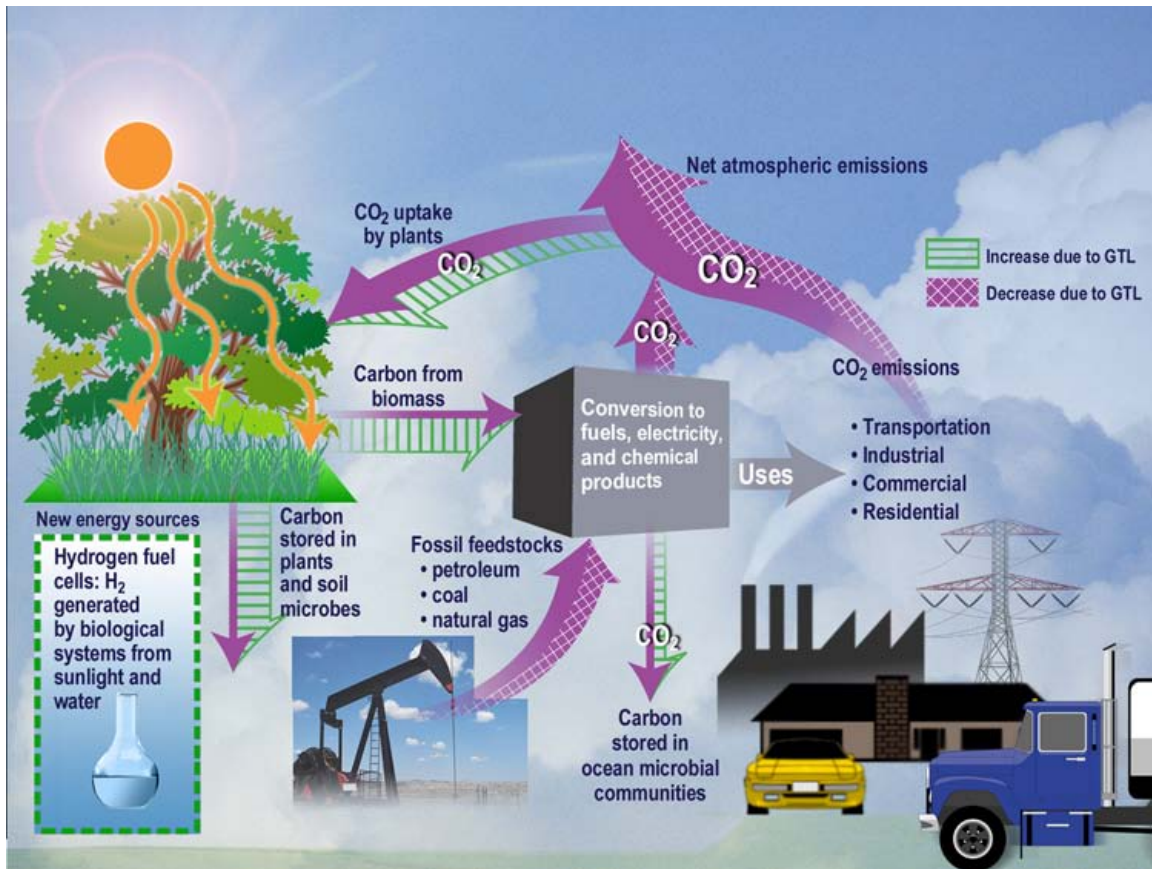
Energetics published in the Proceedings of the Philosophical Society of Glasgow in 1855. W. Ostwald and E. Mach subsequently developed the study and in the late 1800s energetics was understood to be incompatible with the atomic view of the atom forwarded by Boltzmann's gas theory. Proof of the atom settled the dispute but not without significant damage. In the 1920s Lotka then attempted to build on Boltzmann's views through a mathematical synthesis of energetics with biological evolutionary theory. Lotka proposed that the selective principle of evolution was one which favoured the maximum useful energy flow transformation. This view subsequently influenced the further development of ecological energetics, especially the work of Howard T. Odum.

De Villamil attempted to clarify the scope of energetics with respects to other branches of physics by contriving a system that divides mechanics into two branches; energetics (the science of energy) and "pure", "abstract" or "rigid" dynamics (the science of momentum). According to Villamil energetics can be mathematically characterised by scalar equations, and rigid dynamics by vectorial equations. In this division the dimensions for dynamics are *space*, time and mass, and for energetics, *length*, time and mass (Villamil 1928, p. 9). This division is made according to fundamental presuppositions about the properties of bodies which can be expressed according to how one answers to following two questions:

1. Are particles rigidly fixed together?
2. Is there any machinery for stopping moving bodies?

In Villamil's classification system, dynamics says yes to 1 and no to 2, whereas energetics says no to 1 and yes to 2. Therefore, Villamil's in system, dynamics assumes that particles are rigidly fixed together and cannot vibrate, and consequently must all be at zero temperature. The conservation of momentum is a consequence of this view, however it is considered valid only in logic and not to be a true representation of the facts (Villamil, p. 96). In contrast energetics does not assume that particles are rigidly fixed together, particles are therefore free to vibrate, and consequently can be at non-zero temperatures.

Principles of energetics



Ecological analysis of CO₂ in an ecosystem

As a general statement of energy flows under transformation, the principles of energetics include the first four laws of thermodynamics which seek a rigorous description. However the precise place of the laws of thermodynamics within the principles of energetics is a topic currently under debate. If the ecologist Howard T. Odum was right, then the principles of energetics take into consideration a hierarchical ordering of energy forms, which aims to account for the concept of energy quality, and the evolution of the universe. Albert Lehninger (1973, p. 2) called these hierarchical orderings the

“ ... successive stages in the flow of energy through the biological macrocosm ”

Odum proposed 3 further energetic principles and one corollary that take energy hierarchy into account. The first four principles of energetics are related to the same numbered laws of thermodynamics, and are expanded upon in that article. The final four principles are taken from the ecological energetics of H.T. Odum.

- **Zeroth principle of energetics**

If two thermodynamic systems A and B are in thermal equilibrium, and B and C are also in thermal equilibrium, then A and C are in thermal equilibrium.

- **First principle of energetics**

The increase in the internal energy of a system is equal to the amount of energy added to the system by heating, minus the amount lost in the form of work done by the system on its surroundings.

- **Second principle of energetics**

The total entropy of any isolated thermodynamic system tends to increase over time, approaching a maximum value.

- **Third principle of energetics**

As a system approaches absolute zero of temperature all processes cease and the entropy of the system approaches a minimum value or zero for the case of a perfect crystalline substance.

- **Fourth principle of energetics**

There seem to be two opinions on the fourth principle of energetics:

- The Onsager reciprocal relations are sometimes called the fourth law of thermodynamics. As the fourth law of thermodynamics Onsager reciprocal relations would constitute the fourth principle of energetics.
- In the field of ecological energetics H.T. Odum considered maximum power, the fourth principle of energetics. Odum also proposed the Maximum empower principle as a corollary of the maximum power principle, and considered it to describe the propensities of evolutionary self-organization.

- **Fifth principle of energetics**

The energy quality factor increases hierarchically. From studies of ecological food chains, Odum proposed that energy transformations form a hierarchical series measured by Transformity increase (Odum 2000, p. 246). Flows of energy develop hierarchical webs in which inflowing energies interact and are transformed by work processes into energy forms of higher quality that feedback amplifier actions, helping to maximise the power of the system" — (Odum 1994, p. 251)

- **Sixth principle of energetics**

Material cycles have hierarchical patterns measured by the energy/mass ratio that determines its zone and pulse frequency in the energy hierarchy. (Odum 2000,

p. 246). M.T. Brown and V. Buranakarn write, "Generally, energy per mass is a good indicator of recycle-ability, where materials with high energy per mass are more recyclable" (2003, p. 1).

Chapter 11

Energy Quality



Heat, a form of energy, is partly potential energy and partly kinetic energy

Energy quality is the contrast between different forms of energy, the different trophic levels in ecological systems and the propensity of energy to convert from one form to another. The concept refers to the empirical experience of the characteristics, or qualia, of

different energy forms as they flow and transform. It appeals to our common perception of the heat value, versatility, and environmental performance of different energy forms and the way a small increment in energy flow can sometimes produce a large transformation effect on both energy physical state and energy. For example the transition from a solid state to liquid may only involve a very small addition of energy. Methods of evaluating energy quality are sometimes concerned with developing a system of ranking energy qualities in hierarchical order.

Introduction

Since before antiquity there has been deep philosophical, aesthetic and scientific interest in the contrast of quality with quantity. In some respects the history of modern and postmodern thought can be characterized by the phenomenological approach to these two concepts. A central question has been whether the many different qualitative aspects of the world can be understood in terms of rational quantities, or whether the qualitative and quantitative are irreconcilable: that is, there is no "rational quality", or *quale ratio*. Many scientists and analytic philosophers say they are not, and therefore consider some qualitative phenomena like, for instance, spirituality, and astrology to be unquantifiable, unanalysable by scientific methods, and therefore ungrounded in physical reality. The notion of energy quality therefore has a tendency to be linked with phenomena many scientists consider unquantifiable, or at least incommunicable, and are consequently dismissed out of hand.

At the same time many people have also recognised qualitative differences in the way things can be done by different entities (both physical and biological). Humans, for example have qualitatively different capacities than many other mammals, due, in part, to their opposable thumb. In the attempt to formalise some of the qualitative differences, entities were grouped according to distinguishing features or capacities. Different schools of thought used different methods to make distinctions. Some people chose taxonomic and genome structure, while others chose energetic function as the basis of classifications. The former are often associated with biology, while the latter with the trophic food chain analysis of ecology. These can be considered attempts to formalise quantitative, scientific studies of the qualitative differences between entities. The efforts were not isolated to biology and ecology, since engineers were also interested in quantifying the amount of work that qualitatively different sources of energy could provide.

Ohta

According to Ohta (1994, pp. 90–91) the ranking and scientific analysis of energy quality was first proposed in 1851 by William Thomson under the concept of "availability". This concept was continued in Germany by Z. Rant, who developed it under the title, "die Exergie" (the exergy). It was later continued and standardised in Japan. Exergy analysis now forms a common part of many industrial and ecological energy analyses. For example, I.Dincer and Y.A. Cengel (2001, p. 132) state that energy forms of different qualities are now commonly dealt with in steam power engineering industry. Here the

"quality index" is the relation of exergy to the energy content (Ibid.). However energy engineers were aware that the notion of heat quality involved the notion of value - for example A. Thumann wrote, "The essential quality of heat is not the amount but rather its 'value'" (1984, p. 113) - which brings into play the question of teleology and wider, or ecological-scale goal functions. In an ecological context S.E. Jorgensen and G.Bendoricchio say that exergy is used as a goal function in ecological models, and expresses energy "with a built-in measure of quality like energy" (2001, p. 392).

Energy quality evaluation methods

There appear to be two main kinds of methodology used for the calculation of energy quality. These can be classed as either receiver or donor methods. One of the main differences that distinguishes these classes is the assumption of whether energy quality can be upgraded in an energy transformation process.

Receiver methods: view energy quality as a measure and indicator of the relative ease with which energy converts from one form to another. That is, how much energy is received from a transformation or transfer process. For example, A. Grubler used two types of indicators of energetic quality *pars pro toto*: the hydrogen/carbon (H/C) ratio, and its inverse, the carbon intensity of energy. Grubler used the latter as an indicator of relative environmental quality. However Ohta says that in multistage industrial conversion systems, such as a hydrogen production system using solar energy, the energy quality is not upgraded (1994, p. 125).

Donor methods: view energy quality as a measure of the amount of energy used in an energy transformation, and that goes into sustaining a product or service (H.T.Odum 1975, p. 3). That is how much energy is donated to an energy transformation process. These methods are used in ecological physical chemistry, and ecosystem evaluation. From this view, in contrast with that outlined by Ohta, energy quality *is* upgraded in the multistage trophic conversions of ecological systems. Here, upgraded energy quality has a greater capacity to feedback and control lower grades of energy quality. Donor methods attempt to understand the *usefulness* of an energetic process by quantifying the extent to which higher quality energy controls lower quality energy.

Energy quality in physical-chemical science (direct energy transformations)

Constant energy form but variable energy flow

T.Ohta suggested that the concept of energy quality may be more intuitive if one considers examples where the form of energy remains constant but the amount of energy flowing, or transferred is varied. For instance if we consider only the inertial form of energy, then the energy quality of a moving body is higher when it moves with a greater velocity. If we consider only the heat form of energy, then a higher temperature has higher quality. And if we consider only the light form of energy then light with higher

frequency has greater quality. All these differences in energy quality are therefore easily measured with the appropriate scientific instrument.

Variable energy form, but constant energy flow

The situation becomes more complex when the form of energy does not remain constant. In this context Ohta formulated the question of energy quality in terms of the conversion of energy of one form into another, that is the **transformation** of energy. Here, energy quality is defined by the **relative ease** with which the energy transforms, from form to form.

If energy A is relatively easier to convert to energy B but energy B is relatively harder to convert to energy A, then the quality of energy A is defined as being higher than that of B. The ranking of energy quality is also defined in a similar way. (T.Ohta 1994, p. 90).

Nomenclature: Prior to Ohta's definition above, A.W.Culp produced an energy conversion table describing the different conversions from one energy to another. Culp's treatment made use of a subscript to indicate which energy form is being talked about. Therefore, instead of writing "energy A", like Ohta above, Culp referred to " J_e ", to specify electrical form of energy, where "J" refers to "energy", and the "e" subscript refers to electrical form of energy. Culp's notation anticipated Scenceman's (1997) later maxim that all energy should be specified as form energy with the appropriate subscript.

Energy quality in biophysical economics (indirect energy transformations)

The notion of energy quality was also recognised in the economic sciences. In the context of biophysical economics energy quality was measured by the amount of economic output generated per unit of energy input (C.J. Cleveland et al. 2000). The estimation of energy quality in an economic context is also associated with embodied energy methodologies. Another example of the economic relevance of the energy quality concept is given by Brian Fleay. Fleay says that the "Energy Profit Ratio (EPR) is one measure of energy quality and a pivotal index for assessing the economic performance of fuels. Both the direct and indirect energy inputs embodied in goods and services must be included in the denominator." (2006; p. 10) Fleay calculates the EPR as the energy output/energy input.

DIFFERENT HIERARCHICAL RANKS OF ENERGY FORM QUALITY	
HIGHEST QUALITY	
Ohta Ranking	Odum Ranking
Electromagnetic	Information
Mechanical	Human Services

Photon	Protein Food
Chemical	Electric Power
Heat	Food, Greens, Grains
	River-water potential
	Consolidated Fuels
	River Chemical energy
	Mechanical
	Tide
	Gross Photosynthesis
	Average wind
	Sunlight
LOWEST QUALITY	

Ranking energy quality

Energy abundance and relative transformation ease as measure of hierarchical rank and/or hierarchical position

Ohta sought to order energy form conversions according to their quality and introduced a hierarchical scale for ranking energy quality based on the relative ease of energy conversion. It is evident that Ohta did not analyse all forms of energy. For example, water is left out of his evaluation. It is important to note that the ranking of energy quality is not determined solely with reference to the efficiency of the energy conversion. This is to say that the evaluation of "relative ease" of an energy conversion is only partly dependent on transformation efficiency. As Ohta wrote, "the turbine generator and the electric motor have nearly the same efficiency, therefore we cannot say which has the higher quality" (1994, p. 90). Ohta therefore also included, 'abundance in nature' as another criterion for the determination energy quality rank. For example, Ohta said that, "the only electrical energy which exists in natural circumstances is lightning, while many mechanical energies exist." (Ibid.).

Transformity as an energy measure of hierarchical rank

Like Ohta, H.T.Odum also sought to order energy form conversions according to their quality, however his hierarchical scale for ranking was based on extending ecological system food chain concepts to thermodynamics rather than simply relative ease of transformation. For H.T.Odum energy quality rank is based on the amount of energy of one form required to generate a unit of another energy form. The ratio of one energy form

input to a different energy form output was what H.T.Odum and colleagues called transformity: "the EMERGY per unit energy in units of emjoules per joule" (H.T.Odum 1988, p. 1135).

Chapter 12

History of Industrial Ecology

The birth of industrial ecology is commonly attributed to an article devoted to industrial ecosystems, written by Frosch and Gallopoulos, which appeared in a 1989 special issue of Scientific American. But the field's fundamentals appeared much earlier. Industrial Ecology emerged out of several ideas and concepts, some of which date back to the 19th century.

Industrial Ecology before the '60s

The term "Industrial Ecology" has been used along-side "Industrial Symbiosis" since the 1940s. Economic geography was perhaps one of the first fields to use these terms. One of the oldest appearances of the term is found in a 1947 article by George T. Renner, who refers to "The General Principle of Industrial Location" as a "Law of Industrial Ecology". Briefly stated this is:

"Any industry tends to locate at a point which provides optimum access to its ingredients or component elements. If all these component elements be juxtaposed, the location of the industry is predetermined. If, however, they occur widely separated, the industry is so located as to be most accessible to that element which would be the most expensive or difficult to transport and which, therefore, becomes the locative factor for the industry in question."

In the same article the author defines and describes industrial symbiosis:

"Often the location of an industry cannot be fully understood solely in terms of its locative ingredient elements. There are relationships between industries, sometimes simple, but often quite complex, which enter into and complicate the analysis. Chief among these is the phenomenon of industrial symbiosis. By this is meant the consorting together of two or more of dissimilar industries. Industrial Symbiosis, when scrutinized, is seen to be of two kinds, disjunctive and conjunctive."

It appears that the concept of Industrial Symbiosis was not new for the field of economic geography, since the same categorization is used by Walter G. Lezius in his 1937 article "Geography of Glass Manufacture at Toledo, Ohio" published also in the journal of Economic Geography.

The term Industrial Ecology can also be found in a 1958 paper concerned with the relationship between ecological changes caused by increased urbanization, and the value orientations of the people undergoing these changes. The case study is in Lebanon:

"The central ecological variable in the present research is ecological mobility, or the movement of men in space. It is patent that modern Industrial Ecology requires more such adaptive mobility than does traditional folk-village organization."

Industrial Ecology in the '60s

In 1963, we find the term Industrial Ecology (defined as the "complex ecology of the modern industrial world") being used to describe the social nature and complexity of (and within) industrial systems:

"...industrial organisations are social rather than mechanical systems. A firm is not only a working organisation with a working purpose. It is rather a community with its own 'politics', in so far as it is involved in problems concerned with the proper distribution of power between individuals and groups of individuals and with questions of individual and group prestige, influence, status and standing... [and he concludes that] the understanding which the student of management is expected to gain is no less than the attainment of insight into an Industrial Ecology of great complexity."

In 1967, the President of the American association for the advancement of science writes in "The experimental city" that "There are examples of industrial symbiosis where one industry feeds off, or at least neutralizes, the wastes of another..." The same author in 1970 talks about "The Next Industrial Revolution" The concept of material and energy sharing and reuse is central to his proposal for a new industrial revolution and he cites agro-industrial symbiosis as a practical way for achieving this:

"The object of the next industrial revolution is to ensure that there will be no such thing as waste, on the basis that waste is simply some substance that we do not yet have the wit to use... The next industrial revolution is this generating of a huge new [industry that]... will not produce products, it will rather reprocess the things we call wastes so they may be reproduced in the factories into the things we need... Having the city near the rural area will enable waste heat to be used to speed up the biological processes of treating the organic wastes before they go back into the land. This might end in an elegant arrangement-the power plants located close enough to the center of use, to the people who need the power, but also, within the economics, close enough to the agriculture lands so that the waste heat may be used there. This is an example of agro-industrial symbiosis, if you like to call it that"

Notice that in these early articles, the term "Industrial Ecology" is not used to describe a concept or a practice or a research field. It is used in its literal sense - as a system of interacting industrial entities. The relation to natural ecosystems (through either metaphor or analogy) is not explicit. Industrial Symbiosis on the other hand, is already clearly defined as a type of industrial organization, and the term symbiosis is borrowed from the ecological sciences to describe an analogous phenomenon in industrial systems.

Industrial Ecology in the '70s

Industrial Ecology has been a research subject of the Japan Industrial Policy Research Institute since 1971. Their definition of Industrial Ecology is "research for the prospect of dynamic harmonization between human activities and nature by a systems approach based upon ecology (JIPRI, 1983)". This programme has resulted to a number of reports that are available only in Japanese.

One of the earliest definitions of Industrial Ecology was proposed by Harry Zvi Evan at a seminar of the Economic Commission of Europe in Warsaw (Poland) in 1973 (an article was subsequently published by Evan in the *Journal for International Labour Review* in 1974 vol. 110 (3), pp. 219–233). Evan defined Industrial Ecology as a systematic analysis of industrial operations including factors like: Technology, environment, natural resources, bio-medical aspects, institutional and legal matters as well as the socio-economic aspects.

In 1974 the term of Industrial Ecology is perhaps for the first time associated with a cyclical production mode (rather than a linear one, resulting to waste). The necessity for a transition to an "open-world Industrial Ecology", is used as argument for the need to establish lunar industries:

"Low living standards provide one strong motive for most developing countries to increase their productivity and grow economically. Population increase (while it lasts) is a still more powerful driver for increased world consumption. Thus the pressure on resources will continue to grow. Instead of deploring it, we better grow with it. Only through transition to an open-world Industrial Ecology - which includes both benign industrial revolution on Earth and extraterrestrial industrialization - can the present apparent limits to growth be overcome."

Many elements of modern Industrial Ecology were commonplace in the industrial sectors of the former Soviet Union. For example, "kombinirovanaia produkcia" (combined production) was present from the earliest years of the Soviet Union and was instrumental in shaping the patterns of Soviet industrialization. "Bezotkhodnoyi tekhnologii" (waste-free technology) was introduced in the final decades of the USSR as a way to increase industrial production while limiting environmental impact. Fiodor Davitaya, a Soviet scientist from the Republic of Georgia, described in 1977 the analogy relating industrial systems to natural systems as a model for a desirable transition to cleaner production:

Nature operates without any waste products. What is rejected by some organisms provides food for others. The organisation of industry on this principle—with the waste products of some branches of industry providing raw material for others—means in effect using natural processes as a model, for in them the resolution of all arising contradictions is the motive force of progress.

Industrial Ecology in the '80s

By the 80s Industrial Ecology was already "promoted" to a research subject, which several institutes around the globe embraced. In a 1986 article published in the Journal of Ecological Modeling, there is a full description of Industrial Ecology and the analogy to natural ecosystems is clearly stated:

"The structure and inner-working of an industrial society resemble those of a natural ecosystem. The concepts in ecology such as habitat, succession, trophic level, limiting factors and community metabolism can also apply to the study of the ecology of an industrial society. For instance, an industry in a society may grow or decline as a consequence of dynamic changes in exogenous limiting resources and in the hierarchical and/or metabolic structure of that society. When studying the ecology of an industrial society (henceforth termed 'Industrial Ecology'), these concepts and methodologies employed in ecosystems analyses are useful."

In fact, in the above article there is an attempt to model an "industrial ecological system". The model is composed of seven major sections: industry, population, labor force, living state, environment and pollution, general health, and occupational health. Notice the rough similarity with Evan's factors as stated in the above section.

During the 80s the emergence of another related term, "industrial metabolism", is observed. The term is used as a metaphor for the organization and functioning of industrial activity. In an article defending the "biological modulation of terrestrial carbon cycle", the author includes an extraordinary parenthetical note:

"Parenthetically, it should be noted that it is an intrinsic property of life to proliferate exponentially until the encounter of limits set by (1) the availability of biologically utilizable reducing power, or (2) the exhaustion of some critical nutrient, or (3) an autotoxic effect imposed by life on its own environment. These limits are universal, applying to microbial ecosystems as well as to the population dynamics of a seemingly unrestricted biological superdominant such as Homo Sapiens (here, the ultimate limit is likely to be placed by an autotoxic effect exerted by the "extrasomatic" (industrial) metabolism of the human race)."

1989 – Industrial Metabolism and Strategies for Manufacturing

In 1989 two articles were released that played a decisive role in the history of industrial ecology. The first one was titled "Industrial Metabolism" by Robert Ayres. Ayres essentially lays the foundations of Industrial Ecology. In the appendix of the article he

includes "a theoretical exploration of the biosphere and the industrial economy as material-transformation systems and lessons that might be learned from their comparison". He proposes that:

"We may think of both the biosphere and the industrial economy as systems for the transformation of materials. The biosphere as it now exists is nearly a perfect system for recycling materials. This was not the case when life on earth began. The industrial system of today resembles the earliest stage of biological evolution, when the most primitive living organisms obtained their energy from a stock of organic molecules accumulated during prebiotic times. It is increasingly urgent for us to learn from the biosphere and modify our industrial metabolism, the energy - and value - yielding process essential to economic development... we should not only postulate, but indeed endorse, a long-run imperative favoring an industrial metabolism that results in reduced extraction of virgin materials, reduced loss of waste materials, and increased recycling of useful ones."

The term "Industrial Ecology" gains mainstream attention later the same year (1989) through a "Scientific American" article named "Strategies for Manufacturing". In this article, R.Frosch and N.Gallopoulos wonder "why would not our industrial system behave like an ecosystem, where the wastes of a species may be resource to another species? Why would not the outputs of an industry be the inputs of another, thus reducing use of raw materials, pollution, and saving on waste treatment?"

This vision gave birth to the concept of the Eco-industrial Park, the industrial complex that is governed by Industrial Ecology principles. A notable example resides in a Danish industrial park in the city of Kalundborg. There, several linkages of byproducts and waste heat can be found between numerous entities such as a large power plant, an oil refinery, a pharmaceutical plant, a plasterboard factory, an enzyme manufacturer, a waste company and the city itself.

Frosch's and Gallopoulos' thinking was in certain ways simply an extension of earlier ideas, such as the efficiency and waste-reduction thinking announced by Buckminster Fuller and his students (e.g., J. Baldwin), and parallel ideas about energy cogeneration, such as those of Amory Lovins and the Rocky Mountain Institute.

Industrial Ecology in the '90s

In 1991, C. Kumar Patel organized a seminal colloquium on Industrial Ecology, held on May 20 and 21, 1991, at the National Academy of Sciences in Washington D.C. The papers were later published in the Proceedings of the National Academy of Sciences USA, and they form an excellent reference on Industrial Ecology. Papers include "Industrial Ecology: Concepts and Approaches," "Industrial Ecology: A Philosophical Introduction," "The Ecology of Markets," and "Industrial Ecology: Reflections on a Colloquium." All twenty three papers are available online.

Industrial Ecology in the 21st century

The scientific field Industrial Ecology has grown fast in recent years. The Journal of Industrial Ecology (since 1997), the International Society for Industrial Ecology (since 2001), and the journal Progress in Industrial Ecology (since 2004) give Industrial Ecology a strong and dynamic position in the international scientific community. Industrial Ecology principles are also emerging in various policy realms such as the concept of the Circular Economy that is being promoted in China. Although the definition of the Circular Economy has yet to be formalized, generally the focus is on strategies such as creating a circular flow of materials, and cascading energy flows. An example of this would be using waste heat from one process to run another process that requires a lower temperature. This maximizes the efficiency of exergy use. The hope is that strategy such as this will create a more efficient economy with fewer pollutants and other unwanted by products.

Chapter 13

Zero Waste

Zero waste is a philosophy that encourages the redesign of resource life cycles so that all products are reused. Any trash sent to landfills is minimal. The process recommended is one similar to the way that resources are reused in nature. A working definition of zero waste, often cited by experts in the field originated from a working group of the Zero Waste International Alliance in 2004. The definition is as follows: "Zero Waste is a goal that is ethical, economical, efficient and visionary, to guide people in changing their lifestyles and practices to emulate sustainable natural cycles, where all discarded materials are designed to become resources for others to use. Zero Waste means designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources, and not burn or bury them. Implementing Zero Waste will eliminate all discharges to land, water or air that are a threat to planetary, human, animal or plant health."

- In industry this process involves creating commodities out of traditional waste products, essentially making old outputs new inputs for similar or different industrial sectors. An example might be the cycle of a glass milk bottle. The primary input (or resource) is silica-sand, which is formed into glass and then into a bottle. The bottle is filled with milk and distributed to the consumer. At this point, normal waste methods would see the bottle disposed in a landfill or similar. But with a zero-waste method, the bottle can be saddled at the time of sale with a deposit, which is returned to the bearer upon redemption. The bottle is then washed, refilled, and resold. The only material waste is the wash water, and energy loss has been minimized.

- - Zero waste can represent an economical alternative to waste systems, where new resources are continually required to replenish wasted raw materials. It can also represent an environmental alternative to waste since waste represents a significant amount of pollution in the world.

History

1960s: Zero Waste Systems Inc

- The term *zero waste* was first used publicly in the name of a company, Zero Waste Systems Inc (ZWS), which was founded by PhD chemist Paul Palmer in the mid 1970s in Oakland, California. The mission of ZWS was to find new homes for most of the chemicals being excessed by the nascent electronics industry. They soon expanded their services in many other directions. For example, they accepted free of charge, large quantities of new and usable laboratory chemicals which they resold to experimenters, scientists, companies and tinkerers of every description during the 1970s. ZWS arguably had the largest inventory of laboratory chemicals in all of California, which were sold for half price. They also collected all of the solvent produced by the electronics industry called developer/rinse (a mixture of xylene and butyl acetate). This was put into small cans and sold as a lacquer thinner. ZWS collected all the "reflow oil" created by the printed circuit industry, which was filtered and resold into the "downhole" (oil well) industry. ZWS pioneered many other projects.

- - Because they were the only ones in the world in this business, they achieved an international reputation. Many magazine articles were written about them and several television shows featured them. The California Integrated Waste Management Board produced a slide show featuring ZWS's business and the EPA published a number of studies of their business, calling them an "active waste exchange".

- - The heir to the ZWS mantle is the Zero Waste Institute (ZWI), also founded by Paul Palmer. Building on the lessons learned from ZWS, the ZWI considers recycling to be no more than an appendage to garbage creation and the garbage industry. ZWI likewise rejects all attempts to reuse garbage or any kind of waste product. Instead, ZWI calls for the redesign of all of the products of industry and commerce, and the processes that produce, sell and make use of them, so that discard never takes place and there is no waste generated needing to be reused or recycled. Discard is seen as the critical step, a commercial and psychological transfer of responsibility which breaks the chain of custody of a product, removes its owner and subjects it to the degradation of garbage management.

- - The website offers numerous specific examples of ways in which products can be designed so that discard is unnecessary since the lifetime of the product is extended to at least a threshold value of approximately a human lifetime of 100 years. A fully worked out set of principles and analysis is presented, revolving, among other changes, around standardization, modularization and robust design. A theory of Design Efficiency leading to Design Effectiveness is presented, which means that once a product is designed to be used in perpetuity, it can be fitted out with robust features, strong materials and special conveniences that could not be afforded in a product designed to be discarded after a single use. That theory is applied to packages as an example.

- - The ZWI rejects all association with the world of recycling, pointing out that there is no theory of recycling in existence; only a trusting hope that it can be useful.

1998-2003: peak

- The movement gained publicity and reached a peak in 1998+2002, and since then has been moving from "theory into action" by focusing on how a "zero waste community" is structured and behaves. The website of the Zero Waste International Alliance has a listing of communities across the globe that have created public policy to promote zero-waste practices. Finally, there is a USA zero-waste organization named the GrassRoots Recycling Network that puts on workshops and conferences about zero-waste activities.

Present day

- The tension between zero waste, viewed as post-discard total recycling of materials only, and zero waste as the reuse of all high level function remains a serious one today. It is probably the defining difference between established recyclers and emerging zero-wasters. A signature example is the difference between smashing a glass bottle (recovering cheap glass) and refilling the bottle (recovering the entire function of the container).

- - The tension between the literal application of natural processes and the creation of industry-specific more efficient reuse modalities is another tension. Many observers look to nature as an ultimate model for production and innovative materials. Others point out that industrial products are inherently non-natural (such as chemicals and plastics that are mono-molecular) and benefit greatly from industrial methods of reuse, while natural methods requiring degradation and reconstitution are wasteful in that context.

- - Biodegradable plastic is the most prominent example. One side argues that biodegradation of plastic is wasteful because plastic is expensive and environmentally damaging to make. Whether made of starch or petroleum, the manufacturing process expends all the same materials and energy costs. Factories are built, raw materials are procured, investments are made, machinery is built and used, humans labor and make use of all normal human inputs for education, housing, food etc. Even if the plastic is biodegraded after a single use, all of those costs are lost so it is much more important to design plastic parts for multiple reuse or perpetual lives. The other side argues that keeping plastic out of a dump or the sea is the sole benefit of interest.

- - Companies moving towards "zero landfill" plants include Suburu, Xerox and Anheuser-Busch.

Recycling

- - It is important to distinguish recycling from Zero Waste.

- Some claim that the key component to zero waste is recycling while others reject that notion in favor of reusing high function. The common understanding of recycling is simply that of placing bottles and cans in a recycle bin. The modern version of recycling is more complicated and involves many more elements of financing and government support. For example, a 2007 report by the U.S. Environmental Protection Agency states that the US recycles at a national rate of 33.4% and includes in this figure composted materials. In addition many worldwide commodity industries have been created to handle the materials that are recycled. At the same time, claims of recycling rates have sometimes been exaggerated, for example by the inclusion of soil and organic matter used to cover garbage dumps daily, in the "recycled" column. In states with recycling incentives, there is constant local pressure to pump up the recycling rate figures.

- - The movement toward recycling has separated itself from the concept of zero waste. One example of this is the computer industry where worldwide millions of PC's are disposed of each year (160 million in 2007). Those computers that enter the recycling stream are broken down into a small amount of raw materials while most merely enter dumps through export to third world countries. Companies are then able to purchase some raw materials, notably steel, copper and glass, reducing the use of new materials. On the other hand, there is an industry, more aligned with the Zero Waste principle of design for long term reuse, that actually repairs computers. It is called the Computer Refurbishing industry and it predates the current campaign to just collect and ship electronics. They have organizations and conferences and have for many years donated computers to schools, clinics and non-profits. Zero Waste planning demands that components be redesigned for effective reuse over long lives leading to even more refurbishing and repair.

- - There is one seminal example that brings out the difference between Zero Waste and recycling in stark relief. That example, quoted in Getting To Zero Waste, is the software business. Zero Waste is sensitive to the waste of intellectual effort that would be caused by the need to recreate certain basic inventions of software (called objects in software design) as opposed to copying them over and over whenever needed. The waste would occur as the software developers consume resources while solving problems already solved earlier. The application of Zero Waste analysis is straightforward as it recommends conserving human effort. On the other hand, the usual approach of recycling would be to look for some materials that could be found to reuse. The materials on which software is saved (such as paper or diskettes) is of little significance compared to the saving of human effort and if software is saved electronically, there is no media at all. Thus Zero Waste correctly identifies a wasteful behavior to avoid while recycling has no application.

- - The recycling movement has been embraced by the garbage industry because it serves so well as greenwashing i.e a way to show that design for garbage creation is acceptable because materials will be kept out of a dump by recycling them. Zero Waste, on the other hand, offers the garbage industry no such screen against public condemnation of waste, and therefore actually threatens the continued need for garbage disposal. For example, in Alameda County, California, garbage dumping is charged a surcharge of \$8/ton (as of

2009) which goes entirely for a recycling subsidy but none of which goes for any kind of Zero Waste style designing. Zero Waste has received no support from the garbage industry or politicians under their control except in those cases where it can be claimed to consist solely of more recycling.

Reduce and reuse

- Zero waste is poorly supported by the enactment of government laws to enforce the waste hierarchy of reduce, reuse, and recycle. In practice, these laws invariably emphasize destruction and recycling, while the reuse component is marginalized.

- - A special feature of Zero Waste as a design principle is that it can be applied to any product or process, in any situation or at any level. Thus it applies equally to toxic chemicals as to benign plant matter. It applies to the waste of atmospheric purity by coal burning or the waste of radioactive resources by attempting to designate the excesses of nuclear power plants as "nuclear waste". All processes can be designed to minimize the need for discard, both in their own operations and in the usage or consumption patterns which the design of their products leads to. Recycling, on the other hand, deals only with simple materials.

- - Zero Waste can even be applied to the waste of human potential by enforced poverty and the denial of educational opportunity. It encompasses redesign for reduced energy wasting in industry or transportation and the wasting of the earth's rainforests. It is a general principle of designing for the efficient use of all resources, however defined.

- - The recycling movement may be slowly branching out from its solid waste management base to include issues that are similar to the community sustainability movement.

- Zero waste on the other hand, is not based in waste management limitations to begin with but requires that we maximize our existing reuse efforts while creating and applying new methods that minimize and eliminate destructive methods like incineration and recycling. Zero Waste strives to ensure that products are designed to be repaired, refurbished, remanufactured and generally reused.. ("What is Zero Waste?", para 2).

The significance of dump capacity

- Many dumps are currently exceeding carrying capacity. This is often, mistakenly used as a justification for moving to Zero Waste. Others counter by pointing out that there are huge tracts of land available throughout the USA and other countries which could be used for dumps. This is no more of an argument against the need for Zero Waste than is the former an argument for Zero Waste. The underlying need to move to a society designed along Zero Waste principles arises from the huge waste of resources that is inherent in poorly made, short-lived articles and production processes. The locus of the most egregious wasting takes place as articles are built and processes are run wastefully. The actual placing of a now useless item in a dump is barely the icing on the cake, in terms of

the waste it represents. Poorly conceived proposals, that appear with a dismaying regularity on the Internet, to blithely destroy all garbage as a way to solve the garbage problem, make use of the common delusion that it is the garbage itself which is the problem. These proposals typically claim to convert all or a large portion of existing garbage into oil and sometimes claim to produce so much oil that the world will henceforth have abundant liquid fuels. One such plan, called Anything Into Oil was promoted by Discover Magazine and Fortune Magazine in 2004, even though it absurdly claimed to be able to convert a refrigerator into "light Texas crude" by the application of high pressure steam. Zero Waste analysis, which is long on scientific results and short on spectacular claims, receives no such promotion by the media.

Corporate initiatives

- An example of a company that has demonstrated a change in landfill waste policy is General Motors (GM). GM has confirmed their plans to make approximately half of its 181 plants worldwide "landfill-free" by the end of 2010. Companies like Subaru, Toyota, and Xerox are also producing landfill-free plants. GM is supposed to have about eighty producing plants twenty months. Furthermore, The United States Environmental Protection Agency (EPA) has worked with GM and other companies for decades to minimize the waste through its WasteWise program. The goal for General Motors is finding ways to recycle or reuse more than 90% of materials by: selling scrap materials, adopting reusable parts boxes to replace cardboard, and even recycling used work gloves. The remainder of the scraps might be incinerated to create energy for the plants. Besides being nature friendly, it also saves money by cutting out waste and producing a more efficient production. All these organizations all push forth to make our world clean and producing zero waste.

Re-use of waste

The waste sent to landfills may be harvested as useful materials, such as in the production of solar energy or fertiliser for crops.

It may also be reused and recycled for something that we can actually use. "The success of General Motors in creating zero-landfill facilities shows that zero-waste goals can be a powerful impetus for manufacturers to reduce their waste and carbon footprint," says Latisha Petteway, a spokesperson for the EPA.

Construction and deconstruction

- Zero Waste is a goal, a process, a way of thinking that profoundly changes our approach to resources and production. Zero Waste is not about recycling and diversion from landfills but about restructuring production and distribution systems to prevent waste from being manufactured in the first place. The materials that are still required in these re-designed, resource-efficient systems will be reused many times as the products that incorporate them are reused. Deconstruction can be described as construction in reverse. It involves carefully taking apart a building to maximize the reuse of materials, thereby

reducing waste and conserving resources. Deconstruction can capture materials and some components from the millions of buildings that are existing and that were poorly designed for high level reuse but it is not a favored approach from a Zero Waste point of view. Zero Waste favors the design of buildings as assemblages of high level components, not their creation from rough materials such as lumber, cement or plaster. The details are not worked out yet but to the extent that entire rooms, entire walls, roofs or floors or entire utility systems can be pre-built and installed as completed components, that will be the goal of Zero Waste design. Until buildings are built as components capable of later dismantling, deconstruction is a stop-gap process that the United States can use to minimize the waste of building materials. For now, the largest parts that we are able to save tend to be architectural elements, windows, doors, and metals, many of which are being saved and resold by reuse yards such as Urban Ore in Berkeley California. The main parts that still need to be crushed are wood flooring, brick walls, and structural timbers. The demolition of traditional buildings has been long done by wrecking ball or bulldozer. Social and political artifacts, such as demolition contractor licenses and required permits that can only be satisfied by destruction and discard (with partial recycling of rubble and steel), render the destruction and disposal costs cheaper than deconstruction. Approximately seventy pounds of the waste is generated for about every square foot of the residential building demolition. It is arguable that this is artificial economics, based on the cultural preference for wastefulness and that Zero Waste designs of dismantlable components will ultimately be the cheapest as well as the most conservative way to reuse buildings. Further discussions of this topic may be found on the ZWI website.

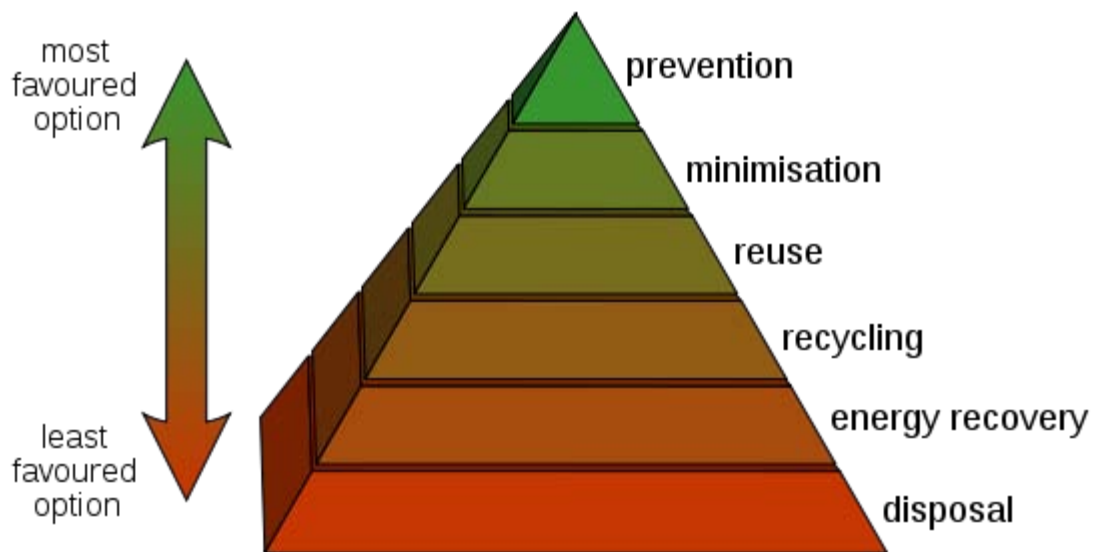
Market-based campaigns

- Market-based, legislation-mediated campaigns like Extended Producer Responsibility (EPR) and the Precautionary Principle are among numerous campaigns that have a Zero Waste slogan hung on them by means of claims they will ineluctably lead to policies of Zero Waste. At the moment, there is no evidence that EPR will increase reuse, rather than merely moving discard and disposal into private-sector dumping contracts. The Precautionary Principle is put forward to shift liability for proving new chemicals are safe from the public (acting as guinea pig) to the company introducing them. As such, its relation to Zero Waste is dubious. Likewise, many organizations, cities and counties have embraced a Zero Waste slogan while pressing for none of the key Zero Waste changes. In fact, it is common for many such to simply state that recycling is their entire goal. Many commercial or industrial companies claim to embrace Zero Waste but usually mean no more than a major materials recycling effort, having no bearing on product redesign. Examples include Staples, Home Depot, Toyota, General Motors and computer take-back campaigns. Earlier social justice campaigns have successfully pressured McDonald's to change their meat purchasing practices and Nike to change its labor practices in Southeast Asia. Those were both based on the idea that organized consumers can be active participants in the economy and not just passive subjects. However, the announced and enforced goal of the public campaign is critical. A goal to reduce waste generation or dumping through greater recycling will not achieve a goal of product redesign and so cannot reasonably be called a Zero Waste campaign.

Chapter 14

Waste Hierarchy & Waste Minimization

Waste Hierarchy



The waste hierarchy

The **waste hierarchy** refers to the 3 (or 4) Rs of reduce, reuse, recycle, (and recover) which classify waste management strategies according to their desirability. The Rs are meant to be a hierarchy, in order of importance. However in Europe the waste hierarchy has 5 steps: reduce, reuse, recycle, recovery, and disposal.

The waste hierarchy has taken many forms over the past decade, but the basic concept has remained the cornerstone of most waste minimisation strategies. The aim of the waste

hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste.

Some waste management experts have recently incorporated a additional R: "Re-think", with the implied meaning that the present system may have fundamental flaws, and that a thoroughly effective system of waste management may need an entirely new way of looking at waste. *Source reduction* involves efforts to reduce hazardous waste and other materials by modifying industrial production. Source reduction methods involve changes in manufacturing technology, raw material inputs, and product formulation. At times, the term "pollution prevention" may refer to source reduction.

Another method of source reduction is to increase incentives for recycling. Many communities in the United States are implementing variable rate pricing for waste disposal (also known as Pay As You Throw - PAYT) which has been effective in reducing the size of the municipal waste stream.

Source reduction is typically measured by efficiencies and cutbacks in waste. *Toxics use reduction* is a more controversial approach to source reduction that targets and measures reductions in the upstream use of toxic materials. Toxics use reduction emphasizes the more preventive aspects of source reduction but, due to its emphasis on toxic chemical inputs, has been opposed more vigorously by chemical manufacturers. *Toxics use reduction* programs have been set up by legislation in some states, e.g., Massachusetts, New Jersey, and Oregon.

How the hierarchy works

The Rs are categories at the top of our disposal options. They include a variety of initiatives for disposing of discards. Generally, options lowest on the list are least desirable.

Reduce - to buy less and use less. Incorporates common sense ideas like turning off the lights, rain barrels, and taking shorter showers, but also plays a part in composting/grasscycling (transportation energy is reduced), low-flow toilets, and programmable thermostats. Includes the terms Re-think, Precycle, Carpool, Efficient, and Environmental Footprint.

Reuse' - elements of the discarded item are used again. Initiatives include hand-me-downs, garage sales, quilting, travel mugs, and composting (nutrients). Includes the terms laundry, repair, regift, and upcycle.

Recycle - discards are separated into materials that may be incorporated into new products. This is different from Reuse in that energy is used to change the physical properties of the material. Initiatives include Composting, Beverage Container Deposits and buying products with a high content of post-consumer material. Within recycling there is distinction between two types:

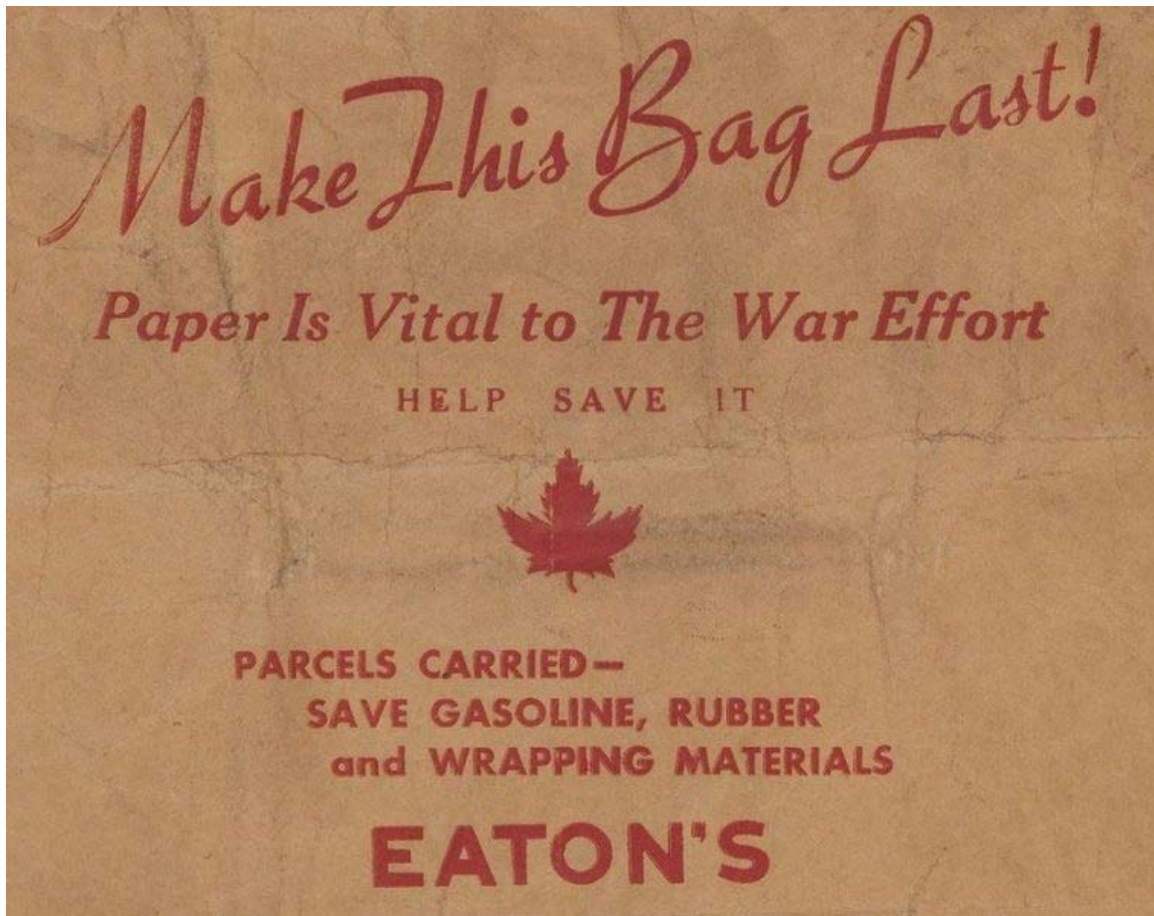
Upcycle- converting low-value materials in high-value products (more desirable)
Downcycle - converting valuable products in to low-value raw materials (less desirable)

Generate - capturing useful material for waste to energy programs. Includes Methane Collection, Gasification and Digestion, and the term Recover.

Incinerate - high temperature destruction of material. Differs from Gasification in that oxygen is used; differs from burning in that high temperatures consume material efficiently and emissions are controlled.

Devastate - to discard into the natural environment, or to "trash" the planet. Includes Litter, Burn Barrels, Unnecessary Vehicle Idling, and Dumping discards onto land or into water.

Incentives for 3R



The promotion of waste minimisation has existed for decades, as evidenced by this paper department store bag which urged shoppers to reuse their bags as part of the World War II war effort

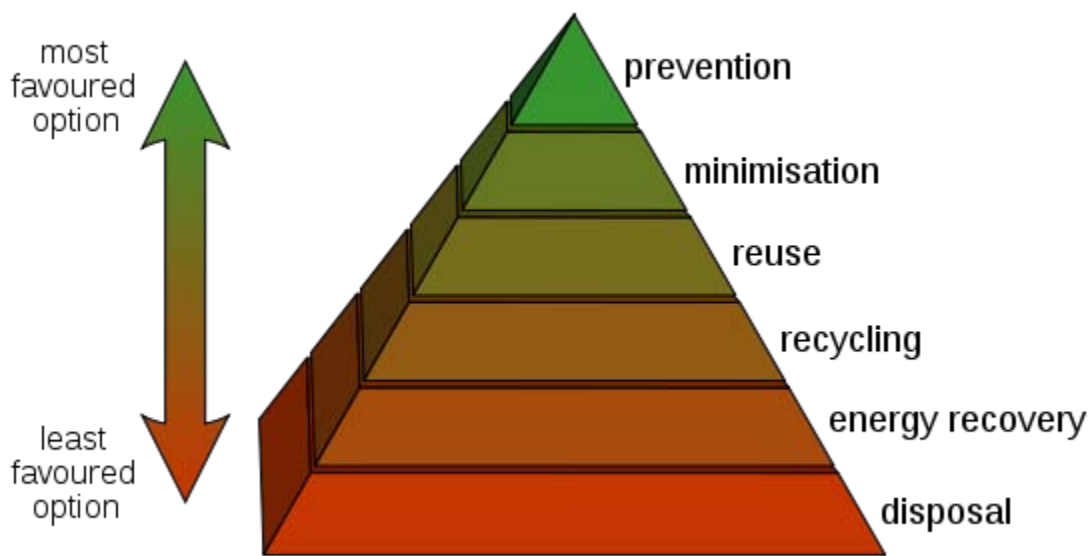
The 3R's of reduce, reuse and recycle have been considered to be a base of environmental awareness and a way of promoting ecological balance through conscious behaviour and choices. It is generally accepted that these patterns of behaviour and consumer choices will lead to savings in materials and energy which will benefit the environment. In this context it may be enquired whether certain economic instruments may be considered to further strengthen these behaviours and choices.

In this context it may be enquired whether certain economic instruments may be considered to further strengthen these behaviours and choices. An example may be to reduce the sales tax or value added tax on goods that are made by recycling used materials, such as paper, plastics, glass, metals. Another example may be to reduce sales tax or value added tax on second-hand goods, which may include books, clothes, household gadgets, bicycles, cars and automobiles, office equipment, medical and scientific equipment, telecommunication equipment, agricultural equipment, industrial and manufacturing equipment, boats, ships, trains and trams, aeroplanes, oil rigs, and so forth.

An additional approach may be to reduce the interest rates on the financial loans, which companies avail of, for their commercial activities in the recycling, re-use and resale of used material and equipments.

It is plausible that this may have a significant impact on consumer behaviour, and may strengthen those sections of the economy and trade that are associated with such goods and services. Additionally, this would be consistent with supporting consumer behaviour and choices that are beneficial for the environment and for the economy.

Waste Minimisation



Waste hierarchy

Waste minimisation is the process and the policy of reducing the amount of waste produced by a person or a society.

Waste minimisation involves efforts to minimise resource and energy use during manufacture. For the same commercial output, usually the fewer materials are used, the less waste is produced. Waste minimisation usually requires knowledge of the production process, cradle-to-grave analysis (the tracking of materials from their extraction to their return to earth) and detailed knowledge of the composition of the waste.

The main sources of waste vary from country to country. In the UK, most waste comes from the construction and demolition of buildings, followed by mining and quarrying, industry and commerce. Household waste constitutes a relatively small proportion of all waste. Reasons for the creation of waste sometimes include requirements in the supply chain. For example, a company handling a product may insist that it should be packaged using particular packing because it fits its packaging equipment.

In the waste hierarchy, the most effective approaches to managing waste are at the top. In contrast to waste minimisation, waste management focuses on processing waste after it is created, concentrating on re-use, recycling, and waste-to-energy conversion.

In industries

In industries, using more efficient manufacturing processes and better materials will generally reduce the production of waste. The application of waste minimisation techniques has led to the development of innovative and commercially successful replacement products. Waste minimisation has proven benefits to industry and the wider environment.

Waste minimisation often requires investment, which is usually compensated by the savings. However, waste reduction in one part of the production process may create waste production in another part.

There are government incentives for waste minimisation, which focus on the environmental benefits of adopting waste minimisation strategies. In the UK, several pilot schemes such as The Catalyst Project and the Dee Waste Minimisation Project, have shown the efficacy of such policies. Fourteen companies in Merseyside took part in the Catalyst Project; the project generated overall savings of £9 million and landfill waste was reduced by 12,000 tonnes per year.

The following is a list of waste minimisation processes:

Resource optimisation

Minimising the amount of waste produced by organisations or individuals goes hand-in-hand with optimising their use of raw materials. For example, a dressmaker may arrange pattern pieces on a length of fabric in a particular way to enable the garment to be cut out from the smallest area of fabric.

Reuse of scrap material

Scraps can be immediately re-incorporated at the beginning of the manufacturing line so that they do not become a waste product. Many industries routinely do this; for example, paper mills return any damaged rolls to the beginning of the production line, and in the manufacture of plastic items, off-cuts and scrap are re-incorporated into new products.

Improved quality control and process monitoring

Steps can be taken to ensure that the number of reject batches is kept to a minimum. This is achieved by increasing the frequency of inspection and the number of points of inspection. For example, installing automated continuous monitoring equipment can help to identify production problems at an early stage.

Waste exchanges

This is where the waste product of one process becomes the raw material for a second process. Waste exchanges represent another way of reducing waste disposal volumes for waste that cannot be eliminated.

Ship to point of use

This involves making deliveries of incoming raw materials or components direct to the point where they are assembled or used in the manufacturing process to minimise handling and the use of protective wrappings or enclosures.

Product design

Waste minimisation and resource maximisation for manufactured products can most easily be done at the design stage. Reducing the number of components used in a product or making the product easier to take apart can make it easier to be repaired or recycled at the end of its useful life.

In some cases, it may be best not to minimise the volume of raw materials used to make a product, but instead reduce the volume or toxicity of the waste created at the end of a product's life, or the environmental impact of the product's use.

Fitting the intended use

In this strategy, products and packages are optimally designed to meet their intended use. This applies especially to packaging materials, which should only be as durable as necessary to serve their intended purpose. On the other hand, it could be more wasteful if food, which has consumed resources and energy in its production, is damaged and spoiled because of extreme measures to reduce the use of paper, metals, glass and plastics in its packaging.

Durability

Improving product durability, such as extending a vacuum cleaner's useful life to 15 years instead of 12, can reduce waste and usually much improves resource optimisation.

But in some cases it has a negative environmental impact. If a product is too durable, its replacement with more efficient technology is likely to be delayed. For example, a washing machine produced 10 years ago may use twice as much water, detergent and energy as one produced today. Therefore, extending an older machine's useful life may place a heavier burden on the environment than scrapping it, recycling its metal and buying a new model. Similarly, older vehicles consume more fuel and produce more emissions than their modern counterparts.

Most proponents of waste minimisation consider that the way forward may be to view any manufactured product at the end of its useful life as a resource for recycling and reuse rather than waste. Recycling a product is easier if it is constructed of fewer materials. Car manufacturers have recently reduced the number of plastics used in their cars from twenty or more to three or four, hence simplifying the recovery of plastics from scrapped cars. However, exceptions (like having a combination of paper and plastic or plastic coating on glass) do exist, and might enable a product to fulfill its role with the minimum of resources.

Making refillable glass bottles strong enough to withstand several journeys between the consumer and the bottling plant requires making them thicker and so heavier, which increases the resources required to transport them. Since transport has a large environmental impact, careful evaluation is required of the number of return journeys bottles make. If a refillable bottle is thrown away after being refilled only several times, the resources wasted may be greater than if the bottle had been designed for a single journey..

Many choices involve trade-offs of environmental impact, and often there is insufficient information to make informed decisions.

In households

Appropriate amounts and sizes can be chosen when purchasing goods; buying large containers of paint for a small decorating job or buying larger amounts of food than can be consumed create unnecessary waste. Also, if a pack or can is to be thrown away, any remaining contents must be removed before the container can be recycled .

Home composting, the practice of turning kitchen and garden waste into compost can be considered waste minimisation.

The resources that households use can be reduced considerably by using electricity thoughtfully (e.g. turning off lights and equipment when it is not needed) and by reducing the number of car journeys made. Individuals can reduce the amount of waste they create by buying fewer products and by buying products which last longer. Mending broken or worn items of clothing or equipment also contributes to minimising household waste. Individuals can minimise their water usage, and walk or cycle to their destination rather than using their car to save fuel and cut down emissions.

In a domestic situation, the potential for minimisation is often dictated by lifestyle. Some people may view it as wasteful to purchase new products solely to follow fashion trends when the older products are still usable. Adults working full-time have little free time, and so may have to purchase more convenient foods that require little preparation, or prefer disposable nappies if there is a baby in the family.

The amount of waste an individual produces is a small portion of all waste produced by society, and personal waste reduction can only make a small impact on overall waste volumes. Yet, influence on policy can be exerted in other areas. Increased consumer awareness of the impact and power of certain purchasing decisions allows industry and individuals to change the total resource consumption. Consumers can influence manufacturers and distributors by avoiding buying products that do not have eco-labelling, which is currently not mandatory, or choosing products that minimise the use of packaging. In the UK, PullApart combines both environmental and consumer packaging surveys, in a curbside packaging recycling classification system to waste minimise. Where reuse schemes are available, consumers can be proactive and use them.

Chapter 15

Material Flow Accounting & Material Flow Analysis

Material Flow Accounting

Material flow accounting (MFA) is the study of material flows on a national or regional scale. It is therefore sometimes also referred to as regional, national or economy-wide material flow analysis.

Definition

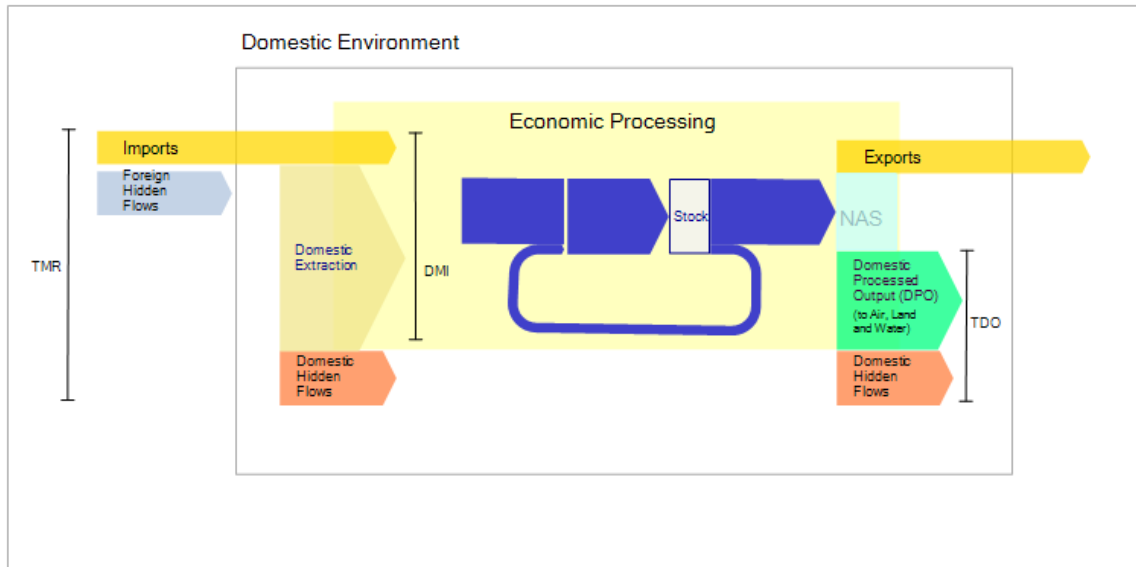
The goal of material flow accounting is to ensure national planning, especially for scarce resources, and to allow forecasting. It also allows to assess environmental burdens through economic activities of a nation or to determine how material intensive an economy is.

The principle concept underlying MFA is a simple model of this interrelation between the economy and the environment, in which the economy is an embedded subsystem of the environment. Similar to living beings, this subsystem is dependent on a constant throughput of materials and energy. Raw materials, water and air are extracted from the natural system as inputs, transformed into products and finally re-transferred to the natural system as outputs (waste and emissions). In order to highlight the similarity to natural metabolic processes, the terms “industrial” or “societal” metabolism have been introduced.

In MFA studies for a region or on a national level the flows of materials between the natural environment and the economy are analyzed and quantified on a physical level. The focus may be on individual substances (e.g. Cadmium flows), specific materials, or bulk material flows (e.g. steel and steel scrap flows within an economy). Research on

MFA is strong in Germany, Austria and the United States. Researchers in this field are organized in the ConAccount network.

Material flow accounting is usually carried out by national statistics bureaus, using economic and physical input/output tables and data on the exchange of material between different sectors of the economy (commodity censuses).



Terms and Indicators

The following indicators are commonly used in material flow accounting to measure the resource efficiency of a country or region:

Total Material Requirement (TMR) includes the domestic extraction of resources (minerals, fossil fuels, biomass), the indirect flows caused by and associated with the domestic extraction (called "Hidden Flows") and the imports.

Domestic Material Input (DMI) summarizes the domestic extraction of resources and the imports, but excludes the indirect flows associated with the domestic extraction, since they are sometimes difficult to quantify.

Direct Material Consumption (DMC): this indicator accounts all materials that are consumed within or remain in the domestic environment. The quantity is the domestic material input minus the exports out of the economy.

Domestic Processed Output (DPO) is defined by the OECD as "the total mass of materials which have been used in the national economy, before flowing into the environment. These flows occur at the processing, manufacturing, use, and final disposal stages of the economic production-consumption chain."

Total Domestic Output (TDO) includes the domestic processed output (DPO) plus the hidden flows associated with the domestic production.

Net Addition to Stocks (NAS), the materials that are neither released to the domestic environment nor exported, but contribute to a physical increase of the economic processing system itself, e.g. infrastructure, buildings, machinery or other durable goods.

Hidden Flows are materials that are extracted or moved, but do not enter the economy. According to OECD, the "displacement of environmental assets without absorption into the economic sphere", such as overburden from mining operations.

Material Flow Analysis

Material flow analysis (MFA) (or **substance flow analysis**; SFA) is a method of analyzing the flows of a material in a well-defined system. MFA is an important tool of industrial ecology, and is used to produce better understanding of the flow of materials through an industry and connected ecosystems, to calculate indicators, and to develop strategies for improving the material flow systems. Material Flow Analysis is the basis for a material flow management.

Material Flow Analysis can be divided into the following three types:

- *On a national or regional scale* (also referred to as Material Flow Accounting): In this type of studies the material exchanges between an economy and the natural environment are analyzed. Indicators are calculated in order to assess the level of resource intensity of the system.
- *Corporate material flow analysis*, or along an *industrial supply chain* involving a number of companies: The goal of material flow analysis within a company is to optimize the production processes in such a way that materials and energy are used in the most efficient manner (e.g. by recycling and reduction of waste). Companies that implement a material flow analysis can use the results to improve their operations costs and environmental performance.
- *In the life cycle of a product*: This is another term for the life cycle inventory step of life cycle assessment.

Development of the discipline

- Friedrich Schmidt-Bleek is considered by many to be the father of the discipline with his concept of Material Input Per Service unit (MIPS). Dr. Schmidt-Bleek is known for his work claiming that resource efficiency could be increased by a **Factor 10**. He inspired others in Germany in the Eighties of the last century to pursue studies in MFA with him at the Wuppertal Institute in Germany, and some of them to set up institutes of their own. One such institute, the Sustainable Europe Research Institute (SERI) in Vienna, Austria (with a related institution in Germany), has developed a data base called materialflows.net.

- Dennis Meadows gave the discipline its biggest boost when he co-authored the bestseller *Limits to Growth* in 1971. Meadows et al. based their predictions on an analysis of Resource stocks.
- Mathis Wackernagel is known for co-developing the concept of the ecological footprint. Dr. Wackernagel founded the Footprint Network.
- The UNEP Resource Panel was set up in 2008 by the United Nations Environment Program, and is headed by Ernst Ulrich von Weizsäcker. Somewhat like the Intergovernmental Panel on Climate Change it brings together experts on the subject to issue common statements. Dr. von Weizsäcker is known for his book **Factor 4** coauthored with Amory Lovins and Mrs. Hunter Lovins.

Critique

- The factors are ambitious by which resource efficiency is said to be improvable.
- Emissions such as carbon dioxide which have been proven elsewhere to have special earth-warming effects as greenhouse gases are treated in much the same ways as any other resource.

Current trends

Starting in 2009 a semi-annual international conference is held in Davos, Switzerland, on Material Flow Analysis and sustainable development, which is called the World Resources Forum. Friedrich Schmidt-Bleek, Dennis Meadows, Ernst Ulrich von Weizsäcker of the UNEP Resource Panel were among the keynote speakers during the 2009 event.

Chapter 16

Full Cost Accounting

Full cost accounting (FCA) generally refers to the process of collecting and presenting information - about environmental, social, and economic costs and benefits/advantages (collectively known as the "triple bottom line") - for each proposed alternative when a decision is necessary. It is a conventional method of cost accounting that traces direct costs and allocates indirect costs. A synonym, **true cost accounting** (TCA) is also often used. Experts consider both terms problematic as definitions of "true" and "full" are inherently subjective.

Triple Bottom Line

Since costs and advantages are usually considered in terms of environmental, economic and social impacts, full or true cost efforts are collectively called the "triple bottom line". A large number of standards now exist in this area including Ecological Footprint, eco-labels, and the United Nations International Council for Local Environmental Initiatives approach to triple bottom line using the ecoBudget metric. The International Organization for Standardization (ISO) has several accredited standards useful in FCA or TCA including for greenhouse gases, the ISO 26000 series for corporate social responsibility coming in 2010, and the ISO 19011 standard for audits including all these.

Because of this evolution of terminology in public sector use especially, the term full-cost accounting is now more commonly used in management accounting, e.g. infrastructure management and finance. Use of the terms FCA or TCA usually indicate relatively conservative extensions of current management practices, and incremental improvements to GAAP to deal with waste output or resource input.

These have the advantage of avoiding the more contentious questions of social cost.

Concepts

Full cost accounting embodies several key concepts that distinguish it from standard accounting techniques. The following list highlights the basic tenets of FCA.

1. Accounting for costs rather than outlays
2. Accounting for hidden costs and externalities
3. Accounting for overhead and indirect costs
4. Accounting for past and future outlays
5. Accounting for costs according to lifecycle of the product

Costs rather than outlays

An outlay is an expenditure of cash to acquire or use a resource. A cost is the cash value of the resource as it is used. For example, an outlay is made when a vehicle is purchased, but the cost of the vehicle is incurred over its active life (e.g., 10 years). The cost of the vehicle must be allocated over a period of time because every year of its use contributes to the depreciation of the vehicle's value.

Hidden costs

With FCA, the value of goods and services is reflected as a cost even if no cash outlay is involved. One community might receive a grant from a state, for example, to purchase equipment. This equipment has value, even though the community did not pay for it in cash. The equipment, therefore, should be valued in an FCA analysis.

Overhead and indirect costs

FCA accounts for all overhead and indirect costs, including those that are shared with other public agencies. Overhead and indirect costs might include legal services, administrative support, data processing, billing, and purchasing. Environmental costs as indirect costs include the full range of costs throughout the life-cycle of a product (Life cycle assessment), some of which even do not show up in the firm's bottom line. It also contains fixed overhead, fixed administration expense etc.

Past and future outlays

Past and future cash outlays often do not appear on annual budgets under cash accounting systems. Past (or upfront) costs are initial investments necessary to implement services such as the acquisition of vehicles, equipment, or facilities. Future (or back-end) outlays are costs incurred to complete operations such as facility closure and postclosure care, equipment retirement, and post-employment health and retirement benefits.

Examples of full-cost accounting

Waste management

For example, the State of Florida uses the term full cost accounting for its solid waste management. In this instance, FCA is a systematic approach for identifying, summing, and reporting the actual costs of solid waste management. It takes into account past and future outlays, overhead (oversight and support services) costs, and operating costs.

Integrated solid waste management systems consist of a variety of municipal solid waste (MSW) activities and paths. Activities are the building blocks of the system, which may include waste collection, operation of transfer stations, transport to waste management facilities, waste processing and disposal, and sale of byproducts. Paths are the directions that MSW follows in the course of integrated solid waste management (i.e., the point of generation through processing and ultimate disposition) and include recycling, composting, waste-to-energy, and landfill disposal. The cost of some activities is shared between paths. Understanding the costs of MSW activities is often necessary for compiling the costs of the entire solid waste system, and helps municipalities evaluate whether to provide a service itself or contract out for it. However, in considering changes that affect how much MSW ends up being recycled, composted, converted to energy, or landfilled, the analyst should focus the costs of the different paths. Understanding the full costs of each MSW path is an essential first step in discussing whether to shift the flows of MSW one way another.

Benefits to waste management

When municipalities handle MSW services through general tax funds, the costs of MSW management can get lost among other expenditures. With FCA, managers can have more control over MSW costs because they know what the costs are.

Using techniques such as depreciation and amortization, FCA produces a more accurate picture of the costs of MSW programs, without the distortions that can result from focusing solely on a given year's cash expenditures.

FCA helps you collect and compile the information needed to explain to citizens what solid waste management actually costs. Although some people might think that solid waste management is free (because they are not billed specifically for MSW services), others might overestimate its cost. FCA can result in "bottom line" numbers that speak directly to residents. In addition, public officials can use FCA results to respond to specific public concerns.

By focusing attention on costs, FCA fosters a more businesslike approach to MSW management. Consumers of goods and services increasingly expect value, which means an appropriate balance between quality and cost of service. FCA can help identify opportunities for streamlining services, eliminating inefficiencies, and facilitating cost-saving efforts through informed planning and decision-making.

When considering privatization of MSW services, solid waste managers can use FCA to learn what it costs (or would cost) to do the work. As a result, FCA better positions public agencies for negotiations and decision-making. FCA also can help communities with publicly run operations determine whether their costs are competitive with the private sector.

FCA gives managers the ability to evaluate the cost of each element of their solid waste system, such as recycling, composting, waste-to-energy, and landfilling. FCA can help managers avoid common mistakes in thinking about solid waste management, notably the error of treating avoided costs as revenues.

As more communities use FCA and report the results, managers might be able to "benchmark" their operations to similar communities or norms. This comparison can suggest options for "re-engineering" current operations. Furthermore, when cities, counties, and towns know what it costs to manage MSW independently, they can better identify any savings that might come from working together.

Motives for adoption

Various motives for adoption of FCA/TCA have been identified. The most significant of which tend to involve anticipating market or regulatory problems associated with ignoring the comprehensive outcome of the whole process or event accounted for. *In green economics, this is the major concern and basis for critiques of such measures as GDP.* The public sector has tended to move more towards longer term measures to avoid accusations of political favoritism towards specific solutions that seem to make financial or economic sense in the short term, but not longer term.

Corporate decision makers sometimes call on FCA/TCA measures to decide whether to initiate recalls, practice voluntary product stewardship (a form of recall at the end of a product's useful life). This can be motivated as a hedge against future liabilities arising from those who are negatively affected by the waste a product becomes. Advanced theories of FCA, such as Natural Step, focus firmly on these. According to Ray Anderson, who instituted a form of FCA/TCA at Interface Carpet, used it to rule out decisions that increase Ecological Footprint and focus the company more clearly on a sustainable marketing strategy.

The urban ecology and industrial ecology approaches inherently advocate FCA - treating the built environment as a sort of ecosystem to minimize its own wastes.

Chapter 17

Industrial Symbiosis & Integrated Chain Management

Industrial Symbiosis



Example of Industrial Symbiosis. Waste steam from a waste incinerator (right) is piped to an ethanol plant (left) where it is used as input to their production process.

Industrial symbiosis can be defined as sharing of services, utility, and by-product resources among industrial actors in order to add value, reduce costs and improve environment. Industrial symbiosis is a subset of industrial ecology, with a particular focus on material and energy exchange. Industrial ecology is a relatively new field that is based on a natural paradigm, claiming that an industrial ecosystem may behave in a similar way to the natural ecosystem wherein everything gets recycled.

Introduction

Eco-industrial development is one of the ways in which industrial ecology contributes to the integration of economic growth and environmental protection. Some of the examples of eco-industrial development are:

- Green Twinning (single material and/or energy exchange)
- Greenfield Eco-industrial Development (geographically confined space)
- Brownfield Eco-industrial Development (geographically confined space)
- Eco-industrial Network (no strict requirement of geographical proximity)
- Virtual Eco-industrial Network (networks spread in large areas e.g. regional network)
- Networked Eco-industrial System (macro level developments with links across regions)

"This classification omits any industrial sector-wide approaches and appreciates the diversity of the industrial system which is a key feature of industrial symbiosis. It is aimed to include initiatives that focus on achieving utility sharing and symbiosis among diverse sectors of industry" . Industrial symbiosis does not limit itself to sectoral boundaries and / or geographical restrictions . It is the diversity and the openness of industrial symbiosis that makes it a unique approach to eco-industrial development.

Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity". The sharing of information is even more critical with the emergence of virtual globes such as Google Earth. These tools can greatly simplify the geographical analysis involved in determining potential IS opportunities.

Industrial symbiosis systems collectively optimize material and energy use at efficiencies beyond those achievable by any individual process alone. IS systems such as the web of materials and energy exchanges among companies in Kalundborg, Denmark have spontaneously evolved from a series of micro innovations over a long time scale; however, the engineered design and implementation of such systems from a macro planner's perspective, on a relatively short time scale, proves challenging. Nevertheless

there are examples of industrial symbiosis being approached as national / regional initiatives with some significant success particularly in Europe.

Often, access to information on available by-products is non-existent. These by-products are considered waste and typically not traded or listed on any type of exchange.

Example

Recent work reviewed government policies necessary to construct a multi-gigaWatt photovoltaic factory and complementary policies to protect existing solar companies are outlined and the technical requirements for a **symbiotic industrial system** are explored to increase the manufacturing efficiency while improving the environmental impact of solar photovoltaic cells. The results of the analysis show that an eight-factory industrial symbiotic system can be viewed as a medium-term investment by any government, which will not only obtain direct financial return, but also an improved global environment.

Integrated Chain Management

Integrated Chain Management (ICM), also known as **Integral Chain Management**, is an approach for the reduction of environmental impact of product chains. Such a product chain exists out of an extraction phase, a production phase, a use phase and a waste phase. The ultimate goal of ICM is a reduction of environmental load over the whole chain. Integrated Chain Management is one of the approaches that can be used to come to sustainable development. Other approaches in this line are the Ecological Footprint and the DTO approach.

Within the ICM approach all phases within the chain must be considered. Therefore it can be seen as a "cradle to grave" approach. Several inputs and outputs can be taken into account when applying the ICM approach. Such as: Energy flows, mass flows, materials, waste flows and emissions. Within ICM material cycles should be closed where possible and the remainder flows of emissions and waste should be brought within acceptable boundaries. Also the use of resources should be kept to a minimum.

Integrated chain management should not be mixed up with Supply Chain Management or Integrated Supply Chain Management. These concepts do not have the reduction of environmental load as their main goal.

An important aspect of ICM is that shifting to other phases in the product chain is avoided. For instance, a producer of chairs can choose to leave away an environment unfriendly material in a new product. The producer can even see this as an extra selling point for the customer. But as a consequence the supplier of raw materials has to use much more energy to produce a material with the same qualities. Within the integrated chain management approach this is not possible.

The chain can be managed by developing new policies and economical or political incentives. Therefore one must have insight into the inputs and outputs of the production chain. Before these policies can be developed one must engage in several actions.

- Analyse the processes into a preferred level of detail
- Determine the boundaries of the chain. Should links outside the companies be involved as well?
- Determine whether there should be a focus on just one or on several environmental problems
- Determine on which material flows or energy flows there should be a focus.

Effective supply chain management can impact virtually all business and production processes

Example

An example of applying the ICM approach would be to develop policies in a particular product area. The responsibility of problems caused by the waste stage can be assigned to the producers of these products. This leads to improved product design and new insight in how to put these products in the market. For instance the product can be sold with a disposal contribution. On the price tag of a radio nowadays can be printed: "this radio costs 25 \$ not including the 3 \$ disposal contribution" The effects can be seen within the whole chain. The producer will try to choose for not to polluting materials, as they increase the costs of the waste-stage. The producer of raw materials will try to improve its production process in order to meet the increased demand for 'clean' primary products. And the consumer will be aware that some products give more pressure on the environment than others when its economical lifespan has run out.