Executive Summary

The evolution of sustainable manufacturing has been facilitated by multi-level eco-innovation

Manufacturing industries have the potential to become a driving force for realising a sustainable society by introducing efficient production practices and developing products and services that help reduce negative impacts. This will require them to adopt a more holistic business approach that places environmental and social aspects on an equal footing with economic concerns.

Their efforts to improve environmental performance have been shifting from "end-of-pipe" pollution control to a focus on product life cycles and integrated environmental strategies and management systems. Furthermore, efforts are increasingly made to create closed-loop, circular production systems in which discarded products are used as new resources for production.

Many companies and a few governments have started to use the term *eco-innovation* to describe the contributions of business to sustainable development while improving competitiveness. Eco-innovation can be generally defined as innovation that results in a reduction of environmental impact, no matter whether or not that effect is intended. Various eco-innovation activities can be analysed along three dimensions:

- *targets* (the focus areas of eco-innovation: products, processes, marketing methods, organisations and institutions);
- *mechanisms* (the ways in which changes are made in the targets: modification, redesign, alternatives and creation); and
- *impacts* (effects of eco-innovation on the environment).

Innovation plays a key role in moving manufacturing industries towards sustainable production, and the evolution of sustainable manufacturing initiatives has been facilitated by eco-innovation. As those initiatives advance, the process of their implementation becomes increasingly complex and industries need to adopt an approach that can integrate the various elements of eco-innovation to leverage the maximum environmental benefits. Such advanced, multi-level eco-innovation processes are often referred to as *system innovation* – innovation characterised by shifts in how society functions and how its needs are met.

Technological eco-innovations are often complemented by non-technological changes

To better represent the contexts and processes that lead to eco-innovation, some illustrative examples of eco-innovative solutions have been collected from three sectors: automotive and transport, iron and steel, and electronics. The examples were examined in light of the three dimensions of eco-innovation mentioned above.

Many eco-innovation initiatives in the automotive and transport industry have focused on improving the energy efficiency of vehicles while heightening their safety. The iron and steel industry has in recent years introduced a number of energy-saving modifications and has redesigned various production processes. While the electronics industry has mostly been concerned with the energy consumption of products, growing consumption of the products themselves has also led the industry's effort to increasing recycling possibilities. Overall, technological advances tend to be the primary focus of current eco-innovation efforts. These are typically associated with products or processes as eco-innovation targets, and with modification or redesign as the principal mechanisms.

Nevertheless, a number of complementary non-technological changes have functioned as key drivers. Such changes have been either organisational or institutional in nature. They include the establishment of separate environmental divisions to monitor and improve overall environmental performance and help direct R&D efforts, and the establishment of inter-sectoral or multi-stakeholder collaborative research networks. Some industry players have even started exploring more systemic eco-innovation through the introduction of new business models and alternative modes of provision, such as bicycle-sharing schemes and product-service solutions in photocopying and data centre energy management.

The essence of eco-innovation cannot necessarily be adequately represented by a single set of target and mechanism characteristics. Instead, it seems best examined in terms of an array of characteristics ranging from modifications to creations across products, processes, organisations and institutions.

Existing indicators can be applied in combination to accelerate corporate sustainability efforts

Indicators help manufacturing companies define objectives and monitor progress towards sustainable production. Existing indicators for sustainable manufacturing are diverse in nature and have been developed on a voluntary basis or set as an industry standard or by legislation. To analyse their effectiveness for guiding companies' sustainable manufacturing efforts, nine representative sets of indicators were reviewed (individual indicators, key performance indicators, composite indices, material flow analysis, environmental accounting, eco-efficiency indicators, life cycle assessment indicators, sustainability reporting indicators, and socially responsible investment indices) based on six benchmarking criteria (comparability, applicability for small and medium-sized enterprises, usefulness for management, effective improvement in operations, possibility of aggregation, and effectiveness for finding innovative solutions).

The benchmarking results show that there is no ideal single set of indicators which covers all of the aspects companies need to address to improve their production processes and products. Except for eco-efficiency indicators, each of the nine categories is mainly designed to help management decision making or to facilitate improvements in products or processes at the operational level. In reality, many companies are applying more than one set of indicators at different levels, often without relating them.

An appropriate combination of existing indicator sets could help give companies a more comprehensive picture of economic, environmental and social effects across the value chain and the product life cycle. The further development and standardisation of environmental valuation techniques could also help companies make more rational decisions on investments in sustainable manufacturing activities. New system-level indicators may also be needed to identify the wider impacts of introducing new products and production processes beyond a single product life cycle. Small and medium-sized enterprises (SMEs) and suppliers need to start by collecting data for a minimum set of individual indicators and then adopt more advanced indicators step by step.

Different data sources would help identify overall patterns of eco-innovation activities

Quantitative measurement of eco-innovation activities would help policy makers and industries grasp trends. It would also raise awareness of eco-innovation among stakeholders and make improvements achieved through eco-innovation more evident. To explore future opportunities for measurement, the strengths and weaknesses of existing methods of measuring eco-innovation at the macro level (*i.e.* sectoral, local and national) are analysed.

It is important to investigate the nature (how companies innovate), drivers, barriers and impacts of eco-innovation in order to capture the overall picture. These aspects can be captured by four categories of data: input measures (*e.g.* R&D expenditure); intermediate output measures (*e.g.* number of patents); direct output measures (*e.g.* number of new products); and indirect impact measures (*e.g.* changes in resource productivity). Relevant data can be obtained either by using generic data sources or by conducting specially designed surveys.

Each measurement approach has its strengths and weaknesses, and no single method or indicator can fully capture eco-innovation activities. Generic data sources can provide readily available information on certain aspects of the nature of eco-innovation, but it may narrow the scope and aspects of eco-innovation to be analysed. While surveys can enable researchers to obtain more detailed and focused information, they are costly to conduct and the number of respondents is likely to be limited. To identify overall patterns of eco-innovation, it is therefore important to apply different analytical methods, possibly combined, and examine information from various sources with an appropriate understanding of the context of the data considered.

Supply- and demand-side policies should be better aligned to facilitate eco-innovation

Governments in OECD countries have mainly used their environmental policies to promote sustainable manufacturing and eco-innovation, without necessarily building coherence or synergy with other policies. More recently, environmental concerns have started to be integrated in innovation policies. This trend needs to be supported to help achieve ambitious environmental and socio-economic goals simultaneously, as environmental and innovation policies can reinforce each other.

To gain insight into current government policies, existing national strategies and overarching initiatives were analysed based on responses to a questionnaire survey from ten OECD countries (Canada, Denmark, France, Germany, Greece, Japan, Sweden, Turkey, the United Kingdom and the United States). The survey found that an increasing number of countries now perceive environmental challenges not as a barrier to economic growth but as a new opportunity for increasing competitiveness. However, not all countries surveyed seem to have a specific strategy for eco-innovation; when they do, there is often little policy co-ordination among the various departments involved.

Initiatives and programmes that promote eco-innovation are diverse and include both supply-side and demand-side measures. Many supply-side initiatives involve the creation of networks, platforms or partnerships that engage different industry and non-industry stakeholders, in addition to conventional measures for funding research, education and technology demonstration. Demand-side measures such as green public procurement are receiving increasing attention, as governments acknowledge that insufficiently developed markets are often the key constraint for eco-innovation.

Current demand-side measures are often poorly aligned with existing supply-side measures and need a more focused approach to leveraging eco-innovation activities. A more comprehensive understanding of the interaction between supply and demand for eco-innovation will be a prerequisite for creating successful eco-innovation policy mixes.

More OECD work on indicators and case analysis would help advance global efforts

The above outcomes of research and analysis are drawn together into nine key findings (see Chapter 6). Identified together with the project's advisory expert group, promising areas for the work of the OECD project on sustainable manufacturing and eco-innovation in the next phase (2009-10), and possibly beyond, include:

- **Provide guidance on indicators for sustainable manufacturing**: The OECD could bring clarity and consistency to existing indicator sets by developing a common terminology and understanding of the indicators and their use. It could also play a role in providing supportive measures for increasing the use of indicators by supply chain companies and SMEs.

- **Identify promising policies for eco-innovation**: Better evaluation of the implementation of various policy measures would be helpful to identify promising eco-innovation policies. The OECD can also facilitate the sharing of best policy practices among governments.
- **Build a common vision for eco-innovation**: The OECD could help fill the gap in understanding eco-innovations, especially those that are more integrated and systemic and have non-technological characteristics, by co-ordinating in-depth case studies. This could form the basis for developing a common vision of environmentally friendly social systems and roadmaps to achieve this goal.
- **Develop a common definition and a scoreboard**: With the substantial insights obtained, the OECD could consider the development of a common definition of eco-innovation and an "eco-innovation scoreboard" for benchmarking eco-innovation activities and public policies by combining different statistics and data.

Chapter 1

Framing Eco-innovation: The Concept and the Evolution of Sustainable Manufacturing

This chapter presents the notions of sustainable manufacturing and eco-innovation. It explores the relation between them in order to facilitate the analysis of manufacturing initiatives directed towards sustainable development. Every shift in such initiatives – from conventional pollution control and cleaner production to the development of new business models and eco-industrial parks – can be understood as facilitated by eco-innovation. The application of the eco-innovation concept offers a promising way to move industrial production in a more sustainable direction and respond to pressing global challenges such as climate change.

Introduction

The primary goals of a sustainable society concern the creation of material wealth and prosperity, the preservation of nature and the development of beneficial social conditions for all human beings. Interest in creating a sustainable society has been building among politicians, business leaders and the general public. This is particularly evident in the current debate on climate change and the level to which the issue has risen on the global political agenda, especially after the economic crisis which began in 2008.

Manufacturing industries account for a significant part of the world's consumption of resources and generation of waste. Worldwide, the energy consumption of manufacturing industries grew by 61% from 1971 to 2004 and accounts for nearly a third of global energy usage. Manufacturing industries are also responsible for 36% of global carbon dioxide (CO_2) emissions (IEA, 2007). However, these figures do not cover the extraction of raw materials and the use of manufactured products; if they did, the impact would be far greater. To date, manufacturing industries have taken various steps to reduce environmental and social impacts, largely owing to stricter regulations and growing pressure to take more responsibility for the impact of their operations. There is also a growing trend for companies to voluntarily improve their social and environmental performance for reasons relating to higher profitability, increased efficiency and greater competitiveness. As a result, industries are gradually moving from pollution control and treatment measures to more integrated and efficient solutions.

Nonetheless, the urgency of further action to avoid continuing environmental degradation is widely recognised. Improvements in resource and energy efficiency in some regions have often been offset by increasing consumption in others, and efficiency gains in some areas are outpaced by scale effects. The International Energy Agency (IEA) predicts that the global energy-related CO_2 emissions will increase by 25% by 2030 even under the current best policy scenario (IEA, 2007). This emphasises the need to alter patterns of production and consumption so as not to put further pressure on the planet.

Hence, the pressure on manufacturing industries to reduce their environmental and social impacts is bound to increase further. At the same time, they can become a driving force for the creation of a sustainable society by designing and implementing integrated sustainable practices that allow them to eliminate or drastically reduce their environmental and social impacts. They can also develop products that contribute to better environmental performance in other sectors. This calls for a shift in the perception of industrial production from one in which manufacturing is understood as an independent process to one in which it is an integral part of a broader system (Maxwell *et al*., 2006). This in turns requires the adoption of a more holistic business approach that places environmental and social aspects on an equal footing with economic concerns.

This chapter introduces the concepts of sustainable manufacturing and eco-innovation and considers the possibility of considering the two concepts within a common analytical framework. The OECD hopes that this exercise will facilitate better understanding of current sustainability initiatives in industry and provide guidance on how to encourage future industry activities in this direction.

The following discussion first categorises different notions of sustainable production that have been promoted and applied in manufacturing industries over the last few decades. Second, it gives a conceptual overview of eco-innovation and indicates how this concept may help the manufacturing sector to improve its sustainable production initiatives. Finally, it explores the conceptual relations between sustainable manufacturing and eco-innovation as a means of analysing current initiatives from a broader perspective and spreading good practices in the sectors, especially among supply chain companies and small and medium-sized enterprises (SMEs). The chapter focuses on environmental aspects of sustainable development.

The rise of sustainable manufacturing

The idea of sustainable development emerged in the early 1980s in the wake of growing concerns over the environmental damage associated with economic growth (IUCN, 1980). Today it is typically associated with development that ensures environmental protection, economic wealth and social equity – known as the three pillars of sustainable development – such that the needs of present generations can be met without compromising the ability of future generations to meet theirs (WCED, 1987). The use of "sustainability" in specific areas such as production, manufacturing, innovation, etc., tend to rely on this definition, albeit within a more confined context.

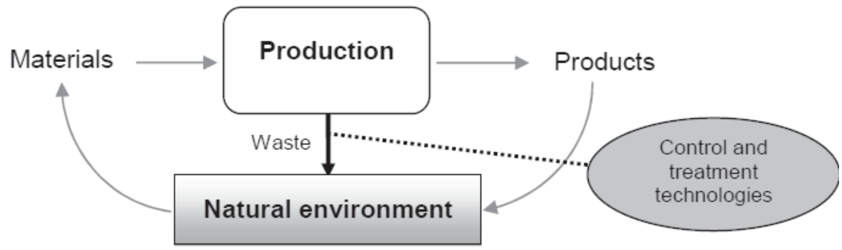
There appears to be no generally accepted definition of sustainable manufacturing but the concept fits well within the broader notion of sustainable production. The concept of sustainable production emerged from the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 as a vital means of realising sustainable development (Veleva and Ellenbecker, 2001). The Lowell Center for Sustainable Production at the University of Massachusetts, Lowell, defines sustainable production as "the creation of goods and services using processes and systems that are: non-polluting, conserving of energy and natural resources, economically viable, safe and healthful for workers, communities, and consumers, and socially and creatively rewarding for all working people" (Nasr and Thurston, 2006). With specific reference to "production in manufacturing sectors", this provides a good starting point for defining sustainable manufacturing and is used as a baseline here, although, as noted, this chapter mainly deals with the environmental aspects.[1] This section describes sustainable manufacturing initiatives and how these have evolved over time.

The first step: pollution control and treatment

In the past, the environmental harm caused by industrial production was typically dealt with on the basis of "the solution to pollution is dilution", that is, by dispersing pollution in less harmful or less apparent ways (UNEP and UNIDO, 2004). More recently, driven by stricter environmental regulations, industry has mostly dealt with environmental harm by attempting to control and reduce the amount of emissions and effluents discharged into the environment through various treatment measures.

Pollution control is characterised by the application of technological measures that act as non-essential parts of existing manufacturing processes at the final stage of these processes. They are often referred as "end-of-pipe" technologies or solutions (Figure 1.1). In general, the alleviation of environmental harm in this way stems from reducing or removing air, soil, and water contaminants that were already formed in the production process.

Figure 1.1. Pollution control and treatment



Since pollution control does not restructure the existing production systems in any major way, the only benefit is better environmental performance. Manufacturing companies have traditionally perceived investment in such measures as a costly burden. They typically feel that industrial competitiveness suffers from the costs of environmental protection and clean-up and that environmental performance weighs on profitability and economic growth (Porter and van de Linde, 1995).

When dealing with environmental harm, curative solutions are still essential for most manufacturing industries and their potential impact is far from insignificant. Examples include biological and chemical components for the treatment of waste water, air filtration systems and acoustic enclosures for noise reduction. In the context of climate change, the latest carbon capture and storage (CCS) technologies are also highly relevant.

Working towards preventive solutions and cleaner production

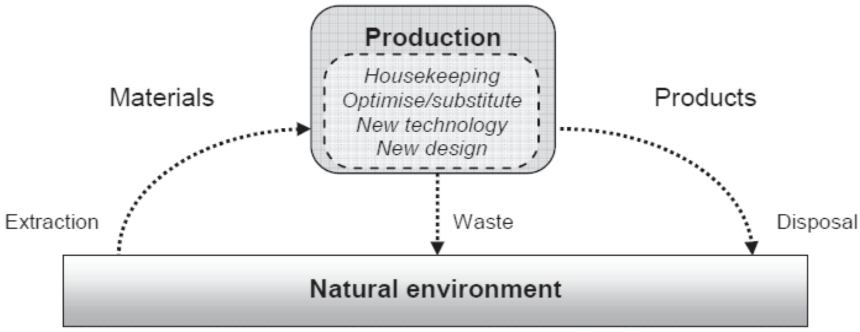
In the effort to shift environmental management from conventional pollution control to a more proactive approach, the United Nations Environment Programme (UNEP) introduced a Cleaner Production Programme in 1989. The concept of cleaner production builds on the precautionary principle, a philosophy of "anticipate and prevent", through an integrated environmental strategy. Since 1994, the UNEP has worked with the United Nations Industrial Development Organization (UNIDO) to set up national cleaner production centres (NCPCs) worldwide to spread the industrial application of this philosophy. By 2007, 37 NCPCs had been established.

The major factor distinguishing cleaner production from pollution control and treatment is the fact that the focus shifts towards earlier stages in the industrial process, *i.e.* the source of pollution. The shift towards cleaner production entails investigating all aspects of the production process and its organisational arrangements to identify areas in which environmental harm can be reduced or eliminated. These areas are often categorised as follows (Ashford, 1994):

- housekeeping, which refers to improvements in work practices and maintenance;
- process optimisation, which leads to the conservation of raw materials and energy;
- raw material substitution, which eliminates toxic materials by shifting to more environmentally sound resources;
- new technologies, which enable reductions in resource consumption, waste generation and emissions of pollutants;
- new product design, which aims to address and minimise environmental impacts.

The concept of cleaner production embraces the notion of efficient resource use while avoiding unnecessary generation of waste (Figure 1.2). Improvements in environmental performance based on lowering pollution at the source require changes to existing manufacturing processes, products/services, and/or organisational structures and procedures. Even though the implementation of cleaner production stays within the manufacturing company, as is the case with pollution control, it leads to a more integrated environmental approach and is considered essential for moving towards eco-efficient production (see next section). The potential economic and environmental benefits of cleaner production are therefore often superior to those of end-of-pipe solutions.

Figure 1.2. Cleaner production



Note: The perspective of the natural environment is broader than for pollution control and treatment (Figure 1.1) as the concept of cleaner production takes the whole production process into account.

The implementation of cleaner production initiatives also constitutes a larger and more challenging task. It may be hampered in particular by barriers within companies that arise from problems of organisational co-ordination as well as insufficient managerial support. Additional obstacles may arise from regulatory environments in which specific technology standards imposed by regulations favour end-of-pipe abatement measures rather than cleaner production (Frondel *et al.*, 2007).

However, a recent survey of more than 4 000 manufacturing facilities in Canada, France, Germany, Hungary, Japan, Norway and the United States (Frondel *et al.*, 2007) shows that more than 75% of respondents reported mainly investments in cleaner production technologies. The data also show that end-of-pipe technologies are typically introduced to comply with regulations, while the implementation of cleaner production technologies is driven by the potential for increasing manufacturing efficiency and reducing costs of operations. This was indicated by a positive correlation between corporate investments in end-of-pipe technologies and respondents' assessment and perception of the stringency of regulatory measures and environmental policies; cost-saving motives and the responding companies' use of specific environmental management tools (*e.g.* environmental policies, accounting, audits, etc.) were correlated with investments in cleaner production.

Managing the transition to eco-efficiency

With the shift from pollution control to pollution prevention, environmental considerations and the improvement of environmental performance in manufacturing industries are also increasingly regarded from the perspective of business interests rather than regulatory compliance. In many cases, companies have found that what is good for the environment is not necessarily bad for business. In fact, it may lead to a competitive edge because of better general management, optimisation of production processes, reductions in resource consumption, and the like (Box 1.1). "Going green" is progressively seen as a potentially profitable direction, and voluntary and pre-emptive sustainability initiatives have become increasingly common in recent years.

Box 1.1. Savings through better environmental performance

The Green Suppliers Network co-ordinated by the US Environmental Protection Agency (EPA) seeks to help SMEs in the manufacturing sectors through programmes that help companies to identify strategies for implementing cleaner production techniques. A review of the results of 60 programmes shows strong evidence of improved environmental performance as well as large savings for the companies. Experiences from European initiatives also show that a considerable number of SMEs are increasingly interested in implementing cleaner production to improve their economic and environmental performance.

Source: Green Suppliers Network, *www.greensuppliers.gov*;
Kurzinger (2004), "Capacity Building for Profitable Environmental Management",
Journal of Cleaner Production, Vol. 12, No. 3.

A range of developments in the global economy are strengthening the demand for greater efficiency. The globalisation of manufacturing production and its value chain, for example, is strengthening competitive pressures, and the need for manufacturing companies to improve their cost-effectiveness is increasing. Combined with growing resource constraints, which have led to higher costs of core manufacturing activities, incentives to ensure resource efficiency are becoming stronger.

To help companies step up their contribution to the creation of a sustainable society while remaining competitive in the global market, the World Business Council for Sustainable Development (WBCSD) introduced the concept of eco-efficiency, which was put forth as one of industry's key contributions to sustainable development at the time of the UNCED in 1992 (Schmidheiny, 1992).[2]

The WBCSD defines eco-efficiency as a state that can be reached 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" (WBCSD, 1996). The goal of eco-efficiency is the adoption of production methods that go hand in hand with an ecologically sustainable society and encompasses a range of other important concepts surrounding sustainable production and manufacturing.

Over the last decade, the original idea and importance of eco-efficiency as a guiding principle for industrial production and business decisions has gained much broader attention and has been promoted with a simple catchphrase "doing more with less", *i.e.* producing more goods and services while using fewer resources and creating less waste and pollution (EC, 2005). This movement has led to a diverse range of conceptual and methodological approaches such as environmental monitoring and auditing and environmental strategies (Maxwell *et al.*, 2006), which companies can use to implement eco-efficiency principles in production.

Such tasks are not trivial for manufacturing companies and place great demands on their organisational management capability. The development of environmental management systems (EMSs) has tied together many of the environmental monitoring and management principles, providing a framework for companies to move towards eco-efficient production (Johnstone *et al.*, 2007).

An EMS is meant to provide companies with a comprehensive and systematic management system for continuous improvement of its environmental performance. Once implemented, the system relies on a structure that is typically characterised by four cyclical, action-oriented steps: *i)* plan; *ii)* implement; *iii)* monitor and check; and *iv)* review and improve (Perotto *et al.*, 2008) (Figure 1.3). These steps are applied across all elements of the company's activities, products and services that interact with the environment (ISO, 2004), and may include the restructuring of processes and responsibilities throughout the company.

Figure 1.3. A typical cycle of environmental management systems

To take account of organisational and industry differences EMSs can be implemented in many ways. Standards nevertheless exist for securing the respect of the main principles. The two main standards, for which a certification also can be obtained, are ISO 14001, developed by the International Organization for Standardization (ISO), and the Eco-Management and Audit Scheme (EMAS), developed by the European Commission. These schemes aim to ensure that companies adopt an environmental policy, that environmental responsibilities are clearly designated throughout the organisation, and that they undergo external audits of the system.

The implementation of an EMS can be useful not only for improving the environmental performance of manufacturing processes (Johnstone *et al.*, 2007) but also for meeting increasing pressures from stakeholders, improving the corporate image, and reducing risks of environmental liabilities and non-compliance (Perotto *et al.*, 2008). Much evidence, albeit mostly from case studies of individual companies, also indicates that the introduction of EMSs leads to better financial performance. The number of EMS certifications has grown substantially in some countries, though the proportion of certified companies is still very low.

The measurement of environmental performance lies at the heart of any EMS as it provides information that is essential for managing and reducing environmental impacts. Assessing environmental performance is not a marginal task, however, and is subject to methodological debates.[3] Environmental performance is typically monitored through process measurements with the help of various indicators that aim to summarise and simplify relevant information from the production system (indicator issues are extensively discussed in Chapter 3).

Life cycle thinking and green supply chain management

Life cycle assessment (LCA) is one of the most widely used tools for measuring environmental impacts and deciding on the development of new products and processes. As the name suggests, its aim is to reduce the use of resources and environmental impacts throughout the entire life span of products and services. Life cycle thinking goes beyond cleaner production as it emphasises the need for companies to look beyond conventional organisational boundaries when considering the environmental impacts of their activities. This involves taking into account environmental impacts and responsibilities that arise from the extraction of materials through the design of products and production processes to the consumption and the final disposal of products. For this reason, LCA is also referred to as "cradle-to-grave" analysis.

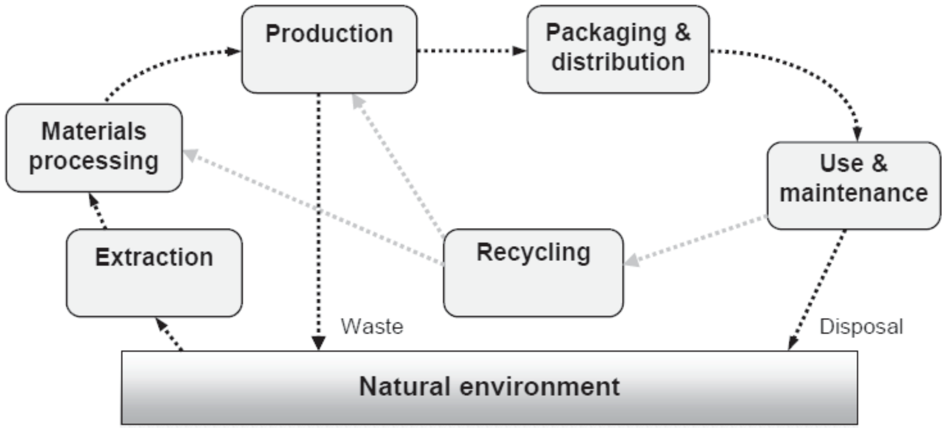
The life cycle philosophy and management approaches have laid the foundation for a range of relatively new and proactive environmental initiatives and business models, in which environmental considerations go beyond the manufacturing facility to the entire value chain. On the policy level, this trend is reflected in Extended Producer Responsibility initiatives and the European Union's Integrated Product Policy which seek to extend the responsibility of producers to the entire product life cycle.

The concept of green supply chain management (GSCM) has emerged from life cycle thinking and its application (Seuring and Muller, 2007). As Figure 1.4 shows, it includes environmental considerations in the total value chain from original source of raw materials, through the various companies involved in extracting and processing, manufacturing, distributing, consumption and disposal (Saunders, 1997).

The adoption of GSCM is very demanding as it requires, in addition to various elements of cleaner production and the implementation of EMS, the development and maintenance of close co-operative relations with external entities such as suppliers and retailers.

In recent years, the pressure for companies to be accountable for their environmental and social responsibilities has risen. This has led to the concept and practice of corporate social responsibility (CSR) whereby companies, on a voluntary basis, declare their commitment to consider the ethical consequences of their business activities and to take responsibilities for them beyond legal requirements.

Figure 1.4. Life cycle thinking



In recent years, CSR has emerged as a mainstream business issue, mostly owing to growing attention to social and environmental issues and rising demand for improved business ethics from governments, activists, the media, investors and the like (Porter and Kramer, 2006). CSR is primarily voluntary but some governments are exerting pressures on companies to improve their accountability, for example by requiring the disclosure of ethical, social and environmental risks in annual corporate reporting (*e.g.* France's new economic regulations of 2001).

Box 1.2. Corporate sustainability reporting

Public sustainability reporting on the environmental and social activities of companies and their supply chain provides a way for companies to inform stakeholders about their accomplishments and sustainable development targets. Reporting is typically voluntary but can be considered as a company's non-financial equivalent to its financial report.

Even though sustainability reporting has been mostly used as a communication tool, it is nevertheless widely recognised as an important mechanism for improving corporate environmental and social performance. A growing number of companies have also engaged in sustainability reporting because bank and investment managers increasingly look into what lies beyond the balance sheet. International initiatives such as the UN Global Compact and the UN Principles for Responsible Investment (PRI) are adding to the pressure on companies to report on their sustainability performance.

Today, several frameworks and guidelines on how and what to report exist. The Global Reporting Initiative's Sustainability Reporting Guidelines are becoming an internationally accepted standard (see Chapter 3).

Yet, while a growing number of companies now address CSR issues, they are often not clear on what exactly is involved and which concrete actions they take (Porter and Kramer, 2006). Sustainability reports (Box 1.2) also tend to offer a compilation of un-coordinated social and environmental activities. Coherent frameworks and strategies for how the company is addressing, or plans to address, its social and environmental responsibilities, and how these are linked to the company's core business strategy, have not been widely addressed (GRI and KPMG, 2008).

A new industrial revolution

To meet the global environmental challenges created by the consumption and production patterns established since the Industrial Revolution, there is a need to find ways to bring together ideas and concepts that have traditionally been viewed as trade-offs. In essence, there is a need for a "New Industrial Revolution" where economic wealth goes hand in hand with environmental and social sustainability. The increasingly blurred demarcation of manufacturing and services (Mont, 2002), or goods and services, can be seen as an early example of developments in this direction. Switching towards better environmental performance through reduced material flows has led to a more integrated approach to sustainable manufacturing, often referred to as a product-service system (PSS). PSS encourages companies to increase the re-use and remanufacturing of products. Taking this further, the need for virgin materials can be drastically reduced by adopting closed-loop production which maximises recycling of materials that already exist in the production system. Advanced solutions adopt an even more holistic view, such as industrial ecology in which the effluents of one producer's operations are used in another's production.

Product-service system (PSS)

Whereas traditional manufacturing focuses on the production and supply of goods to consumers, a PSS focuses on the delivery of consumer utility and product functionality. For example, when producing and supplying photocopiers to their consumers, a company based on the PSS model retains product ownership and supplies the photocopier as a function. In this way consumers purchase the copying service and not the product itself.

The PSS concept is widely discussed in sustainability-related articles but rarely in the mainstream business literature (Tukker *et al.*, 2006). In the latter, however, concepts such as "functional sales" and "servicising" have a similar meaning. In fact, the PSS approach has been applied in business-to-business contexts for many years. Since product ownership is not transferred from the producer to the consumer, the costs of product maintenance, retirement and replacement are internalised for the producer's profit maximisation objectives. As such, because the entire stock of manufactured goods is essentially "stored" by consumers, companies need not sell more products to maximise profits. Instead, they can reap profits by minimising material consumption and increasing product reuse, recycling and remanufacturing. This can result in far-reaching environmental benefits.

Product-use intensity is another environmental benefit that could be gained from PSS by sharing the same products among many consumers. Today, a car is parked rather than driven most of the time and an electric drill is typically used a few times a year. The PSS could lead to a radical reduction in the production of physical goods and thus to less consumption of materials and generation of waste. PSS also offers the opportunity to alleviate the pressure of realising profits in markets characterised by rapid changes in consumer preferences and in technological developments (Behrendt *et al.*, 2003).

The adoption and financial viability of PSS depends on the degree of change in economic, social and technological infrastructures as well as business models (Mont, 2002). From the perspective of manufacturing companies, for instance, PSS could imply a shift from the traditional point-of-sale business model to one centred on long-term service contracts. This would affect the organisational management and marketing of products. The major issue from consumers' perspective is product ownership. For the PSS model to function, consumers need to see products as leased rather than owned and shared rather than used. However, ownership of certain products is strongly entangled with consumers' identity and status (*e.g.* cars, luxury goods, houses) (Box 1.3).

Box 1.3. An application of product-service systems

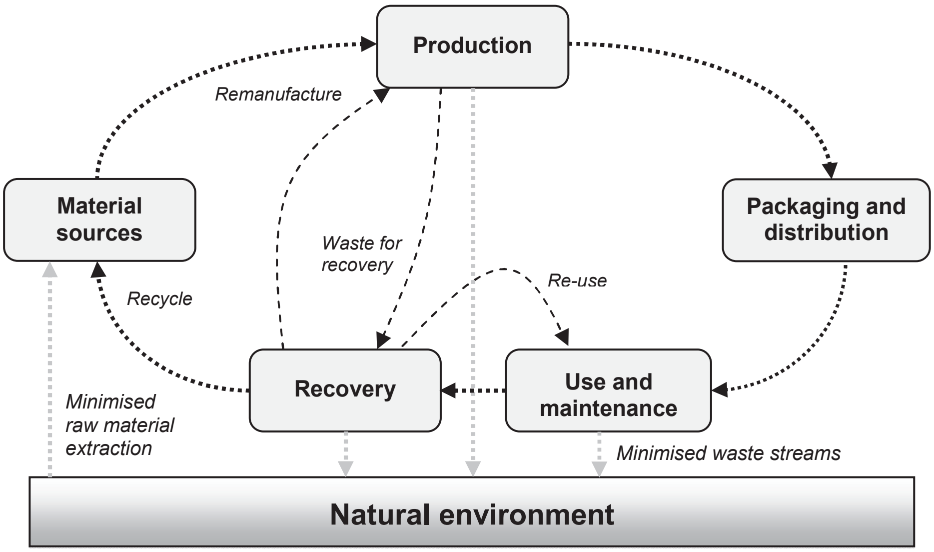
InterfaceFLOR, an American producer of carpets, is offering carpet rotation and replacement services instead of selling carpets. This PSS is part of a broader initiative called "Mission Zero" through which the company aims to eliminate all forms of waste from its facilities by 2020, including carpets that are sent to landfill after usage. The company is using the rotation and replacement service as a model to take back old carpets for what they call "re-entry" – recycling materials that can be used for new carpets to decrease the use of virgin petroleum-based raw materials.

Source: InterfaceFLOR website, *www.interfaceflor.com*.

Closed-loop production

Closed-loop production is similar to life cycle thinking but distinguishes itself by "closing" the material resource cycle (Figure 1.5). This implies that all components that exist in the system are reused, remanufactured or recycled in some way. This entails a shift from traditional linear production methods to a circular and more systemic perspective in which products and processes are designed with "reincarnation" in mind. The need for virgin materials is eliminated, or drastically reduced, and waste is recycled into the system. Closed-loop production, therefore, constitutes advancing "cradle to grave" thinking towards "cradle to cradle" (McDonough and Braungart, 2002).

Figure 1.5. Closed-loop production system



The development of closed-loop manufacturing requires a strong focus on the product design process. In addition to minimising the material and energy use needed to make and distribute products as well as the impacts from product use and disposal, the design process must also take into account means of recovering products and waste. For heavy machinery, for instance, vehicle design can be optimised not only by using the fewest possible harmful materials and aiming for the highest fuel efficiency, but also by designing the vehicles for disassembly/separation, cleaning, inspecting, repairing, replacing, a long life-time, and reassembling and "rebirth". By tapping into the large resource potential that exists in current waste, the need for virgin materials and waste disposal could be significantly reduced. PSS can facilitate business conditions for realising closed-loop production as an important building block for sustainable manufacturing (Behrendt *et al.*, 2003) (Box 1.4).

Box 1.4. Remanufacturing and PSS

Remanufacturing is a practice that can reduce environmental impacts while increasing revenue. Caterpillar, an American construction and mining equipment manufacturer, has embraced this idea as an integral part of its business model and has improved its environmental conduct by doing so. It established ongoing revenue opportunities for several generations of their product lines through new design strategies and collection mechanisms that maximise remanufacturing possibilities. Using financial incentives for customers to return equipment after the end of its life, the company is able to remanufacture components for a fraction of the original cost while keeping attractive profit margins even if the remanufactured products are sold at discount prices with the same warranties as new products.

Source: Gray and Charter (2006), *Remanufacturing and Product Design*, Centre for Sustainable Design, Farnham.

Industrial ecology

The extensive application of closed-loop production views and techniques across industries and society at large, *i.e.* beyond the boundary of a single company, is called industrial ecology. Industrial ecology, which stems from systems theory, views environmental ecology and uses natural eco-systems as a metaphor and model for better organising industrial production (Frosch and Gallopoulos, 1989). More specifically, industrial ecology considers the industrial production system as an interdependent part of the eco-system (Garner and Keoleian, 1995). That is, the industrial society must be understood not in isolation from its surrounding systems but in harmony with them (Jelinski *et al.*, 1992).

With respect to closed-loop production, industrial ecology might be viewed as "a system of systems", which ties several closed-loop production systems together by a circular flow of resources such that one system's effluents are used as another system's input, while also operating in harmony with the greater ecosystem. This means that industrial ecology not only relies on materials that can be recycled in the industrial production system, such as aluminium, but also on materials that are reusable in the natural environment, such as textiles that can serve as biodegradable garden mulch after life as an upholstery fabric. Mimicking eco-system terminology, these materials can be referred to as technical and biological nutrients (McDonough and Braungart, 2002). The development and implementation of such a system necessitates a multidisciplinary and multi-organisational approach in which stakeholders from various industrial sectors, areas of society and disciplines engage in intelligent and co-operative partnerships. Thus no company can become sustainable on its own.

At present, there is a considerable gap between theoretical approaches to industrial ecology and what is being implemented in a world in which the value chain of manufacturing companies is increasingly globalised. However, some applications of industrial ecology have been attempted through the establishment of "eco-industrial parks". These parks are comprised of a cluster of companies that seek to harness industrial symbioses through close co-operation with each other, and with the local community, by sharing resources to improve economic performance while minimising waste and pollution (Box 1.5). This idea is also promoted by the United Nations University (UNU) Zero Emissions Forum, which is establishing pilot eco-park projects as well as researching industrial synergies and sustainable transactions (Kuehr, 2007).

Box 1.5. An eco-industrial park in Denmark

One of the earliest and best-known eco-industrial parks is located in Kalundborg, Denmark. Rather than the result of a carefully planned process, the eco-park has developed gradually through co-operation among a number of neighbouring industrial companies. The main participating companies are a coal-fired power plant (Asnæsværket), a refinery (Statoil), a pharmaceutical and industrial enzyme plant (Novo Nordisk and Novozymes), a plasterboard factory (Gyproc), a soil remediation company (AS Bioteknisk Jordrens), and the municipality of Kalundborg through the town's heating facility.

The eco-park began when Gyproc located its facility in Kalundborg in 1970 to take advantage of the butane gas available from the Statoil refinery. At the same time this enabled Statoil to stop flaring the gas. Since then, the network has grown and today the participating companies are highly integrated. For instance, surplus heat from the power plant is used to heat about 4 500 private homes and water for fish farming, and fly ash is supplied for production of cement. Process sludge from fish farming and Novo Nordisk is supplied to nearby farms as fertiliser. Novo Nordisk also supplies farms with surplus yeast from insulin production for pig food. The Statoil refinery supplies pure liquid sulphur from its desulphurisation operations to a sulphuric acid producer (Kemira).

The exchanges above only describe a part of the material flow of the Kalundborg eco-park, which in total has been estimated to be around 2.9 million tonnes a year including fuel gases, sludge, fly ash, steam, water, sulphur and gypsum. This industrial symbiosis has served to reduce the environmental impacts of industrial production and led to significant economic savings. The participating companies are constantly co-operating to find new ways of improving the industrial symbiosis based on economic and environmental consciousness.

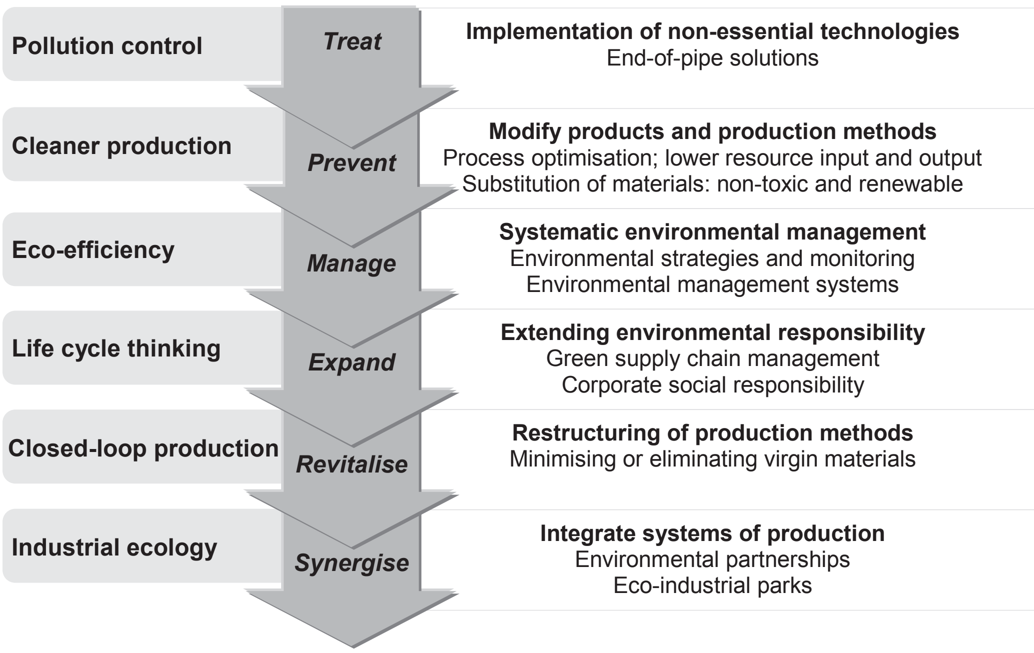
Source: Industrial Symbiosis Institute website *www.symbiosis.dk*;
Gibbs (2008), "Industrial Symbiosis and Eco-industrial Development: An Introduction", *Geography Compass*, Vol. 2, No. 4.

Summing up

To sum up, the thinking and practices surrounding sustainable manufacturing have evolved in several ways in the last decades, from the application of technology for the treatment of pollution at the end of the pipe through prevention of pollution to minimising inputs and outputs and substituting toxic materials. Recently, manufacturing companies have focused on solutions that integrate methods of minimising material and energy flows by changing products/services and production methods and revitalising disposed output as new resources for production.

Advances towards sustainable manufacturing have also been achieved through better management practices. Environmental strategies and management systems have allowed companies to better identify and monitor their environmental impacts and have facilitated improvements in environmental performance. Although such measures were initially limited to plant-specific production systems, they have evolved towards support for better environmental management throughout the life cycle of products and the value chain of companies.

Figure 1.6. The evolution of sustainable manufacturing concepts and practices



More integrated and systematic methods to improve sustainability performance in manufacturing industries have laid the foundation for the introduction of new business models such as PSS which could lead to significant environmental benefits. Furthermore, although still few in numbers, more efficient and intelligent ways of structuring production systems are being established, such as eco-industrial parks in which economic and environmental synergies between traditionally unrelated industrial producers are harnessed (Figure 1.6).

Understanding eco-innovation

In the last few years, many companies and consulting firms have started using eco-innovation or similar terms to present positive contributions by business to sustainable development through innovation and improvements in production processes and products/services. A few governments and the European Union (EU) are now promoting the concept as a way to meet sustainable development targets while keeping industry and the economy competitive.

In the EU, eco-innovation has been considered to support the wider objectives of its Lisbon Strategy for competitiveness and economic growth. In 2004, the Environmental Technology Action Plan (ETAP) was introduced to promote the development and implementation of eco-innovation.[4] The ETAP defines eco-innovation as "the production, assimilation or exploitation of a novelty in products, production processes, services or in management and business methods, which aims, throughout its life cycle, to prevent or substantially reduce environmental risk, pollution and other negative impacts of resource use (including energy)". The action plan provides a general roadmap for promoting environmental technologies and business competitiveness by focusing on bridging the gap between research and markets, improving market conditions for environmental technologies, and acting globally. Eco-innovation now forms part of the EU's Competitiveness and Innovation Framework Programme 2007-13, which offered EUR 28 million in funding in 2008 to stimulate the uptake of environmental products, processes and services especially among SMEs.

In the United States, environmental technologies are also seen as a promising means of improving environmental conditions without impeding economic growth, and are being promoted through various public-private partnership programmes and tax credits (OECD, 2008). In 2002, the Environmental Protection Agency laid out a strategy for achieving better environmental results through innovation (EPA, 2002). Based on this strategy, it set up the National Center for Environmental Innovation and is promoting the research, development and demonstration of technologies that contribute to sustainable development in partnership with state governments, businesses and communities.

While the promotion of eco-innovation so far has focused mainly on the development and application of environmental technologies, there is an increasing emphasis on going beyond these. This reflects the growing understanding of and research on the non-technological aspects of innovation, such as organisational innovation and marketing innovation, as defined in the latest version of the OECD's *Oslo Manual* (OECD and Eurostat, 2005). It also reflects the fact that eco-innovation's focus on sustainable development demands broad structural changes in society.

In Japan, the government's Industrial Science Technology Policy Committee introduced the term eco-innovation in 2007 as an overarching concept which provides direction and a vision for the societal and technological changes needed to achieve sustainable development. The committee considers that the current pattern of economic growth achieved through "functionality-oriented, supplier-led mass consumption" is approaching its limit owing to constraints on the environment, resources and energy. As Japan's people have been highly satisfied in material terms, it argues that economic growth in the 21st century can be pursued by appealing to people's *kansei* (sensitivity). This would also require the establishment of a new socio-industrial structure in which environmental conservation and economic growth are fused. In short, the committee defines eco-innovation as "a new field of techno-social innovations [that] focuses less on products' functions and more on [the] environment and people". In more concrete terms, the committee proposes promoting the construction of "zero emission-based" infrastructures in energy supply, transport and town development, as well as sustainable lifestyles by selling services instead of products and by promoting environmental and *kansei* values (METI, 2007).

While overall aims for promoting eco-innovation seem to have in common the parallel pursuit of economic and environmental sustainability, there is some diversity in the application of the concept. To improve the conceptual understanding of eco-innovation and to facilitate the construction of an analytical framework that combines eco-innovation with sustainable manufacturing, this section attempts to draw together a conceptual and typological overview of eco-innovation and the different areas to which the concept can be applied for diverse types of businesses.

A conceptual overview

The term eco-innovation seems to have first appeared in *Driving Eco-Innovation,* a book by Claude Fussler and Peter James in 1996. The authors defined the concept as "new products and processes that provide customer and business value while significantly decreasing environmental impacts". Under the overarching concept of sustainable development the meaning of eco-innovation has come to include social and institutional aspects. Although some strands in the literature attempt to discern and highlight differences between concepts such as "eco-innovation", "environmental innovation", "innovation for sustainable development" and "sustainable innovation", they are mostly used interchangeably (Charter and Clark, 2007). This chapter primarily uses the term eco-innovation but makes no distinction with the related concepts.[5]

Eco-innovation is closely related to the conventional understanding of innovation which, according to the *Oslo Manual* (OECD and Eurostat, 2005), can be described as the implementation of new, or significantly improved, products (goods or services), or processes, marketing methods, or organisational methods in business practices, workplace organisation or external relations. It is distinct from invention, which refers to the phase in which the idea behind the innovation is conceived. It is also distinct from the dissemination of the innovation. Combined, however, invention, innovation and dissemination constitute what is referred to as the innovation process. This process should also be applicable to eco-innovation.

Eco-innovation can, however, be distinguished from conventional innovation in two significant ways. First, it is not an open-ended concept as it represents innovation which explicitly emphasises the reduction of environmental impacts, whether intended or not. Second, eco-innovation is not limited to innovation in products, processes, marketing methods and organisational methods, but also includes innovation in social and institutional structures (Rennings, 2000). This reflects the fact that the scope of eco-innovation can extend beyond the conventional organisational boundaries of the innovating company to encompass the broader societal sphere. It thus involves changes in social norms, cultural values and institutional structures – in partnership with stakeholders such as competitors, companies in the supply chain, those from other sectors, governments, retailers and consumers – to leverage more environmental benefits from the innovation.

Based on the *Oslo Manual* and drawing from other sources (*e.g.* METI, 2007; Reid and Miedzinski, 2008; MERIT *et al.*, 2008),[6] eco-innovation can be described as "the implementation of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which, with or without intent, lead to environmental improvements compared to relevant alternatives". On this interpretation, innovation and eco-innovation are distinguished from relevant alternatives solely by their environmental effects. The definition therefore only provides a weak conceptual demarcation of innovation and eco-innovation and should only be seen as a starting point for analysis of eco-innovation. To facilitate the analysis of different business activities aimed at eco-innovation, the concept and its typology are further elaborated below.

A typology

Inspired by existing innovation and eco-innovation literature (*e.g.* OECD and Eurostat, 2005; Charter and Clark, 2007; Reid and Miedzinski, 2008), it is proposed that an eco-innovation can be understood on the basis of three key axes: its target, its mechanism and its impact:

- **Target** refers to the basic focus of eco-innovation. Building upon the typology of the *Oslo Manual*, the target of an eco-innovation can be categorised under: *i)* products (both goods and services); *ii)* processes, such as a production method or procedure; *iii)* marketing methods, referring to the promotion and pricing of products, and other market-oriented strategies; *iv)* organisations, such as the structure of management and the distribution of responsibilities; and *v)* institutions, which include broader societal areas beyond a single company's control such as broader institutional arrangements as well as social norms and cultural values.
- **Mechanism** relates to the method by which the change in the eco-innovation target takes place or is introduced. It is also associated with the underlying nature of the eco-innovation, *i.e.* whether the change is technological or non-technological in nature. Four basic mechanisms are identified: *i)* modification, such as small, progressive product and process adjustments; *ii)* redesign, referring to significant changes in existing products, processes, organisational structures, etc.; *iii)* alternatives, such as the introduction of goods and services that can fulfil the same functional needs and operate as substitutes for other products; and *iv)* creation, comprising the design and introduction of entirely new products, processes, procedures, and organisational and institutional settings.
- **Impact** refers to the eco-innovation's effect on environmental conditions, across its life cycle or some other scope. The impact depends on the combination of the innovation's target and mechanism, here referred to as the innovation's design, and can be illustrated across a continuous range starting from incremental environmental improvements to the complete elimination of environmental harm. For particularly well-defined areas, it can be related to the concept of "Factor" which is used to describe technological performance with respect to energy and resource efficiency (Weizsacker *et al.*, 1998).

A Factor 2 improvement in CO_2 emissions, for example, denotes a 50% reduction, everything else being equal.

Based on this typology, companies can design and analyse their eco-innovative initiatives and strategies with respect to specific areas (targets), the type of progress that is being made (mechanisms), and the resulting effects (impacts). While this approach can be applied to eco-innovative initiatives across all targets and mechanisms, it is generally possible to distinguish the underlying nature of change with respect to eco-innovation in products and processes from that in marketing methods, organisations and institutions. Eco-innovation in products and processes, for instance, is typically considered more closely related to technological advances regardless of the eco-innovation's basic mechanism. For marketing methods and organisational structures, on the other hand, eco-innovative mechanisms tend to be associated with non-technological changes (OECD, 2007). This notion extends to changes in institutional arrangements. These differences, along with the impact of eco-innovation, are further illustrated below.

Eco-innovation in products and processes

Advances in products and processes, which tend to rely on technological change, cover a broad range of tangible objects that can improve environmental conditions and might therefore be referred to as technological eco-innovations. Examples include computer chips that are faster but consume less energy, cars that are more fuel-efficient, and production methods that use fewer resources. Generally, they are also curative or preventive in nature.

Curative eco-innovative technologies are equivalent to the end-of-pipe technologies described above, because they seek to reduce or eliminate contaminants that have already been produced. Preventive eco-innovative technologies, on the other hand, aim to reduce or eliminate the source of the pollutants. These technologies are thus related to cleaner production techniques but may be unintended results of efforts to improve general business profitability.

Both curative and preventive eco-innovative products and processes can tackle environmental challenges. Yet, from a broader sustainability perspective, they should only be seen as part of the solution (Brown *et al.*, 2000). Moreover, if they are not tested with a view to their potential adverse effects, some may even create new environmental hazards and problems (Reid and Miedzinski, 2008) (Box 1.6).

Box 1.6. The rise and fall of CFC gases

Chlorofluorocarbon (CFC) gases were developed in the 1930s to replace hazardous materials such as sulphur dioxide and ammonia. Owing to their non-toxic, non-flammable and non-corrosive properties, and being both inexpensive and efficient, they were long considered to be an ideal refrigerant. The use of CFCs increased rapidly after their market introduction not only in air conditioning and refrigeration equipment but also in a large range of industrial applications.

In the 1970s, however, it was found that CFC gases have an ozone-depletion effect. Large reductions in the ozone layer, particularly over Antarctica, were reported in the mid-1980s and concerns arose about the increased likelihood of skin cancer. This eventually led to the ban of CFC gases under an international agreement when the Montreal Protocol on Substances that Deplete the Ozone Layer entered into force in 1989.

Source: World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) (1998), *Scientific Assessment of Ozone Depletion: 1998*, WMO Ozone Report No. 44, WMO, Geneva; WMO and UNEP (2006), *Scientific Assessment of Ozone Depletion: 2006*, WMO, Geneva.

Eco-innovation in marketing, organisations and institutions

Contrary to products and processes, eco-innovation in marketing methods, organisational structures and institutional arrangements tends to rely on non-technological mechanisms. Such changes constitute a relatively new area in the innovation literature and were only covered in the third and latest revision of the *Oslo Manual* in 2005 by the introduction of innovation in marketing methods and organisational structures.

Eco-innovation in marketing includes new ways of integrating environmental aspects in communication and sales strategies. Eco-innovative marketing concerns the company's orientation towards customers and can play a significant role in leveraging environmental benefits by influencing them. For instance, the company can improve general product and company appeal in connection with the development and/or sale of eco-efficient products through better market research, direct contact with consumers, and marketing practices that appeal to environmentally aware consumers. Eco-innovation in marketing may also include new business models that change the way products are priced, offered and promoted such as the adoption of PSS.

Organisational eco-innovation includes the introduction of new management methods such as EMSs and corporate environmental strategies. While these areas concern general environmental business practices, organisational eco-innovation can also take place through changes in the company workplace, such as the centralisation or decentralisation of environmental responsibilities and decision-making powers or the establishment of training programmes for employees designed to improve environmental awareness and performance. Organisational eco-innovation also includes changes in how companies organise their relations with other firms and public institutions, such as the adoption of GSCM and the participation in public-private partnerships for environmental research and projects.

Although institutional innovation is not covered by the *Oslo Manual*, the literature on conventional innovation emphasises the importance of co-evolving social and institutional changes in connection with, but as a separate part of, the innovation process (Grubb, 2004; Reid and Miedzinski, 2008). In the context of sustainability, however, a small but growing body of literature argues that changes in social norms, cultural values and institutional structures can be considered eco-innovation in themselves or constitute integral parts of an eco-innovation (Rennings, 2000). This view is gaining ground from a policy perspective. In Japan for instance, eco-innovation is increasingly viewed as a field of techno-social innovations that not only can improve environmental conditions but also satisfy subjective values (METI, 2007).

The concept of institutions generally covers a wide range, from social norms and cultural values to codified laws, rules and regulations, and from loosely established social arrangements to deliberately created institutional frameworks. In some cases institutions are seen as exogenous and outside the domain of market transactions; in others they are seen as endogenous (van de Ven and Hargrave, 2002; Aoki, 2007). This study distinguishes between informal institutions such as social norms and cultural values, which tend to be endogenous, and formal institutions such as codified laws, regulations, and formal institutional frameworks and arrangements, which tend to be based on policy and economic decisions.

Eco-innovation in informal institutions refers to changes in value patterns, beliefs, knowledge, norms, etc., that lead to improvements in environmental conditions through social behaviour and practices. For instance, this would include shifts in the choice of transport modes, *i.e.* from personal automobiles or flights to trains, buses or bicycles because of users' higher environmental awareness or education. It may also include the growth of self-help health groups, community action for cleaning up the surrounding environment, organic food movements, etc.

Formal institutional eco-innovation refers to structural changes that redefine roles and relations across a number of independent entities. It typically relies on legal enforcement, international agreements, or voluntary but formal multi-stakeholder arrangements. Institutional eco-innovative solutions may range from agencies to administer clean local water supplies, financial platforms for funding the development of environmental technologies, and the establishment of eco-labelling schemes and environmental reporting frameworks to new regimes of global governance such as the establishment of an institution with responsibility for global climate and biodiversity issues (Rennings, 2000). In terms of sustainable manufacturing, the establishment of eco-industrial parks, where resource sharing is optimised across seemingly unrelated industrial producers can be considered an example of formal institutional eco-innovation.

Impacts of eco-innovation

The environmental impact of an eco-innovation stems from the interplay between the innovation's design (target and mechanism) and the socio-technical environment in which the innovation is introduced. From an analytical perspective, the assessment of this impact is very important because it determines whether or not the eco-innovation can in fact be classified as such. Also, from a practical point of view, it is important to show that the eco-innovation improves overall environmental conditions. However, the impact assessment of eco-innovation requires extensive knowledge and understanding of the innovation and its contextual relationships.

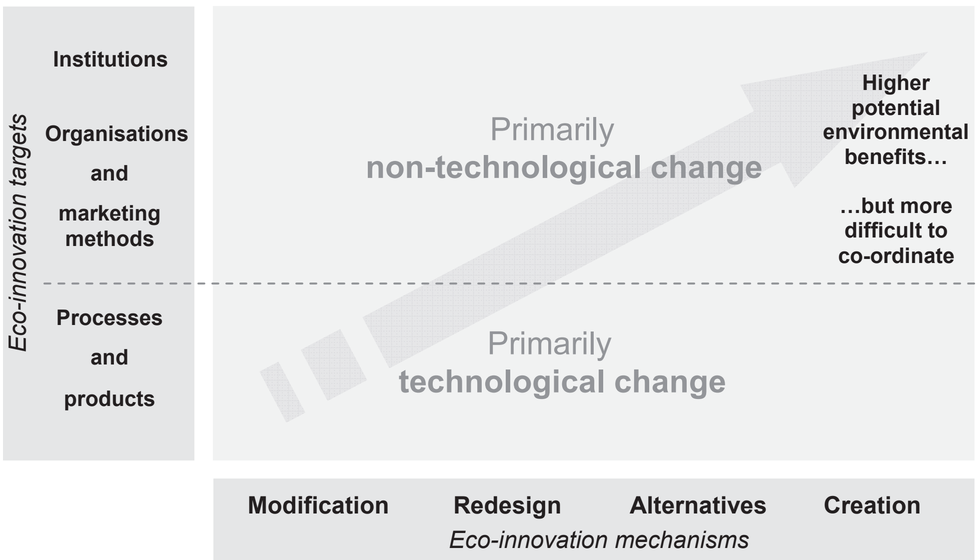
For example, rather simple adjustments that are not intended to improve environmental performance can have significant environmental benefits. These may occur as a result of an unexpected interaction with other factors and occur through indirect systemic changes. An illustrative example is the provision of power outlets and wireless Internet connections in trains. While these adjustments require extra resources and consume additional energy, thus leading directly to a decline in environmental performance, the overall environmental impact could more than offset this negative effect if the new facilities, through "green marketing", attracted business travellers who otherwise would travel by air or automobiles.

Hence, eco-innovation assessments must consider the eco-innovation's life cycle at several levels (Reid and Miedzinski, 2008), including the behavioural and systemic consequences of the innovation's application and/or usage. These can be categorised according to the innovation's characeristics at the micro level, referring to companies and individuals; at the meso level, including supply chains, sectoral structures, local perspectives, etc.; and at the macro level, referring to countries, economic blocs and the global economy. A problem in this regard is the lack of recognised methodological approaches, in part because eco-innovation remains a relatively unrecognised field in innovation policy and general policy frameworks (MERIT *et al.*, 2008).

Summing up

To sum up, eco-innovation can be categorised according to its target (products, processes, marketing methods, organisational structures and institutions); its mechanism (modification, redesign, alternatives and creation); and its environmental impact. The target of the eco-innovation can generally be associated with its technological or non-technological nature: eco-innovation in products and processes tends to rely heavily on technological development, and eco-innovation in marketing, organisations and institutions relies more on non-technological changes. Potential environmental impacts stem from the eco-innovation's target and mechanism and their interplay with the innovation's socio-technical context. Given a specific target, the magnitude of the environmental impact nevertheless tends to follow the eco-innovation's mechanism: modifications generally lead to lower potential environmental benefit than creations. Figure 1.7 sketches an overview of eco-innovation and its typology.

Figure 1.7. The typology of eco-innovation

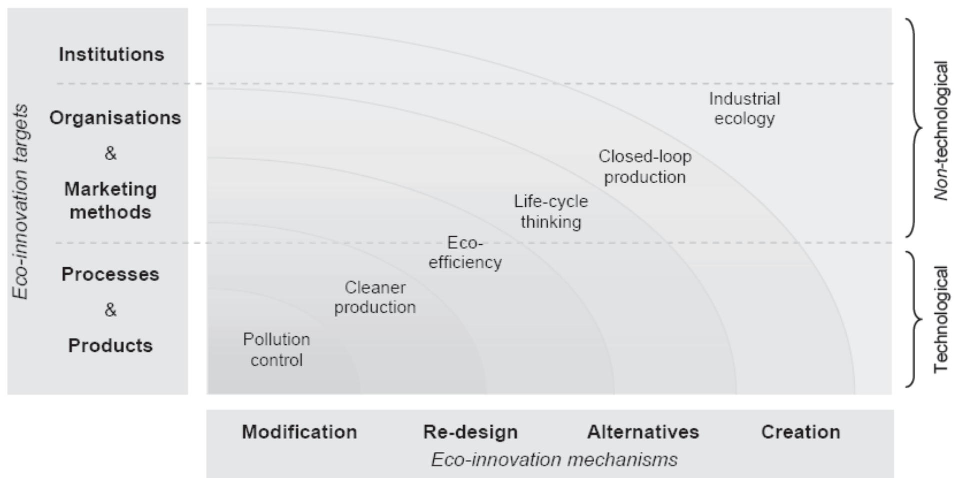


So far, the primary focus of eco-innovation, as of conventional innovation, has been the development and application of different technologies, but recent evidence suggests that non-technological changes are becoming more important (Reid and Miedzinski, 2008). It is also important for eco-innovative solutions to go beyond products, processes, marketing methods and organisational structures, and start to tap into areas relating to social norms, cultural values and formal institutional structures. This is particularly important because the greatest potential for system-wide environmental improvements is typically associated with the development of new social structures and interactions, including changes in value patterns and behaviour, rather than in incremental technological advances.

Eco-innovation as a driver of sustainable manufacturing

There are clearly many conceptual overlaps between eco-innovation and sustainable manufacturing. Pollution control, for instance, can be related to the modification of products and processes; cleaner production initiatives are often associated with the implementation of more integrated changes such as redesign of products and production methods. Eco-efficiency and life cycle thinking are related to eco-design of products and processes, as well as the adoption of EMSs and GSCM. Closed-loop production may refer to alternative business models such as the adoption of PSS, while industrial ecology can generally be associated with the creation of entirely new production structures.

Figure 1.8. Conceptual relations between sustainable manufacturing and eco-innovation



Using Figure 1.7 as a basis for understanding eco-innovation, Figure 1.8 attempts to give a simple illustration of the general conceptual relations and overlaps that exist between the concepts of sustainable manufacturing and eco-innovation. The evolutionary steps of sustainable manufacturing are depicted in terms of their primary association with eco-innovation, *i.e.* with innovation targets on the left, and mechanisms at the bottom. The underlying nature of eco-innovation (technological or non-technological) is depicted on the right. The "waves" spreading towards the upper right-hand corner of the figure indicate the path dependencies of different sustainable manufacturing concepts.

In the medium to long term, the most potentially significant environmental improvements from eco-innovation in manufacturing industries are associated with more advanced sustainable manufacturing initiatives such as the establishment of eco-industrial parks and the like. However, these can generally only be realised through a combination of a broader range of innovation targets and mechanisms; hence those initiatives cover the bigger area of the figure. It is not enough, for instance, simply to locate manufacturing plants with symbiotic relationships close together if no technology or procedure for exchanging resources exists. Process modification, product design, business model alternatives and the creation of new methods, procedures and arrangements should go hand in hand and must evolve together to leverage the economic and environmental benefits from such initiatives. This also means that as sustainable manufacturing initiatives advance, the nature of the eco-innovation process becomes increasingly complex and more difficult to co-ordinate.

The co-evolutionary eco-innovation processes that are necessary to establish more advanced sustainable manufacturing systems are often referred to as "system innovation" – an innovation characterised by large-scale foundational shifts in how societal functions and needs are being provided for and fulfilled, such as a change from one energy source to another (Geels, 2005).

More systemic eco-innovation in manufacturing depends on the interplay between changes across a number of areas, including technological developments, changes in formal institutional structures as well as in social norms and values. Indeed, although systemic innovations may arise from technological developments, technology alone cannot make large differences. It has to be harnessed in association with human enterprise, organisations and social structures. While this highlights the difficulty of achieving large-scale environmental improvements, it also hints at the need for manufacturing industries to adopt an approach that seeks to integrate the various elements of the eco-innovation process, in such a way that the interplay of changes leverages environmental benefits (Box 1.7 gives advanced examples).

Box 1.7. Examples of eco-innovative solutions

The BMW Group, which has been developing hydrogen engine technologies for more than 25 years, has recently unveiled a new "mono-fuel" internal combustion engine. The engine is introduced in the new mono-fuel Hydrogen 7 saloon, which was first displayed at the SAE World Congress in Detroit in 2008. Initial testing of the exhaust from the car's near-zero-emissions engine shows that the air is cleaner in components such as non-methane organic gases (NMOGs) and carbon monoxide (CO) than the air coming in as the engine absorbs and burns ambient air pollutants.

McDonough Braungart Design Chemistry (MBDC), which was established in 1995 to advance the "New Industrial Revolution" and the realisation of the "cradle-to-cradle" thinking, developed an ice cream package for Unilever based on eco-innovative thinking. The packaging consists of polymers, which take the form of a film in its frozen state but degrades to a liquid over a couple of hours when exposed to room temperature. The polymer packaging also includes seeds for rare plants. This essentially makes littering a way to improve biodiversity. It also demonstrates a radical conceptual change as waste literally creates potential new life.

Source: Wired (2008), "BMW Hydrogen 7 Mono-Fuel Eats Smog for Breakfast", 16 April; UNIDO (2002), "The New Industrial Revolution: Michel Braungart at Venice II", *UNIDO Scope Weekly News*, 20-26 October.

From an eco-innovation perspective, manufacturing industries have typically been more concerned with the modification and redesign of existing products, procedures and organisational structures than engaging in the creation of new and alternative solutions. The current focus and application of eco-innovative efforts in manufacturing industries have therefore been relatively narrow and limited to technical advances. This does not imply that environmental performance is not improving, but it can affect views of eco-innovative solutions and how they are developed and applied to manufacturing. It may also explain why the potentially transformative power of eco-innovation has remained largely peripheral in most corporate sustainability initiatives (Charter and Clark, 2007).

To conclude, eco-innovation plays a key role for driving manufacturing industries towards sustainable production. Every shift in environmental initiatives – from traditional pollution control to cleaner production initiatives and the establishment of eco-industrial parks – can be characterised as shifts facilitated by eco-innovation. The concept of eco-innovation can help companies and governments to consider and make these shifts through technological advances, changes in management tools, social acceptance of new products and procedures, as well as changes in institutional frameworks for facilitating progressive change.

Conclusions

The concept of sustainable development has been gaining attention in recent years and the topic has risen to the top of the international political agenda, particularly owing to concerns over climate change. Growing media coverage of environmental issues and rising public awareness have further increased the pressure for manufacturing industries to take responsibility by adopting more advanced and integrated responses to environmental concerns.

This has led to a substantial expansion of ways of applying sustainable development to production in general and to the establishment of a range of tools and management philosophies on sustainable business practices. In terms of sustainable manufacturing, this has involved a movement towards the application of technological solutions that enable the substitution of toxic materials by non-toxic alternatives and the reduction of material consumption and waste. With rising pressures on companies to take environmental responsibility beyond their organisational boundaries, many manufacturing companies have also adopted life cycle perspectives for their operations and are increasingly involved in green supply chain management. In recent years, the concept of a circular manufacturing process has gained ground and new business models, such as product-service system, which facilitate the move towards closed-loop production systems, have emerged. Many sustainable manufacturing initiatives, however, have primarily focused on the development and application of environmental technologies. While they have improved general environmental performance, environmental gains have mostly been incremental and in many cases have been outweighed by rising volumes of production and consumption (OECD, 2001).

To meet the growing environmental challenges, much attention has been paid to innovation as a way of developing sustainable solutions, also known as eco-innovation. This concept is gaining ground in industry and among policy makers as a way to facilitate the more radical and systemic improvements in corporate environmental performance that are increasingly needed. This has led to understanding eco-innovation in the sense that solutions concern not only technological developments but also non-technological changes such as those in consumer behaviour, social norms, cultural values, and formal institutional frameworks. Changes across all these areas, however, cannot be achieved by a single company (Jorna *et al.*, 2006; Reid and Miedzinski, 2008).

The concepts of sustainable manufacturing and eco-innovation are closely related, but not identical. Earlier and more traditional sustainable manufacturing initiatives, for instance, tend to take the form of adjustments to products and processes, marketing methods and organisational structures. Later and more advanced sustainable business practices, on the other hand, are related to the creation of new products and processes, alternative business models, and circular production systems in which discarded goods can be reutilised as new material inputs and seemingly unrelated industrial processes can be connected, with large environmental gains.

Eco-innovation can thus be understood as a driving force for moving manufacturing industries towards sustainable production. The application of the eco-innovation concept can offer a promising way to move industrial production towards true sustainability. However, it requires manufacturing industries to integrate and apply the concept in a more holistic way. It entails a deliberate re-examination of each phase of the production system in order to identify areas for applying potential eco-innovative solutions, including the development of new institutional arrangements such as knowledge networks and partnerships that can function as co-creative processes.

Notes

1. The US Department of Commerce (DOC) has recently defined sustainable manufacturing for the purposes of its Sustainable Manufacturing Initiative. It states that sustainable manufacturing is "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound." See the DOC's Sustainable Manufacturing Initiative and Public-Private Dialogue website: *www.trade.gov/competitiveness/sustainablemanufacturing/how_doc_defines_SM.asp)*.
2. In 1992, the UNCED concluded that "the major cause of the continued deterioration of the global environment is the unsustainable patterns of consumption and production, particularly in industrialized countries, which is a matter of grave concern, aggravating poverty and imbalances". This statement was put forward, particularly to Western countries, as a challenge to change current consumption and production patterns, backed by a global plan for action known as Agenda 21.
3. To address the difficulties in environmental performance measurement, the ISO issued the ISO 14031 standard in 1999 which contains guidance on the design and use of environmental performance evaluation in alignment with the ISO 14001 EMS standard.
4. The ETAP is actively seeking to consolidate an EU-wide market for environmental technologies. A core area is the development of an environmental technology verification (ETV) system that can help to accelerate market acceptance of key innovative technologies by providing accurate and verified information on technology performance. The European Commission is working closely with the United States and Canada where ETV systems have already been implemented.
5. Japan's eco-innovation concept aims at higher satisfaction of human needs and higher quality of life as well as environmental protection. In this publication, the concept of eco-innovation is only described in terms of its environmental aspects. However, the inclusion of social aspects can be considered by simple extension of the application areas and impacts of eco-innovation.
6. For example, the EU-funded Measuring Eco-Innovation (MEI) project proposes that eco-innovation be defined as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (MERIT *et al.*, 2008).

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