CHAPTER (3)

ENVIRONMENTAL IMPACTS OF CORROSION

3-1 Introduction

Our mother earth is almost crying and begging for help from the human beings, whose populations are increasing at high rates and increasing the consuming of the limited resources at unaffordable paces, to minimize all sort of pollutants otherwise their life on earth shall be at risk. In other words; determination of all sorts of lives on earth will be inevitable. Efforts in all direction must be seriously taken to minimize or eliminate, if possible, all sorts of harmful emissions and pollutants. In facts such efforts are the job and duties of the scientists and engineers.

At the end of the 20th Century [33], it is thought to be very hard for the world economy to continue developing. One reason is depletion of resources and another is degradation of global environments. Iron and steel are two of the most popular materials on earth and will remain so in the 21st Century. Therefore, the development of such materials into an eco-material will greatly affect both issues of resources and environment. In producing iron and steel, a lot of resources such as electricity, water, fossil fuels, iron ore, limestone, re-fractories and metallic elements like molybdenum, cobalt, vanadium, niobium, nickel, chromium, zinc, aluminum, manganese and silicon are consumed, and further technological progress and development is required to save resources and energy from a viewpoint of ongoing depletion of resources [34].

Meanwhile, from the viewpoint of the global environment, emissions of carbon dioxide and sulfur oxides associated with producing iron and steel impact strongly on the global environment. In addition, there remains the disposal problem of industrial wastes such as slag and dust. Thus, it is necessary to develop an efficient manufacturing process for iron and steel production in a way that does not reduce the level of efficiency already obtained.

Every product we make and use contributes to environmental degradation in many different ways. It has an ecological footprint that extends well beyond national boundaries and long after a product has been used and discarded [35].

The manufacture, use and disposal of each product contribute to environmental damages in a variety of ways. An illustrative example, figure 3.1, shows some of the links between a steel structure and the environment.

Another well known harmful phenomenon are the acid rain, the greenhouse effect and the depletion of the ozone layer are just some of the observed changes to our fragile planet that have led to demands for control over processes likely to affect the environment. This change in social perspective has already led to considerable amounts of international agreement and legislation and will only increase in the foreseeable future. Control of corrosion is an integral part of this pressure, for, properly implemented, engineering systems can perform more efficiently for longer periods, with less wastage of material and energy resources and greatly reduced pollution. Scientists and engineers must now take fully into account the environmental effects of their activities.

The 'polluter pays' policy, now established in the United States but not internationally, spells danger for the old management technique of saving initial costs without caring about those which follow. The corrosion failure of a chemical reactor which results in a leak of pollutants into the environment is a very serious financial liability. Much more favourable is the alternative of investing more in the cost of the initial design to achieve long life and low maintenance.

It has been calculated that in the United Kingdom, 1 tonne of steel is converted completely into rust every 90 seconds. Apart from the waste of metal, the energy required to produce 1 tonne of steel from iron ore is sufficient to provide an average family home with energy for three months [36].

To illustrate the size of the problem and the controlling factors, the life cycle of a steel product from 'cradle to cradle' is shown schematically in figure 3.2 [35]. The inputs of the industry are energy and raw materials. The energy is input in the form of coal, fossil fuel and electricity, while the raw materials are lime stones, coke, metallic elements and refractory.

To start with examples of the life cycle perspectives, the activity associated with some of these perspectives are highlighted in the followings.

3-2 Iron Mining

3-2-1 Environmental Impact of Mining

The impacts of metal mining vary depending on the mining methods, ore processing, ore type, metal being mined, pollution control efforts, and environmental factors such as climate and topography [37]. Surface mining or mining that includes on-site ore processing that generates large quantities of tailings or spoils can have major impacts off-site on soils, groundwater, and streams as well as the local vegetation, wildlife and human population [38-40]. Ideally, when there is no on-site ore processing, unnaturally high concentrations of metals would not be found outside of the mine, although even with limited processing some contamination can occur [41]. If no on-site ore processing is done, and efforts are made to minimize contamination to soil, streams or groundwater, there may be little off-site impact from mining.

However, off-site impacts vary not only with mining and pollution control efforts, but also with environmental factors that affect metal solubility and availability. Factors which affect the solubility of metals include the type and content of metals, pH, redox reactions, and organics and other complexing ligands [42]. Not all metals deposited in wastes will be rapidly or slowly soluble, be available for plant uptake, or become incorporated into the food chain. If the spoils, tailings, or other mining wastes contain predominantly metals that have formed precipitates or are strongly sorbed and not soluble or extractable over long periods of time, then there may be little leaching resulting in few consequences to off-site streams [43].

3-2-2 Acid Mine Drainage

Acid mine drainage (AMD) [44] from mine waste and the contamination of water and soils with heavy metals are considered major problems in mining areas [45]. In addition, natural mineralized areas, even when not mined, can affect the environment [46]. Acid water is produced by the oxidation of the common iron disulfide mineral pyrite. Heavy metals can be leached from rocks that are exposed to the acid water. This process is also significantly enhanced substantially by bacterial action [47]. In mining areas, release of heavy metals is accelerated due to the increased oxidation rates, which are caused by providing greater accessibility of air through mine workings, waste rock, and tailings by mineral processing [48]. Furthermore, there is the added risk of mining accidents such as in Aznalco´llar (Spain 1998) or Baia Mare/Borsa, (Romania 2000) [49, 50]. During these accidents, huge amounts of mine waste and toxic substances (heavy metals, cyanide) were set free in one go, contaminating rivers and alluvial soils.

3-2-3 Grade Control

Iron ore is extracted from inland mines and railed to a port, where it is loaded onto ships for export [51]. Quality depends upon uniform composition ("grade control"), not only in iron, but also in several contaminant minerals. To achieve grade control, and to provide a buffer between production and demand, crushed ore is stored on to large stockpiles and then reclaimed, either at the mine or at the port. Environmental impact (and cost) is reduced if the land area devoted to stockpiles can be reduced without loss of grade control. There may also be environmental benefits in building the stockpiles at the mine rather than at the port. The stockpile array can be considered as a low-pass filter, filtering out short-term fluctuations in composition. Techniques considered include the use of multiple build and/or reclaim stockpiles, with and without intelligent stacking and reclaiming. Because of the complex correlations between the minerals and across time, design of the stockpile array is not readily amenable to mathematical analysis.

3-2-4 Arsenic Contamination

Since large areas have been contaminated by arsenic-rich industrial and mining by-products in several countries, knowledge of arsenic (As) behavior in soils and water is of major concern for reclamation of polluted sites and evaluation of environmental risk [52]. Investigation of surface and ground water and the solid As-bearing phase was performed on suspended particulate material (SPM) shows that most of total extracted As (78%) and Fe (77%) is bound to an iron hydrous oxide phase, which was determined to be lepidocrocite (γ-FeOOH) by x-ray diffraction and infrared spectrometry. Particulate material was >220 times more concentrated that dissolved As. The theoretical stability of As(V) corresponds to a large association between As and particulate material, and large amounts of the metalloid are released in solution when As-rich particles come from oxidized ground waters to moderately reduced conditions.

3-2.5 Toxic Effects of Mining

The extraction and processing of iron ore locally into pellets are the production operations that affect the environment in the form of air pollution and wastewater emissions to surface and ground water [53]. The toxic effects of the mining effluents on fish gills have the relative proportion of phosphatidylcholine was elevated and cholesterol reduced, while the histological structure of the gills was changed. The number of mucus cells, as well as the sizes and the lengths of open areas in the chloride cells, had increased in spring and summer. The hypertrophy of chloride cells is possibly caused by the increased ambient concentrations of K^+ and Li^+. Changes in gill cholesterol and phospholipid proportions increase the fluidity of membranes and possibly strengthen their protective qualities, counterbalancing the adverse changes in chloride cell structure. The bioavailability and toxic effects of metals on fish are reduced by the hardness and high pH of water discharged by the mining plant.

The effluent water is contaminated with sulfates, nitrates, lithium, potassium, and heavy metals, all of which change the water quality and natural geochemical cation ratios in the lakes downstream [54-56]. The natural, slightly acidic soft water has changed to alkaline hard water in the lakes close to the effluent source. This has affected the biota at all trophic levels [57].

3-2-6 Recycling Economic Impact

A report on EPA analysis of Recycling Economic Impact which focuses on employment and income impacts associated with economic activity was presented [58]. The recycling companies employ more than one million people with salary of $37 billion per year. The economic impact studies offer valuable insights into relative importance of industry but EPA limits direct job count for recycling industry to workers collecting and processing recyclables.

In Egypt, there are no references on the effects of mining discharges on populations and communities of the shallow subtidal habitats. A study should be carried out to account for the chemical characterization of iron discharges, the distribution of heavy metals. The distribution of heavy metals in water, changes the composition and quality of phycocolloid and morphology, as well as the effects upon the macroinvertebrate community associated with holdfast and on the rocky subtidal community. The levels of heavy metals in seawater, plants and alginates in contaminated and pristine sites are highly variable.

3-3 Carbon Dioxide and the Greenhouse Effect

The Earth's atmosphere plays a vital role in restricting temperature variations to enable life forms to survive; there arc seasonal variations, night/day changes and actual temperature conditions which vary from perhaps 220 Kelvin to 330 Kelvin (-53°C to +58°C) but the Global average temperature remains fairly constant at around 300 Kelvin [59].

Significant variations of this Global average have been caused by ice-ages and inter-glacial periods with intervals of the order of hundred thousand years. The reason for the relatively stable average temperature stems from the presence in the atmosphere of carbon dioxide and water vapour. The Sun's rays reach the surface of the Earth with a preponderance of their energy in the yellow part of the spectrum: the ozone layer protects us from much of the ultra-violet content, but some of this gets through. Part of the energy is reflected back by cloud layers or by reflective surfaces such as deserts or snow fields, but the remainder is absorbed by the Earth's surface during daylight hours and then re-radiated upwards as infra-red energy with wavelengths from a few μm to around 100 μm. It is this re-radiated energy which is controlled by the content of the atmosphere and thus retained in the boundary layer just as the heat is retained in a greenhouse.

Carbon dioxide, which has always been present in the atmosphere, absorbs wavelengths between 13 μm and 100 μm, and water vapour, either in the atmosphere or condensed in low cloud formation, prevents the escape of heat with wavelengths up to 7 μm. This leaves a gap or 'window' between 7 μm and 13 μm through which, prior to the industrial age, the energy was lost into outer space.

The very existence of life on earth is crucially dependent on the balance between retention and loss of energy and this delicate equilibrium is the outcome of the evolution of the Planet over billions of years.

Without the greenhouse effect there would be variations of temperature of thousands of degrees between night and day and life could not survive. Space probes have shown that the planets and their moons in our solar system are without life because of the absence of an atmosphere similar to our own and the consequent extremes of temperature.

Reliable estimates suggest that the increase in carbon dioxide content of the atmosphere since pre-industrial times is at least 25% and that present trends in worldwide fossil fuel consumption could lead to a 100% increase by early in the 21st century.

On the other side of the ecological balance there is a relentless destruction of tropical rain forests estimated at a rate of 200 000 square kilometres per year. The complex process of photo-synthesis in plant life involves carbon dioxide, oxygen, and energy from the Sun and results in a net reduction of CO_2 and a net increase of O_2.

3-4 CO_2 Emission in Iron and Steel Industry

In the last few years the discussion on mitigating anthropogenic green house gas (GHG) emissions has gradually emerged as a key issue in the international agenda [60]. The 1997 Kyoto Protocol (KP) to the United Nations Convention on Climate Change (UNFCCC) sets, for the first time, binding emission reduction targets for developed countries. GHG emissions of the so-called Annex B countries are to be reduced by 5.2% over the 2008 - 2012 period, with respect to the 1990 emission levels. This protocol can be interpreted as a first step in a series of international agreements with the aim of stabilizing GHG concentration in the atmosphere, the long-term objective of the UNFCCC [61].

The KP will enter into force after the ratification of 55 parties to the UNFCCC accounting for at least 55% of the 1990 CO_2 emissions of the countries listed in the Annex B of the protocol. Currently 100 parties have ratified the protocol, the EU, the candidate countries to the EU, Canada and Japan among them. The KP would enter into force with the ratification of the Russian Federation, even after the withdrawal of the USA from the protocol in 2001.

The adoption of the protocol, and particularly the implementation of its so-called flexible mechanisms, raises several questions and concerns, at regional and global level, about its effects on the energy-intensive industrial sectors, such as their future technological evolution and the possible leakage to the countries without GHG mitigation commitments. For instance, in the EU these sectors will have to face new stringent environmental regulations and, in particular, the CO_2 emission trading market already launched in 2005, and the Integrated Pollution Prevention and Control (IPPC) Directive

The iron and steel industry is the largest energy consuming industry in the world, as well as one of the most important sources of CO_2 emissions and other pollutants. According to the World Energy Council [62] energy consumption of the iron and steel sector in 1990 accounted for 12% of the world energy consumption. The related CO_2 emissions were 1425 Mt CO_2. World steel production increased from 200 Mt in 1950 to 847 Mt in 2001, and is expected to grow further in the future, primarily due to the increasing demand in developing countries. While production in OECD countries has been around 350 Mt since the eighties, production in the developing world (mainly China, India and South America), is now growing at almost 7% annually. Analysts commonly agree that such growth trends will continue over the next decades. In particular, the World Energy Council [62] foresees a world production level of 1300 Mt by 2020, assuming a business as usual (BAU) scenario. The same foresight exercise predicts that by 2020 world energy consumption in the steel sector would reach 600 MTOE, and consequently, CO_2 emissions would increase up to 1700 Mt CO_2.

With regard to the EU (see Table 3.1) the iron and steel industries accounted for 21% of final energy consumption and 27% of emissions in the total manufacturing sector in 1990. Almost the same shares are observed in the year 2000 (19% and 28%, respectively). Production of crude steel grew from 148 to 160 Mt in that period,

Table 3.1 Energy use and CO_2 emission in the EU-15 industry [63]

Sector	1990		2000	
	Final energy use (MTOE)	CO_2 emission (Mt CO_2)	Final energy use (MTOE)	CO_2 emission (Mt CO_2)
Total industry	266.01	573.44	271.68	629.36
Iron and steel	**56.04**	**153.45**	**51.49**	**179.04**
Non-ferrous metals	10.83	13.54	10.44	15.85
Chemicals	50.59	75.21	45.33	97.62
Glass, pottery and building materials	35.65	89.28	34.88	99.50
Ore extraction	2.99	4.84	2.68	5.81
Food, drink and tobacco	22.02	46.20	25.02	45.80
Textile, leather and clothing	8.75	13.85	8.45	16.56
Paper and printing	17.99	67.38	31.12	28.91
Engineering and other metals	27.35	33.72	24.51	42.73
Other industries	20.64	68.38	34.96	45.05

Note: 1990 figure do not include the German Democratic Republic [63].

3-5 Environmental Sustainability of Steel

Metals are well suited to sustainable development goals. They are not biodegradable and have virtually an unlimited lifespan and the potential for unlimited recyclability [64]. Thus metals can be considered as renewable materials. However mineral resources, the source of primary metals, are 'non-renewable' as their supply is finite, but this does not necessarily mean scarcity. Some of the environmental impacts (Total Energy, Global Warming Potential and Acidification Potential) associated with primary metal production and how they will be exacerbated by declining ore grades; new processing technologies with lower energy consumptions and improved metal extraction efficiencies that will reduce reserve depletion and environmental impacts; increasing the utilization of 'metals in use' by recycling, and the potential impact of a carbon tax on metal prices and how this may influence the ways in which metals are used in the future.

The Integrated Product Policy (IPP), one of the most recent initiatives of the European Commission in the field of sustainable products and services development, considers Life Cycle Assessment (LCA) as natural tool to provide environmental product declarations and verified environmental labels [65]. The need of transparency of environmental performance is getting more importance also in the field of corrosion protection technology. First results of a Life Cycle Assessment on a 'hot-dip zinc galvanizing process' for generic steel products are here reported to present a set of environmental sustainability indicators of that industrial sector and to support the preparation of a document with an environmental declaration. The study has been carried out according to ISO 14040 standard and the system referred to an average process resulting from two Italian medium-size plants (about 12.000 metric tons of galvanised steel per year each). Different frameworks such as poles and pylons for energy transportation have been considered from a cradle-to-grave (eco-profile) point of view, adding up to energy and environmental results also on the basis of the steel product service life within different corrosion scenarios.

The various aspects of clean technologies for a sustainable steel industry are important [66]. Increasing environmental awareness and regulations have led to a new approach and philosophy in steelmaking. An important innovation in clean tinplating technology is the new low-sludge tin dissolution process for electrolytic tinning lines (ETL) with insoluble anodes. A major characteristic of the electric furnace is the higher recycling rate of waste materials from the iron industry and from end users.

3-6 The Energy Awareness

The energy awareness issues regarding combustion safety, fuels and efficiency, environmental concerns and energy costs are of prime importance. The use of energy in the steel industry involves fuel gases, coal and fuel oil [67]. The members of the Energy and Combustion Engineering Division strive to ensure that the conversion of finite fossil fuel supplies to energy is done with maximum safety, maximum efficiency and minimum impact on the environment.

Steel making technology poses strong potentials for environmental protection in three directions. One is pollution control on steel making process itself [68]. Secondary, those process technologies can be applied to reduce environmental burden in other industrial sectors. One of the successful examples is municipal waste treatment facility. Thirdly, development of high performance steel products, such as high strength steel for automobile body, can contribute to improve environmental performance during their use, based on the concept of life cycle assessment.

3-7 Wastes and Emissions Minimization

Emphasis is placed on the development of resource circulatory system for the minimization of various wastes and emissions of green house gases (GHG), toxic gases and polluting particulates [69]. The minimization includes:

a) Rationalization of iron and steelmaking processes;

b) Implementation of available relevant measures/technologies;

c) Life cycle assessment in designing steel from semis to assembled products;

d) Reduction, reuse and recycling of materials and energies; and

e) Utilization of core competence technologies to process domestic and industrial wastes.

In view of global nature of the above wastes- and emission-issues, inter-industrial linkage and international cooperation across the borders between countries have become more important. Inter-industrial linkage definitely serves to cut back the wastes and emissions. Examples of such linkage and factors influencing the sustainability of the linkage are described with expectation for further development of the linkage. Importance of international cooperation cannot be overstressed under the circumstances where steel production in China exceeded 220 Mt and world production exceeded 945 Mt in 2003 and is still increasing. Practical measures are discussed to enhance the linkage and cooperation for effectively promoting the reduction, reuse and recycling, including implications for the nonferrous industry.

3-7-1 Reduction

In the recent past, the steel industry in Europe has demonstrated a major commitment to reduce the environmental burden of its activities[70]. Depending on the definition used, the investment in environmental protection can be estimated between 5 and 15% of the total capital expenditures to improve the individual operations. These efforts are strengthened by the technological evolution of the steelmaking sector and mainly by the growing availability of scrap allowing for an increase of the recycling route. The overall improvement of the last ten years has been impressive. Today, some new and great challenges are ahead requiring the development and implementation of viable techniques to further reduce the emissions to the air, mainly from the sinter plants, and to decrease the amount of waste to be disposed. Among the possible solutions the development and application of recycling techniques seem to be attractive and promising. Finally it will become necessary in the future to fundamentally rethink the use of reducing agents in the steelmaking process to improve drastically the CO_2 emissions of the iron making route. Here also schemes can be devised based on the idea of maximal and systematic recycling of carbon in the process.

Solid wastes generated by integrated iron and steel works cause environmental pollution and therefore must be discarded accordingly [71]. Extensive research is being conducted for the recovery and elimination of the iron oxide that these wastes contain. The production of sponge iron from these wastes could be considered a method of beneficiation. The reduction of cold-bonded pellets produced from the solid wastes, using different reducing agents, was applied. The activation energy of the reduction was found to be 48.5 kJ/mol.

Redsmelt NST is a new iron making process based on two reduction steps: pre-reduction in a rotary hearth furnace (RHF) and DRI smelting in an innovative oxy-coal reactor called "new smelting technology" (NST)[72]. The two main process units are designed to process up to 55 000 t/year of iron-bearing materials to produce about 30 000 t of pig iron. In comparison to other iron smelting units, the NST smelter is characterized by a very high productivity and limited investment cost.

The Japanese government has committed itself to a 6% reduction of greenhouse gas (GHG) emissions in the period 2008–2012, compared to the emissions in 1990 (UNFCCC, 1997) [73]. Ninety percent of the Japanese GHG emissions are carbon dioxide (CO_2) emissions, the bulk of which is related to the use of fossil fuels (UNFCCC, 2000). Approximately, half of all GHG emissions are emitted by industry. As a consequence, any significant emission reduction implies also emission reduction in industry. CO_2 emissions in the iron and steel industry amounted to 160 Mt in 1998, 14% of the total Japanese CO_2 emission (IEE, 2000). The iron and steel industry is the most important industrial sector from the point of view of CO_2 emissions.

The steel industry produces steel products. Currently two main process routes exist for crude steel production: the blast furnace (BF) - basic oxygen furnace (BOF) route and the electric arc furnace (EAF). The first route is based on the use of coal and iron ore. The second route is based on the use of scrap and electricity. In 1999 69.5% of the Japanese was produced in BOFs, 30.5% in EAFs (IISI, 2000). Total crude steel production amounted to 94.2 Mt (MITI, 2000). Total final steel production amounted to 85.7 Mt in 1999, (see Table 3.2).

Table 3.2 Japanese finished steel production, 1999 (MITI, 2000)

	Mt/year
Rails	0.43
Sheet piling	0.80
Cold formed sheet piling	0.05
Shapes	9.53
Bars	17.44
Wire rods	7.01
Heavy plates	6.96
Medium plates	0.20
Hot rolled sheets	11.38
Cold rolled sheets and strips	7.68
Cold rolled electrical sheets and strips	1.82
Tin plates	1.47
Tin free steel	1.14
Galvanised sheet	10.94
Other metallic coated sheets	1.15
Steel pipes and tubes	7.62
Tires and wheels	0.06
Total	**85.68**

3-7-2 Recycling

The recycling of steel is a crucial aspect of the shift toward a sustainable metals industry [74]. The emphasis on steel recycling through the introduction of the scrap based mini-mill concept is also matched with a desire for greater product quality and reduced environmental impact, which, in turn, has generated important innovations. There have been significant advances in the technology for recycling steel over the last 20 years. An overview of these developments and future directions in steel recycling including scrap management, control of tramp elements, electric arc furnace technology and ladle metallurgy are under consideration.

The recycling of metals can be very efficient with careful selection of the material being recycled [75]. The volume and value of recycled ferrous scrap has lead to the development of steel mini-mills which in turn has caused major changes to the steel industry. The recycling rates of steel are considerably lower due to longer use and non-uniform product usage that results in less efficient segregation and processing. It is clear that recycling of steel has advantages but its sustainability is uncertain. Metal recycling has technical, economic and social impacts. It is relatively easy to assess recycling on a technical basis, but the social impacts are harder to evaluate.

3-7-3 Retreatment and Recovery

The characterization techniques were applied to complex waste products from metal production and processing operations with the aim of devising treatment methods for upgrading the metal content for recycling [76]. A waste stream was selected to illustrate the role of characterization in adapting mineral processing techniques to provide an effective recycling strategy. The waste product chosen was steel shredder sludge that contains copper wire and other metallic in a matrix of plastic and natural fibres, iron oxides, metallic iron, and other compounds. Characterization methods include chemical analysis, phase analysis, sizing analysis, and general techniques such as particle shape, surface area, and porosity determinations. The applicability of these techniques to the waste products is considered in relation to their advantages and disadvantages, and sampling issues. Treatment techniques considered for the waste product included comminuting, screening, air or water classification, simple water leaching, gravity separation, magnetic separation, flotation, and eddy current separation for shredder used magnetic separation to produce a metallic iron-rich product.

3-8 Global Warming

The origins and operation of the Intergovernmental Panel on Climate Change (**IPCC**) and some aspects of the greenhouse gas theory of global warming are examined [77]. It is concluded that while it is extremely unlikely that any accurate prediction can be made now of the climate a century hence, and there is doubt that emissions of CO_2 from man's activities are a major causative factor in global warming, government initiatives based on acceptance of the theory provide the spur for the steel industry to seek process routes with CO_2 emissions much lower than they are today.

3-9 Dioxins and the Environment

Emissions of dioxins from steel mills melting scrap iron are well known and have been measured in a lot of industries [78]. Dioxins (chlorinated dibenzodioxins and dibenzofurans) have up to now primarily been considered an outdoor environmental problem, which affects the population in general as a consumer of specific products such as fish and human milk.

Frequently, outdoor environmental problems are also work environment problems. Thus dioxins have to be considered from this point of view as well.

In some of the processes where dioxins are formed, the dioxins pass through the work environment before being emitted to the outdoor environment. The concentration in the work environment can often be expected to be tens of times higher than in the outdoor environment at some distance from the source. Inhalation of dioxin contaminated air at a distance from the source has not been considered to constitute a health hazard [79]. Due to the increased concentration, this need not be so when it comes to the inhalation of dioxin contaminated air in the work environment.

One of the processes from which dioxins are emitted is the melting of scrap iron. The melting process also includes some steps which release large amounts of dust, which is supposed to be evacuated from the electric furnace and prevented from reaching the work environment However, the melting process generates so much heat that the ventilation system cannot capture all of the dust generated This results in airborne dust in the work environment.

The dust emitted, containing dioxins, thus passes through the work environment before being emitted to the outdoor environment. Some of the dust settles in the furnace hall and may in that way give rise to secondary dust and dioxin emissions.

Main results of the second stage of the so-called ''European Dioxin Emission Inventory'' are presented [80]. They cover emission testing data gained from various facilities in the **EU** (among these the first emission measurements reported from Portugal and Greece) and some central European countries. Further, updated dioxin emission estimates for the most important emission sources in the 17 western European countries and an evaluation of the emission time trend from 1985 to 2005 are presented. The major conclusions are that:

- At present, iron ore sintering is likely to be the most important emission source type followed by the former ''No. 1'', municipal waste incineration;
- Measurement data from a considerable number of installations are still missing, in particular from the metal industries in Spain and Italy;
- There still exist an unknown number of health care waste incinerators with flue gas PCDD/F concentrations above 100 ng I-TEQ/m^3 which must be considered as important local sources;
- In general, considerable emission reduction has been achieved with respect to the industrial emission sources, whereas emissions from non-industrial sources hardly decreased;
- Hence, in the near future the emissions from non-industrial sources are likely to exceed those from industrial installations;
- The goal of 90% emission reduction set in the 5^{th} **EU** Action Programme will be achieved for some source types only.

The Japanese Government promulgated the "Law Concerning Special Measures against Dioxins" on 16 July 1999 and it was enforced on 15 January 2000 [81]. This is a unique law specialised to protect the environment by the control of dioxin emissions from waste incinerators and several industrial processes. In this law, a few metallurgical processes other than waste incinerators are designated as 'specified facilities' emitting certain dioxins. Thus, emission standards for dioxins to the air were set for **E**lectric **A**rc **F**urnaces (**EAF**) for steelmaking, iron ore sintering, zinc recovery from EAF dust and aluminum recycle processes. The inventory of dioxin emissions for Japan and the recent research and development to reduce emissions from those processes are introduced.

3-10 PAH Emission

A large number of chemical compounds that damage the ambient air quality are formed during incomplete combustion of organic materials[82]. Among the formed compounds are polycyclic aromatic compounds including **P**olycyclic **A**romatic **H**ydrocarbons (**PAHs**). Several PAHs are known to be mutagenic and/or carcinogenic toward rodents, and considered as potential human carcinogens [83]. PAHs are generated by the incomplete combustion and/or pyro-synthesis of organic material. Natural sources such as forest fires and volcanic eruptions also contribute to PAHs. For the most part, however, these pollutants are generated by human activities, like industrial production, transportation, and waste incineration [84].

In the steel and iron industries, PAHs are released from coke manufacturing, sintering, iron making, casting, mold poring and cooling, and steel making [85]. The International Agency for Research on Cancer (IARC) classifies coal tar pitch volatile containing PAHs in coke production as carcinogenic, and it has documented the evidences of carcinogenicity to humans relating to the operation of the iron and steel industry [86]. An epidemiological study has estimated a high risk of lung cancer among humans exposing to PAHs in the neighborhood of coke ovens in the steel industry [87]. Another epidemiological study has also revealed a 2.5 times greater risk of lung cancer for the steel foundry workers in comparison to a standard population [88]. As estimated by a study in Norway [84], PAH emission from the iron and steel industries represents a second major source, accounting for 12% of the yearly total-PAH emission. PAH concentrations in soil near a blast furnace plant have been found increasing with decreasing distance from the plant [89].

At the water surface outside the steel plant on the Swedish Baltic coast, the annual flux of PAHs (sum of 15 PAH compounds) in a 10-km^2 area adjacent to the emission source is 290 kg/year. This high loading rate is evidently effectuated by the steel plant [90]. Although considerable efforts have been made to investigate the ambient concentration and characteristics of PAHs in coke plant or near coke oven, yet very few studies have focused on the PAH emission from the stacks in the iron and steel industries [91-93]. For some years, the compositions of trace elements have been widely used to identify the sources of air pollution and to apportion the source contributions to the ambient aerosols through receptor model. Because Pb and Br no longer emitted from automotive vehicles after the modification of petroleum fuel and the inability to distinguish among certain types of emissions by using trace metals, organic compounds have been used as tracers to analyze particles or toxic air pollutants sources in recent years [94]. Among these application of organic compounds, the compositional differences in PAHs resulted from the combustion of different fuels have been successfully used for source identification [92, 95]. However, modeling with PAHs is still limited due to the difficulties associated with analytical methods and the availability of reliable chemical composition data.

The steel and iron industries are classified into three categories on the basis of auxiliary energy source. Category I uses coal as fuel, Category II uses heavy oil as fuel and Category III uses electric arc furnace.

The pollution source profiles are obtained by averaging the ratios of individual PAH concentrations to the total concentration of 21 PAHs and total particulate matter measured in this study. Results show that low molecular weight PAHs are predominant in gas plus particulate phase for all three categories. For particulate phase PAHs, however, the contribution of large molecular weight compounds increases. Large (or heavy) molecular weight PAHs (HMWPAHs) are carcinogenic. Over all categories, these compounds are less than 1% of the total-PAH mass on the average.

Average total-PAH emission factors for coal, heavy oil and electric arc furnace were 4050 μg/kg-coal, 5750 μg/lit-oil, 2620 μg/kWh, respectively. Carcinogenic benzo[a]pyrene for gas plus particulate phase was 2.0 g/kg-coal, 2.4 μg/lit-oil and 1.4 μg/kWh for Category I, II and III, respectively. Table3.3 summaries the above three categories.

Table 3.3 Classification of steel and iron industries

Category / Parameter	**I**	**II**	**III**
Energy source	Coal	Heavy oil	Electric arc furnace
PAH	4050 μg/kg	5750 μg/lit	2620 μg/kW-h
Carcinogenic	2.0 g/kg	2.4 μg/lit	1.4 μg/kW-h

3-11 Cadmium

The steel industry and waste incineration, followed by volcanic action and zinc production, are estimated to account for the largest emissions of atmospheric cadmium in the region [96]. Waste disposal results in the single largest input of cadmium to land; the quantity of cadmium associated with this source is greater than the total from the four other major sources-coal combustion, iron and steel production, phosphate fertilizer manufacture and use, and zinc production. The characterization of cadmium inputs to aquatic systems is incomplete but of the sources considered, the manufacture of cadmium-containing articles accounts for the largest discharge, followed by phosphate fertilizer manufacture and zinc production.

3-12 Waste Management Strategy

An integrated industrial waste management strategy can reduce both disposal costs and environmental pressures, while contributing to overall profitability at a time of rising energy and raw materials prices [97]. While such a residuals management programme obviously involves liquid and gaseous emissions, and energy accounting, major emphasis is placed in this paper on solid wastes and the iron and steel industry, Key elements of the suggested strategy include: making an inventory of the residuals for each process, including energy; reducing the loss or degrading of materials and energy; increasing recovery, regeneration and recycling; optimizing collection, handling and transportation; developing uses for residuals; designing storage and disposal sites; and co-coordinating and reviewing activities within a waste management group. Implementation requires active senior level participation to ensure that the interacting objectives are achieved.

3-13 Energy Management

3-13-1 CO_2 Removal

CO_2 removal in electricity production has received a lot of attention, but CO_2 removal in iron and steel production as yet [98]. Worldwide, about 420 Mt of coke and coal were used in blast furnaces in 1999 [99]. This fossil fuel consumption results in 1.1 Gt of carbon dioxide (CO_2) emissions. Global CO_2 emissions (excluding deforestation and land use change) amounted to 23.9 Mt of CO_2 in 1996 [100]. The emissions in the iron and steel life cycle represent about 4.6% of the total global CO_2 emissions.

CO_2 is considered to be a key **G**reen **H**ouse **G**as (**GHG**). An increase of GHG concentrations in the atmosphere poses a threat of climate change. In the framework of the United Nations Framework Convention on Climate Change (UNFCCC), countries have agreed to reduce GHG emissions.

CO_2 can be captured from flue gas streams and stored below ground. The term CO_2 removal is used for the combination of both activities. Globally, a lot of attention is paid to CO_2 removal from power plants as a strategy to reduce GHG emissions [101]. However, CO_2 could also be removed in the iron and steel industry. A 500 MW coal fired power plant emits about 3.8 Mt of CO_2/yr. A 3 Mt blast furnace emits about 4 Mt of CO_2/yr. One steel plant may consist of up to five blast furnaces, such as the Kwangyang steel plant in Korea. This plant is a source of 20 Mt of CO_2 emissions per year. Such steel plants represent the single largest point source of energy related CO_2 emissions in the world. The larger the emission source, the better the economies of scale is for CO_2 capture. A clear global tendency exists towards larger primary steel production locations, so the number of large production sites may increase even further. Especially in the East Asia region (representing about 40% of the global primary steel production), these trends are apparent.

Blast furnace gas consists of a mixture of CO_2, CO (carbon monoxide), N_2 (nitrogen) and H_2 (hydrogen). The concentration of both CO_2 and CO is about 20% (v/v). This high concentration could warrant CO_2 removal. However, CO_2 removal from blast furnaces has received little attention as of yet. The goal of this study is an appraisal of CO_2 removal in the iron and steel industry.

Only one study has been found about CO_2 removal in the iron and steel industry [102], concluding that the costs for CO_2 capture would be about 35 US$/t CO_2.

3-14 Utilization of Hydrogen Energy

Today-as in the past-iron ore is reduced by carbon from coal or charcoal for iron/steel fabrication [103]. The ensuing carbon dioxide (CO_2) emissions at a rate of some 2.2 kg CO_2 per kg of liquid steel for reduction are in the order of 10% of the world's anthropogenic CO_2 emissions from burning fossil fuel. Iron/steel production being thus amongst the most intensive single CO_2 polluter, hydrogen substituting carbon would have a large potential to reduce the greenhouse gas CO_2 emissions. Hydrogen is an excellent and clean reluctant emitting water vapour instead of CO_2 and does not introduce extra impurities as coke does (sulphur in particular). If generated with relatively cheap and abundant hydropower, its application in steel fabrication might become competitive even in terms of direct operation costs. The penetration of hydrogen into the steel industry would be favoured by the fact that steel fabrication is rather centralized, the power per steel production plant being in the order of GW compared with, for instance, 100 kW per motor car, which eases the logistics of intervention of hydrogen in steel fabrication.

3-15 Renewable Energy Resources

The iron blast furnace is the most widely used and efficient producer of liquid iron [104]. The integrated steel works is however under environmental pressure largely due to emissions from sintering and coking. The combustion of coke breeze during sintering contributes to greenhouse gases (e.g. carbon dioxide) and is the source of much of the emissions of SO_X and NO_X. Coke breeze, the fines produced during coking of coal, is also suffering supply issues as coke demand increases while coking capacity is constrained by environmental concerns. CSIRO Minerals has been investigating the use of wood biomass/char as a substitute for coke during sintering. Wood biomass, or char produced from it, is an attractive carbon source as carbon dioxide can be sequestered into growing biomass prior to combustion. It has great potential to reduce the emissions from integrated steelworks and improve their environmental acceptability. Harvested biomass/char is also a renewable and sustainable resource. Samples of pine wood flour, sawdust and red gum wood char were characterized and used in small-scale granulation and sintering tests. Red gum char granulated as well as coke and could be used to make acceptable sinter. Large-scale sinter pot test were conducted with char to produce sufficient sinter for ISO quality tests and calculate sintering performance parameters. Results showed that coke could be completely substituted by red gum char during sintering without loss of quality and with actual improvements in sintering performance. Furthermore, gas analyses made during sintering showed that there were significant reductions in SO_X and NO_X when char was substituted for coke. It is anticipated that the results reported here, although preliminary, will stimulate an increased effort into further research on the use of char in iron ore sintering.

3-16 Environmental Legislations

At the 1992 Earth Summit in Rio de Janeiro over 150 countries signed the United Nations Framework Convention on Climate Change (**FCCC**), aiming to protect the climate by stabilizing greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system (UN, 1992) [105,106]. After that, in Kyoto in December 1997, governments around the world agreed to take further actions to reduce emissions of six greenhouse gases of which CO_2 is most significant (IISI, 2000) [107]. At the third conference of the parties to the Convention in Kyoto, legally binding emission reduction targets were set for the so-called Annex-I countries (**OECD** countries and the countries of Eastern Europe and the former Soviet Union).

Although the Parties to the Convention were unable to come to an agreement on key elements of the Convention at the last meeting in The Hague (2000), the need to control and mitigate GHG-emissions is not likely to disappear from the international policy agenda. Hence, there will remain a need to better understand GHG emission trends and drivers.

Since the global manufacturing industry emits 43% of global CO_2 emissions [108], the environmental impacts of this sector have become an increasingly important topic of public debate. Establishing effective greenhouse gas mitigation polices requires detailed knowledge regarding past emissions trends, opportunities and potentials for mitigation, and the effectiveness of polices and measures designed to reduce these emissions.

The overview of the environmental pressure caused by making of metals has hitherto been fragmentary in Finland, although environmental protection has long traditions in the Finnish metals industry [109]. Even if the largest individual emissions have been reduced, environmental impacts in some life cycle stages of products may still increase as a consequence of the growing flow of products. Due to increasing awareness of environmental issues, clients and financiers of the metals manufacturing companies have become interested in the environmental management of the companies. In order to respond to the demands of the markets and to improve environmental performance the companies have begun to direct their attention to reducing interventions (extractions of raw materials, emissions and land use) along the life cycle of products. Moreover, Finland, among several countries in Europe, has simultaneously started to move the environmental focus towards products and product systems because environmentally sound products are considered to be key issues in ecologically sustainable development [110]. For this reason, the environmental administration in Finland intends to enhance the use of life cycle thinking and thus upgrade eco-efficiency in Finnish industry. According to the OECD (1998) [111], eco-efficiency expresses the efficiency with which ecological resources are used to meet human needs.

It was against this background that an extensive R&D project, **Life Cycle Assessment (LCA)** as a Tool for the Management of Environmental Issues in the Finnish Metals Industry.

3-17 Life Cycle Assessment

The main objectives of the LCA study were:

a) To give a general view of the use of materials and energy, and of the emissions and environmental impacts caused by the various life cycle stages of the products of the metals industry;

b) To identify important areas of environmental protection from the point of view of eco-efficiency.

The purpose of the study was not to measure eco-efficiency, i.e. to assess both 'outputs' (values of products and services) and 'inputs' (the sum of environmental pressures) caused by the companies of the metals industry (OECD, 1998) [111].

Only the environmental aspects of eco-efficiency were studied on the basis of results obtained from product-specific LCAs. In the future, it is expected that the material of the study can be used in product development and environmental management, and as part of LCA studies on metallic end products, see figure 3.3.

3-18 Life Cycle Inventory

For each metal product, a **L**ife **C**ycle **I**nventory (**LCI**) was conducted according to the recommendations of ISO 14040, 1997; ISO 14041, 1998[112,113]. In LCIs material inputs, consumption of primary energy, wastes and emissions to water and air were assessed, beginning from the extraction of raw materials and ending with the delivery of products from the factories[35]. The LCI data was compiled according to the following life cycle stages:

a) Concentrate (mining and concentration).

b) Scrap (collection, transportation and processing of external scrap).

c) Other materials (production of additives and chemicals).

d) Production (of metals).

e) Energy (grid electricity used in the production stage).

f) Transports (of raw materials).

g) By-products (credits).

The LCI data for each individual product was jointly compiled by the Finnish Environment Institute and the company producing the metal. The inventory data for raw materials were compiled from the international LCI studies (IISI, 1998; ICA, 1998; IZA, 1998) [107, 114, and 115]. The inventory data for collection, transportation and processing of externally supplied scrap [116], the electricity generation model for Finland and the specific emission coefficients for transportation were elaborated in the study itself.

In the case of multi-product systems, inputs and outputs were allocated in ratio to mass of products. Concerning by-products, allocation was avoided by attributing all inputs and outputs to the product system and by giving credits to the production of by-products assuming that their production replaces alternative production of similar products ('the system expansion method') (ISO 14041, 1998) [113].

The experts constructed a value tree for impacts, figure 3.4. It covered all relevant impact categories which give a fair and relevant description of the environmental effects caused by the production stage studied. Under each impact category, interventions causing the defined effects of the impact category were determined. The value tree also included the impact categories and interventions of the national scale impact assessment model. The new impact categories with interventions were:

- Ecotoxicity (metals to the air and water, oil, cyanides),
- Health effects (POPs (e.g. PCB, PAH, dioxins), As, Pb, Cd, Ni, SO_2, NO_x),
- Direct effects on flora (SO_2, NO_x , fluoride, dust),
- Oxygen depletion (biological/chemical oxygen demand, ammonium),
- Solids to water,
- Thermal load,
- Impacts on amenities (dust),
- Wastes (different groups),
- Noise,
- Smell,
- Soil and ground water pollution (different interventions).

3-19 Contamination Due to Oil Leakage

The corrosion problems can be so severe that local perforation of tank bottoms is likely. This situation requires special attention as serious soil contamination due to leakage of crude oil (or other loading) from the storage tank could lead to environmental problems. Besides the contamination risk it is evident that severe leakage of crude oil or other loads may also lead to considerable financial loss.

The corrosion processes which occur within crude oil storage tanks are numerous. However, the main corrosive action is enhanced by the acidic nature of the crude oil and chloride containing water which separates from the crude oil during storage. This combined with the elevated temperatures at which crude oils are normally stored ensures that the corrosion process becomes highly active. Further corrosive action is attributed to sulphate reducing bacterial species which may generate corrosive products under anaerobic conditions which occur during long static crude oil storage periods.

Confronted with the serious damage observed to the bottoms of crude oil storage tanks, many tank farm owners realize that adequate maintenance of these areas is required. Maintenance procedures sometimes include steel renewal and filling deep pits by welding and steel patching procedures, but above all quality conscious tank farm owners will invest in proper protective coating system which will result in a considerable life time extension of their storage tanks. In this way reducing the maintenance periods and restricting the risk of perforation of the tanks to a minimum.

3-20 Corrosion Audit and Corrosion Control

Corrosion audit and corrosion control, figures 1.1 and 1.3 [1, 117] have become the watchword of the major industrial sectors in view of their major impacts on the performance and capacity of industrial plants. It is being increasingly realized that application of the existing knowledge on corrosion control alone can bring about substantial savings in the cost of maintenance and repair, besides ensuring quality products with minimum financial inputs.

Corrosion of metals and alloys is still controlled by conventional methods [118,119] like application of surface coating, use of inhibitors, application of electrochemical protection methods, besides the use of more corrosion processes and also the technique involved in control of the same have led to the use of more efficient methods at less cost.

An investigation assumes that steel piles and sheet piles in soil and water are expected to remain in place for a long period of time without corrosion affecting their bearing capacity. In many cases, the life span requirement in soil is in the range of 100 years [120, 121].

The work began with a theoretical presentation of the way in which corrosion attacks steel piles and sheet piles and the factors influencing this process. A comparison was made with the corrosion resistance of unprotected piles of carbon steel and piles of ductile iron.

This was followed by a summary of the results of Swedish and foreign field tests of corrosion of steel piles and sheet piles in soil and water. The emphasis was on reporting the corrosion rates measured in the tests.

Detailed accounts were given of the various measures that can be used to inhibit corrosion on piles and sheet piles. These are the introduction of a corrosion allowance (i.e. oversized cross-sections of piles), anti-corrosion painting, application of a polyethylene coating (on steel tube piles), zinc coating, electro-chemical (cathodic) protection and casting in cement mortar or concrete. Detailed comments were given on the protection efficiency of the anti-corrosion systems in various conditions.

Information was also provided on calculation of the corrosion allowance. Finally, the approximate costs of the various protective measures are stated. The average values of average corrosion penetration on steel piles and steel sheet piles are given in Table 3.4

Table 3.4 average values of average corrosion penetration on steel piles and steel sheet piles

Conditions	Salt water	Fresh water
Water at surface	100 mm/year	50 mm/year
Salt water in splash zone	300 mm/year	200 mm/year
Below the water level	100 mm/year	100 mm/year
Bottom sediment	50 mm/year	20 mm/year

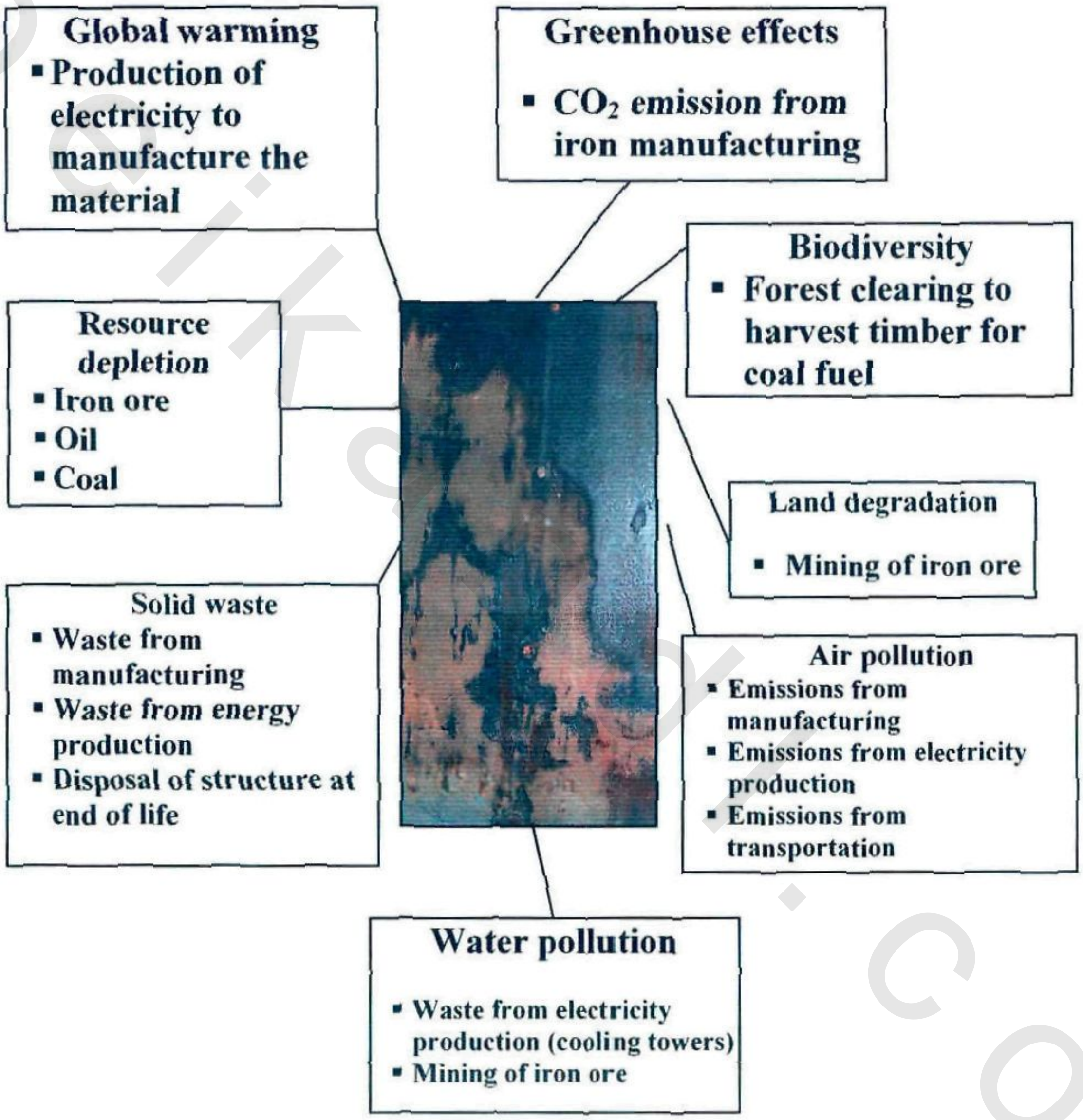

Figure 3.1 ecological footprints of iron and steel productions

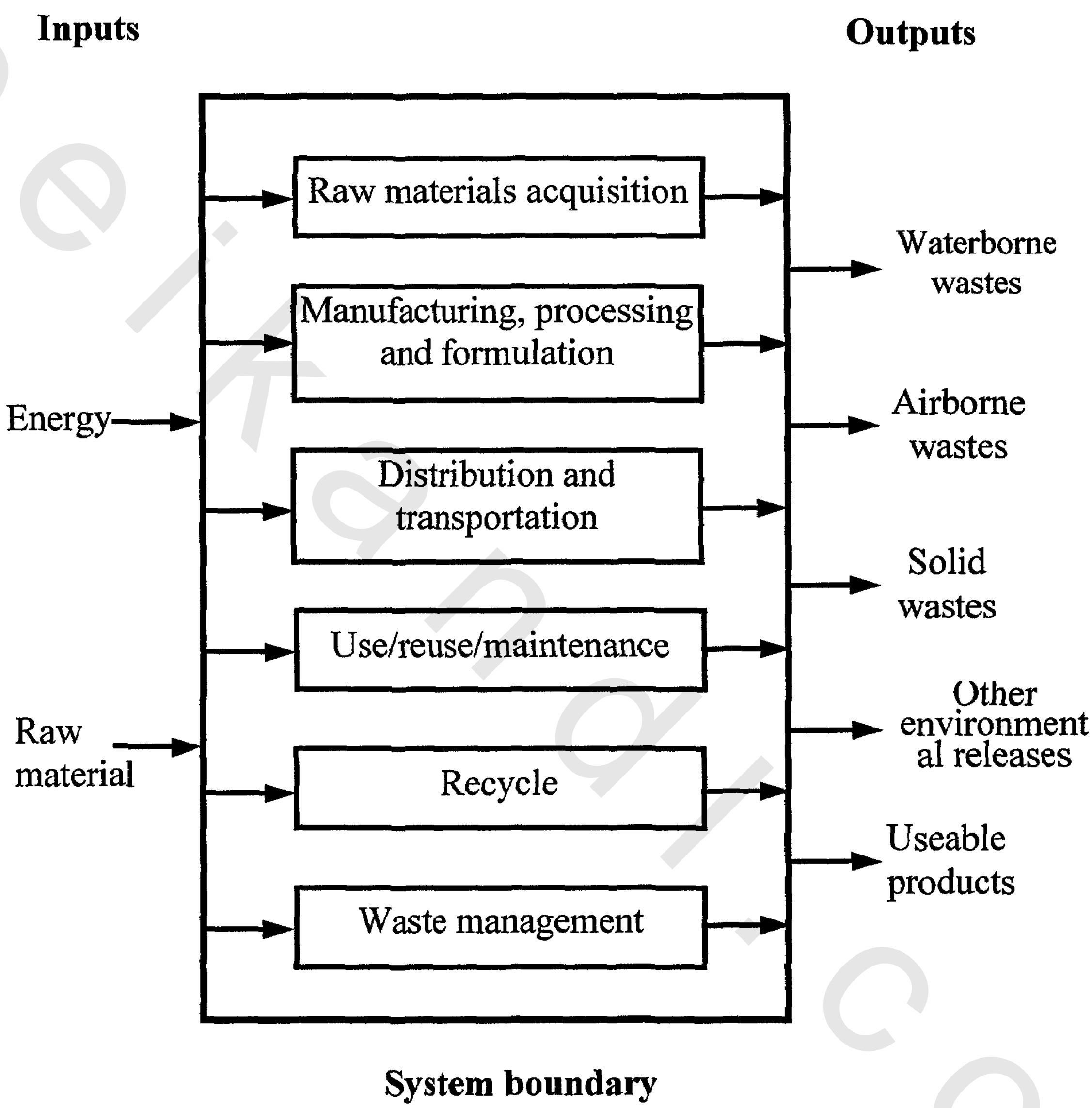

Figure 3.2 product systems from a life cycle perspective [35].

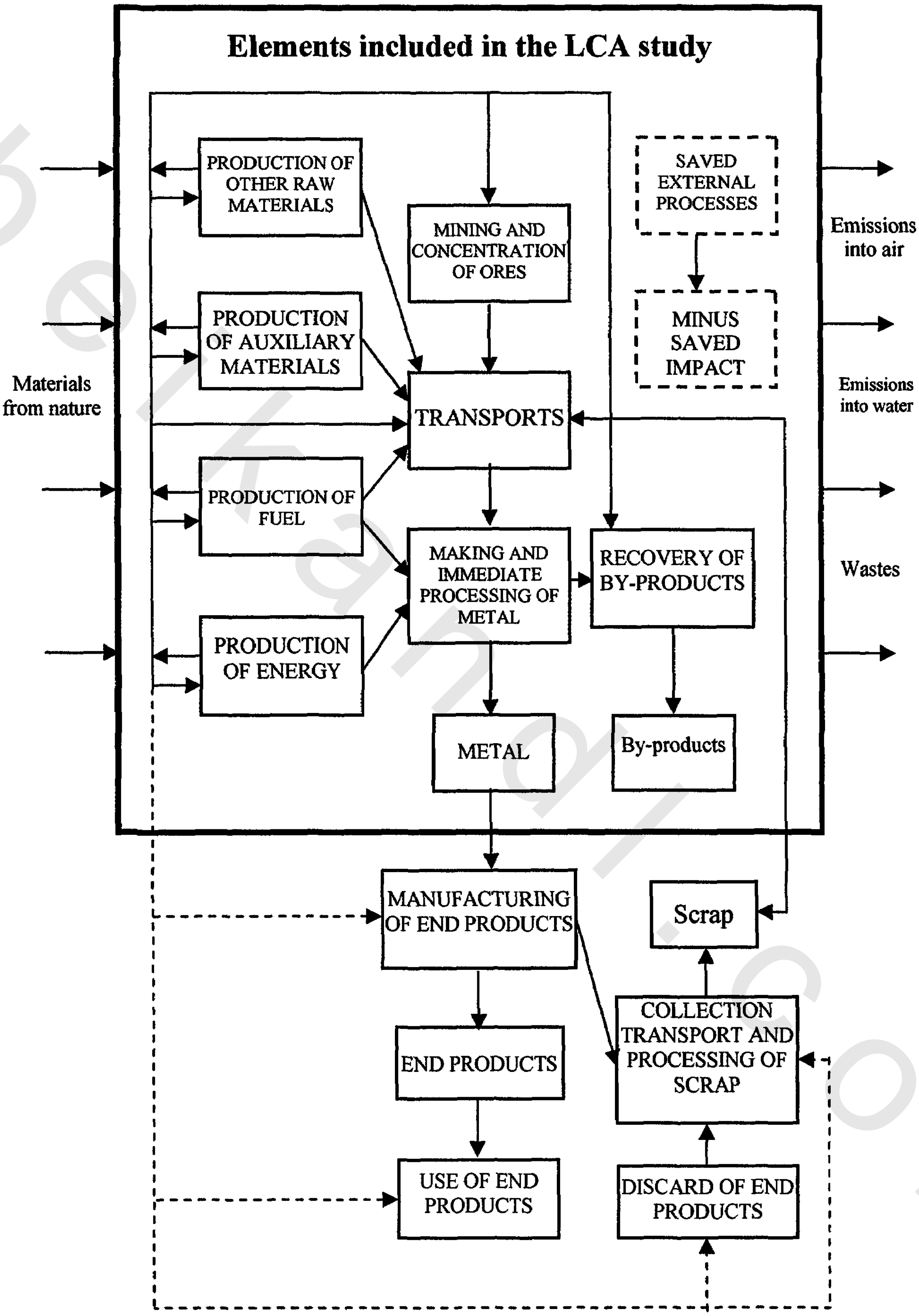

Figure 3.3 Emissions of the product systems included in the LCA

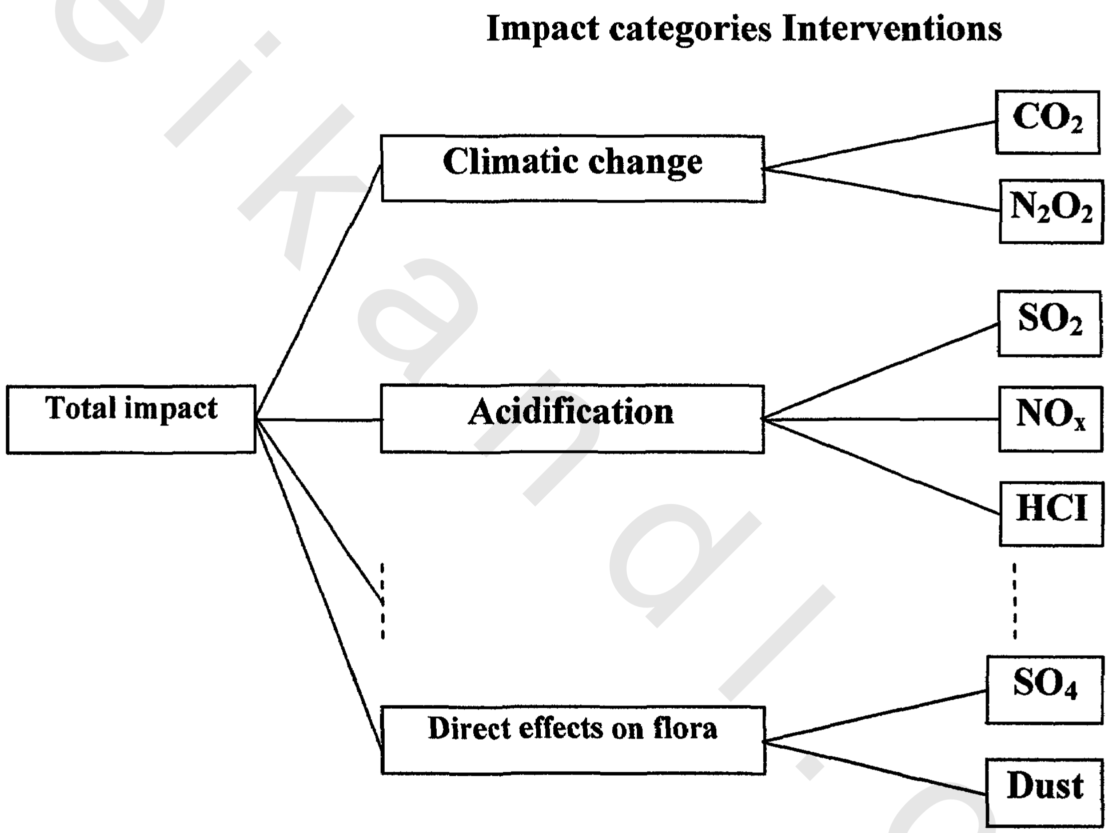

Figure 3.4 Framework for the total environmental impact assessment of production stages, arranged.