



**forthcoming, please do not quote without
authors permission**

**Cleaner Production at the System Level:
Industrial Ecology as a Tool for Development
Planning (Case Studies in India)**

**Suren ERKMAN And Ramesh RAMASWAMY, Institute for Communication and Analysis of
Science and Technology (ICAST), Geneva and Bangalore.**

Contact:

Suren Erkman

Institute for Communication and Analysis of Science and Technology (ICAST)

P. O. Box 474

CH - 1211 Geneva 12

Switzerland

E-mail:suren.erkman@icast.org

September 2000

INTRODUCTION

Governments traditionally have approached development and environment issues in a sectoral and compartmentalized way. This is illustrated in the classical end-of-pipe strategy for the treatment of pollution, which has proven to be quite useful, but not adequate in the long run to make an efficient use of limited resources, in the context of a growing population with increasing economic aspirations. By contrast, Cleaner Production, by addressing the issues in a preventive way, represents definitely an important progress. However, today, Cleaner Production and Eco-efficiency remain mainly targeted towards particular manufacturing processes and business strategy within individual companies (1). Thus, one could think of going even further, and try to apply Cleaner Production at the level of a cluster of various companies, or at the level of an industrial zone, or even for a whole region - in other words applying Cleaner Production at the level of a system. For the past few years, this emerging approach has been currently known under the name of "Industrial Ecology".

Industrial ecology aims at looking at the industrial system as a whole. Industrial ecology does not address just issues of pollution and environment, but considers as equally important, technologies, process economics, inter-relationships of businesses, financing, overall Government policy and the entire spectrum of issues that are involved in the management of commercial enterprises. As such, industrial ecology can provide a conceptual framework and an important tool for the process of planning economic development. Also, industrial ecology may offer options which are not only effective for protecting the environment but also for optimizing the use of scarce resources (2).

INDUSTRIAL ECOLOGY IN A NUTSHELL

Industrial Ecology explores the assumption that industrial system can be seen as a certain kind of ecosystem. After all, the industrial system, just as natural ecosystems, can be described as a particular distribution of materials, energy, and information flows. Furthermore, the entire industrial system relies on resources and services provided by the Biosphere, from which it cannot be dissociated (3-4).

In order to avoid any confusion, we should like to specify what is meant in this paper by "Industrial Metabolism" and "Industrial Ecology".

"Industrial Metabolism" is the whole of materials and energy flows going through the industrial system. It is studied through an essentially analytical and descriptive approach (basically an application of materials-balance principles), aimed at understanding the circulation of the materials and energy flows linked to human activity, from their initial extraction to their inevitable reintegration, sooner or later, into the overall biogeochemical cycles.

Industrial Ecology goes further: The idea is to first understand how the industrial system works, how it is regulated, and its interaction with the Biosphere. Then, on the basis of what we know about ecosystems, to determine how it could be restructured to make it compatible with the way natural ecosystems function.

So far, there is no standard definition of Industrial Ecology, but whatever the definitions may be, all authors more or less agree on at least three key elements of the industrial ecology / metabolism perspective:

- a) it is a systemic, comprehensive, integrated view of all the components of the industrial economy and their relations with the Biosphere.
- b) it emphasizes the biophysical substratum of human activities, i. e. the complex patterns of material flows within and outside the industrial system, in contrast with current approaches which mostly consider the economy in terms of abstract monetary units, or alternatively on energy flows.
- c) it considers technological dynamics, i. e. the long term evolution (technological trajectories) of clusters of key technologies as a crucial (but not exclusive) element for the transition from the actual unsustainable industrial system to a viable industrial ecosystem.

Industrial Ecology has been manifest intuitively for a very long time. In the course of the past thirty years the several isolated attempts made in that direction have usually been rather fruitless. The expression re-emerged in the early 1990's, at first among a number of industrial engineers connected with the National Academy of Engineering in the United States. Today the concept is progressing with unprecedented vigor (5-9).

TOWARDS APPLIED INDUSTRIAL ECOLOGY

The first step for putting Industrial Ecology into practice is to study the Industrial Metabolism, that is, to carry out studies of material and energy flows. This analytical approach can show how, effectively material and energy resources are utilized through all sectors of socio-economic activity. This helps to understand the issues and identify priority areas for action. Therefore, Industrial Metabolism studies should be one of the critical elements in the planning process of a developing country.

Many earlier studies of material flows have been targeted towards making an assessment of specific pollutants, usually heavy metals or certain chemicals. Also, the few studies concerning the total flow of matter have been carried out almost exclusively in developed countries so far (10-13).

A lot of attention has been given to the industrial symbiosis model in Kalundborg (Denmark), where a few disparate large units have worked out an effective system to optimize their material and energy resources (14). Kalundborg can also be seen as a successful example of an industrial complex minimizing pollution and optimizing the use of various resources (15).

There is no doubt that the Kalundborg model has fruitfully inspired the recent thinking on environmental management of industrial estates and eco-industrial networks (16-19). However, there is also a growing recognition that we need to look beyond Kalundborg. This is especially true regarding the implementation of industrial ecology in developing countries, where the industrial pattern is very unlike Kalundborg.

INDUSTRIAL ECOLOGY IN THE CONTEXT OF DEVELOPING COUNTRIES: OUR INDIAN EXPERIENCE

In an attempt to test and adapt the methodology of industrial metabolism in the context of a developing country, the authors of this paper have undertaken various studies in India. The purpose of the studies was to try and develop a broad conceptual framework for planning development strategies for developing countries, which use the basic principles and concepts drawn from industrial ecology.

Our work in India has been founded on the following premises:

1. "What is obvious gets measured and what gets measured gets well managed". The developing countries are characterized by a huge "informal sector", the magnitude of which is not immediately obvious. For example, in place of large factories that are seen in the developed countries, millions of small and individual enterprises contribute substantially to the economies of the developing countries. The collective consumption of materials (and the resultant problems of pollution and waste) in this "informal sector" is often larger than in the formal sector. However, since it is the formal sector which is obvious, all measurements and actions plans are restricted to the formal sector, leaving the difficult-to-measure huge informal sector out.

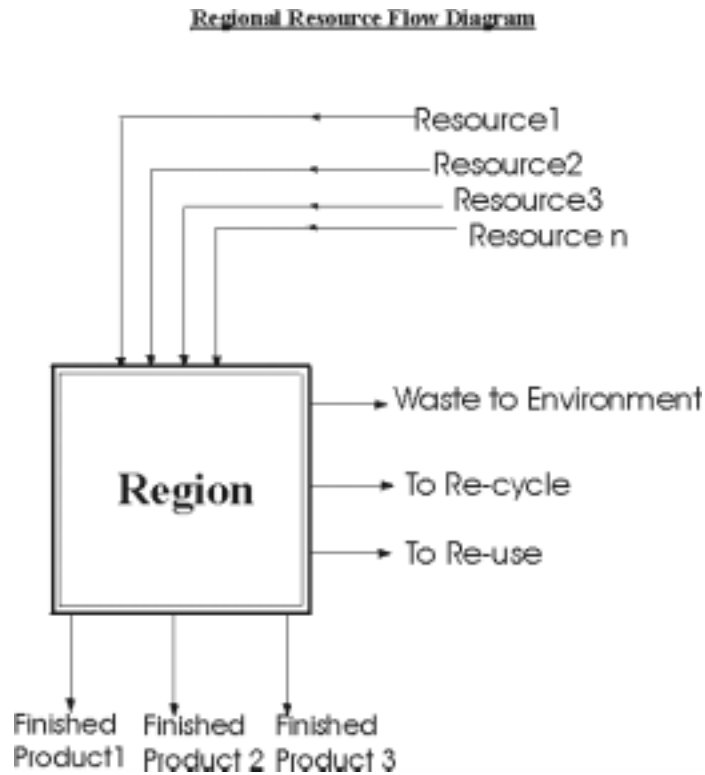
Hence, new "metrics" are needed, including the informal sector, to evaluate the state of the environment and indeed, the quality of life, in a developing country. In this context, new tools are also needed to aid fresh assessment, based on which new development strategies can be planned and implemented. The tools have to be accurate enough for good decision making and action has to be quick enough for the strategy to be relevant.

2. Issues of environment are closely linked to the productivity of scarce resources - the poorer the resource utilization, the greater the waste. In developing countries, where resources are scarce, issues of resources required for survival of life today, gain precedence over concerns over the future of the planet. A more efficient resource utilization would in turn result in greater competitiveness and improved relationship between the industry and the community.

In order to get a good idea of the material flows, in brief, our effort has been to collate and present data as shown in Figure 1 (below). The essence of the approach is to divide the economic activity in an identified region into specific homogeneous segments and study the flow of materials through each such segment. The material flows through each segment are integrated to view the flow of

materials through the entire region. The presentation of the data in this manner highlights the relative importance of different material and energy resources in the region, which would help development agencies to set priorities in planning their tasks.

Figure 1



The "loose ends" in the material flow would be very obvious and would immediately give an indication of unused resources, which are presently wasted. Based on this planners could find ways by which such wastes could be minimized, or by which the wastes could be possibly used by other existing enterprises within the region or new activity initiated to use such wasted resources for other productive purposes.

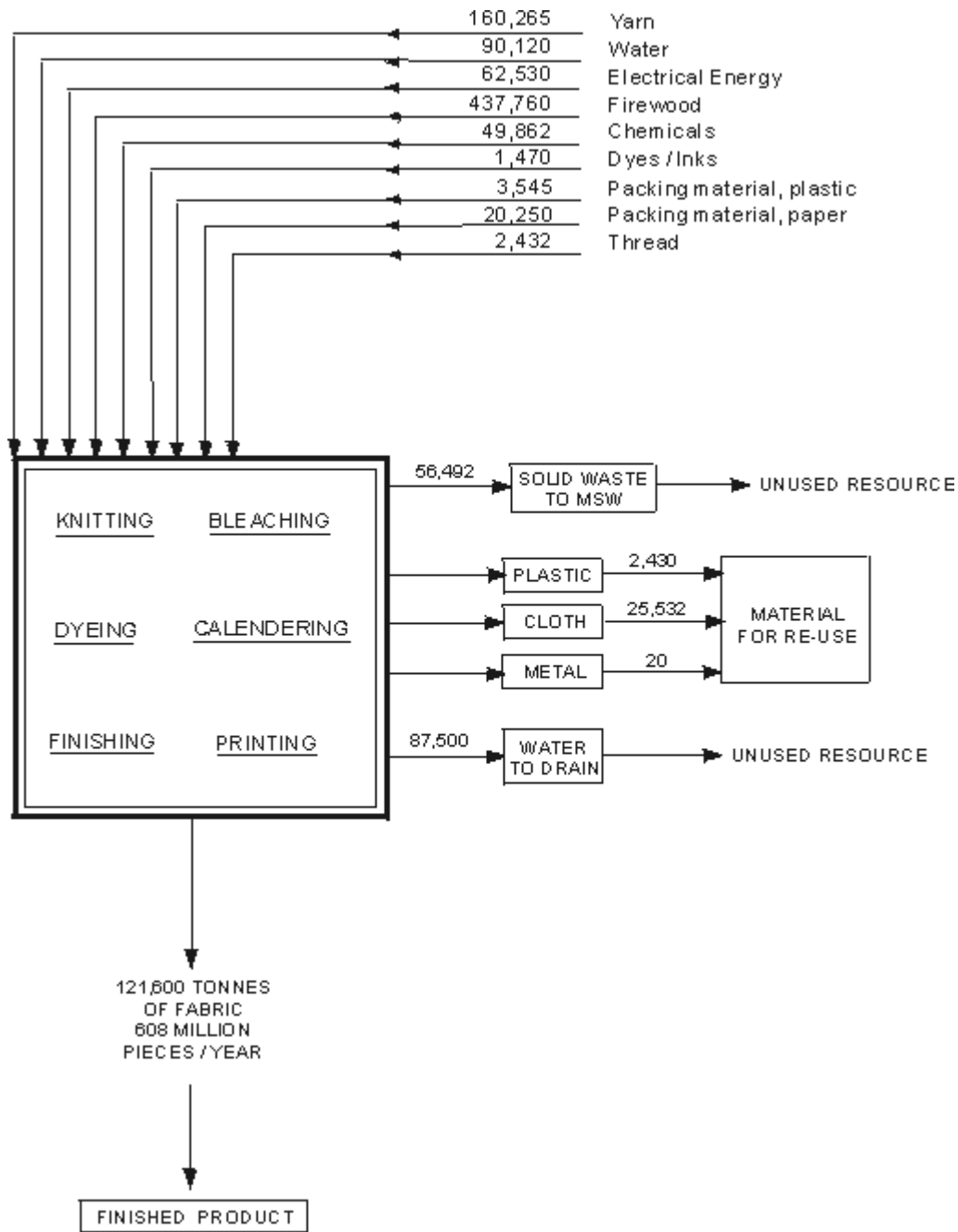
CASE STUDIES IN INDIA AND CONCEPTS

In structuring this paper, we have chosen to first present a gist of the case studies that we have undertaken and then present the concepts that have been derived from these cases. For the purpose of this paper, we have selected four case studies, which are to be presented with full details in a forthcoming book (20). Each case study illustrates either a format for analysis or a specific strategy option that has been the outcome of a particular resource flow study.

Case Study of Tirupur Town

A Resource Flow Analysis (RFA) was undertaken for the town of Tirupur, in the south of India, which stood as an example of how a Regional Resource Flow Analysis could be effectively used. The RFA for Tirupur is shown in Figure 2.

Figure 2: Resource Flow Analysis for Tirupur Town (units: water – thousand liters *per day*, electrical energy – thousand kWh per year, others – tons per year)



Tirupur is a major center for the production of knitted cotton hosiery. The town is located in the south of India and has a population of about 300,000. The 4000 small units in the town specialize in different aspects of the manufacturing process. The aggregate annual value of production in the town is around US \$ 700 million. Much of the produce is exported, bringing in very valuable foreign exchange.

Water is scarce in the area and the wet processing of textiles has rendered the ground water unusable. A large quantity of salt is used in the dyeing process and the process wastewater (90 million litres per day) is highly saline and is contaminated with a variety of chemicals. As there is hardly any source of fresh water nearby, water is brought in by trucks from ground water sources

(which are yet to be polluted) as far as 50 Kms away at an enormous cost. A massive US \$ 30 million project is under way to treat the wastewater at Central Effluent Treatment Facilities. After such expensive treatment, the water will still be unusable, as the facility does not include any system for desalination of the wastewater.

A detailed Resource Flow Analysis was carried out for the town. Only when the figures were aggregated did the industrialists realize that they were collectively spending over US\$ 7 million annually on buying water and in addition, the annual maintenance cost of the effluent treatment plant would be an enormous burden. The aggregate figures immediately showed that water could be recycled profitably. On the basis of the study, a private entrepreneur developed a water recycling system, which could be installed in each dyeing unit. The system used the waste heat from the boilers already working in the dyeing units for the recycling process. This is a relatively low cost system, which is gaining popularity in the town.

The second outcome of the study was that the study highlighted the fact that the calorific value of the solid waste (garbage) was high as it contained large quantities of textile and paper wastes. This could be used effectively to partially replace the 500,000 tones of scarce firewood being used in the town (there is grave concern over rapid deforestation in India). Since the use of the firewood is distributed over nearly 1200 points, it was not obvious that such large quantities of firewood were being used. The possibility of setting up a central steam source (needed by some of the industries) is also under serious consideration in order to reduce the consumption of firewood

Case Study of the Foundries in Haora

Industrial Ecology is often discussed in the context of a symbiotic relationship between different industrial units in a region. Hence, the concept of preparing an Industrial Ecology case study on the foundries in a region demanded a new thought process. While carrying out an Industrial Ecology study of the foundries, it is first essential to look at the processes connected directly with the foundries. However, this need not be a limiting factor and it is useful to look at the other activities in the region. Such interrelationships between different activities in the region can have far reaching implications on the strategy options for the available resources (See Figure 3).

There are nearly 500 foundries in Haora, a suburb of Calcutta, in Eastern India. The air pollution from the foundries has been a source of concern. The pollution control authorities have been insisting on the foundries installing pollution control systems to mitigate the pollution. The poor health of the engineering industry in the eastern region has affected the financial health of the foundries here, who now subsist on manufacturing very low value-added products like man-hole covers.

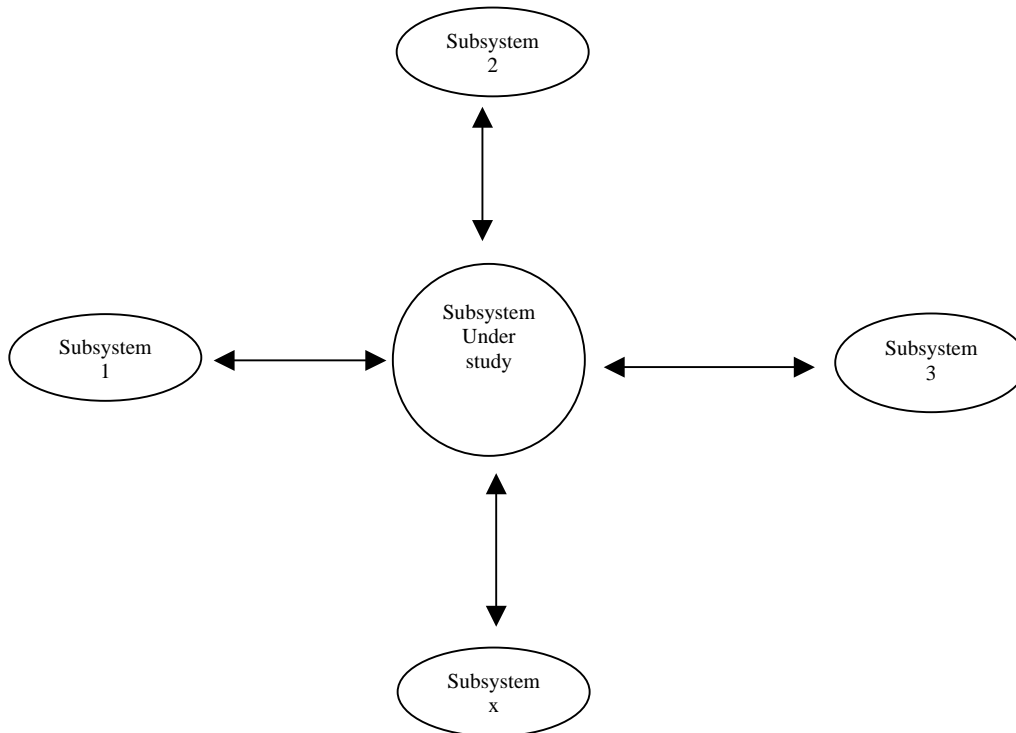


Figure 3 : Interrelationships Between Industrial Subsystems In A Region

A new technology for the use of Natural Gas instead of Coke in the foundries (coke is the main cause of pollution from the foundries) has been developed and it is likely that the authorities may insist on the foundries using the new technology to eliminate the pollution problem. However, since Natural gas is not available in the region, the use of this new technology could substantially increase the cost of production and the foundries would not be competitive.

A detailed study of the foundries and the region showed that the industry could adapt the new technology to use Coke oven gases instead of Natural gas. As the eastern region is a major coal-producing region and as there are many independent Coke ovens, Coke oven gas is easily available in the region and is often wasted. Depending on the economics, either the foundry could be relocated near the coke ovens or the Coke oven gases could be transported to the foundries.

Case Study of the Leather Industry in Tamil Nadu

This case study is intended to highlight the option of strategic relocation of an industry segment to ensure its long-term survival.

Tamil Nadu, a state in the south of India, is the premier center in India for the processing of leather. Water is extremely scarce in Tamil Nadu. The leather industry has been flourishing in the region for decades. Its growth has been possibly due to the fact that Madras was a major trading center during the British rule in India. The industry is a major foreign exchange earner and important to the economy of the state. The strict enforcement of environmental regulations in the developed countries have also helped the leather industry to grow, as the buyers in the developed countries prefer to source their tanned products from India. Compliance with strict environment regulations has rendered the processing very expensive in the developed world.

The leather industry (which is made up of thousands of small industries) is a major user of water, as each ton of hide/skin needs 30,000 to 50,000 litres of water for processing. This is a large volume, as the average per capita water availability for human settlement in India is estimated at around 30 litres per day. The industry has been under pressure from the pollution control authorities and many have subscribed to Central Effluent Treatment Plants. The water after treatment continues to be unusable, as it is very saline. The sludge from water treatment, estimated at 250 Kgs per 1000 Kgs of hide processed, continues to be a problem. The sludge is carelessly dumped and the pollutants leach into the groundwater. The industry often buys water in trucks at a high cost.

A detailed study in the context of Industrial Ecology helped in redefining the problem. The problem till now, was only viewed as a pollution control problem, where the effluents did not meet the specifications laid down by the Pollution Control Authorities. Many academic studies have been undertaken to ensure that the effluent quality "comes as close as possible" to the standards.

However, the problem is much more serious. The industry is using a resource, water, which is extremely scarce in the region. It is also contaminating ground water in the region, which is causing great hardship to the population, as it is depriving them of desperately needed water. The industry has been using the slow judicial process in India to survive. However, it will not be long before the social pressure brings the industry to a halt.

In the long term, an alternate solution will need to be found. One of the options that may be considered in the context of Industrial Ecology, would be to relocate the entire industry along the coast, where the industry draws sea water, desalinates it for use, treats the waste water and discharges the saline waste water into the sea. The process of desalination is expensive. In order to reduce the cost of desalination, it may be possible to set up a thermal power plant and use the waste heat for desalination. The sludge from the process could also be incinerated and the energy used in the desalination process (Figure 4).

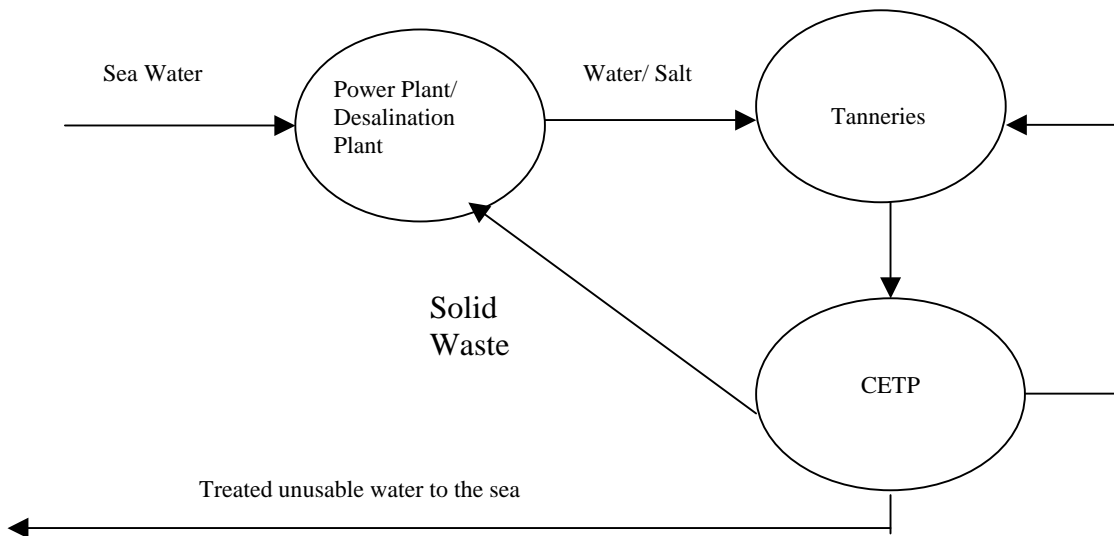


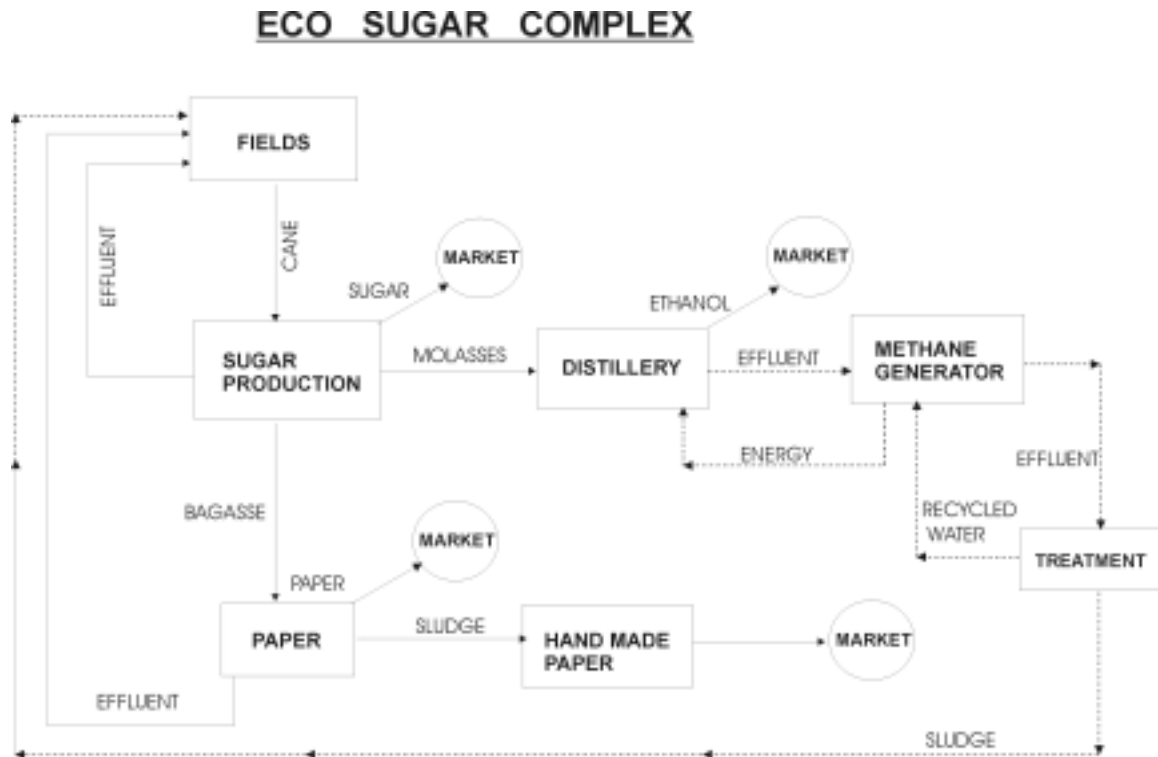
Figure 4: A Conceptual Picture Of An Ideal System built around the Leather Industry

Case Study of Seshasayee Paper and Board Ltd.

This case study illustrates growth strategy adopted by a corporate group, by which a majority of the wastes from one activity were used as a feed stock for another activity.

The company started a paper mill some years ago. In order to ensure regular supply of raw material, a sugar mill was set up. The waste from the sugar mill (called bagasse) was used as a raw material for paper-making. Another waste from the sugar mill, molasses, was used in a distillery for the production of ethyl alcohol. In order to ensure regular supply of sugarcane, the company took interest in the cultivation of sugarcane by organizing the farmers in the region. The company struck long term agreements with the farmers to buy back their produce and in turn, took the responsibility of supplying them with water. Part of the water supplied for cultivation was the treated wastewater from the manufacturing operations. The company also used bagasse pith (a waste after the paper making) and other combustible agricultural wastes in the region, as an energy source. This example could be viewed as an Agro Industrial Eco-complex. A diagrammatic representation is shown an eco-sugar complex in Figure 5

Figure 5



CONCEPTS FROM THE FIELD STUDIES IN INDIA : NEW APPROACHES FOR DEVELOPMENT PLANNING

From this new perspective, the approaches to development planning in a defined socio-economic system (maybe a city, state, country or a clearly defined region) could involve:

- Analyzing the "flow of resource" through the system
- Redefining issues from the context of "resources"
- Setting priorities for action and identifying resources, the uses of which are of immediate concern
- Doing a detailed analysis of the utilization of identified critical resources
- Preparing a strategic plan for optimizing the use of the selected resources

Material Flow Analysis

In the context of development planning, especially when the object is to optimize the use of scarce resources, "Material Flow Analysis" (MFA) could be referred to as "Resource Flow Analysis" (RFA).

Analysis of the flow of materials and energy used in an economic system, which includes the quantity of resources used, the way they are used and the impact of their use on the local environment could form the corner stone for planning. An analysis of the flow of resources could generate criteria on the basis of which a development agency could plan development work in a region.

In Figure 6, we present a possible framework within which the issues may be discussed. The purpose of the illustration is to depict the "flow" of resources through the socio economic system. Land has been specifically included as an important resource, the "flow" or use of which by different economic sectors needs careful and critical examination in view of the high population density in many developing countries and consequently high demand from different sectors of the economy.

One of the aims of a resource based development plan could be simply to ensure that the total flow of resources, particularly scarce resources or resources whose use or disposal is harmful, are optimized. This can be achieved in the following ways:

- by eliminating the use of such resources
- by reducing use of such resources using lighter or benign materials which perform the same function,

FLOW OF RESOURCES IN AN ECONOMIC SYSTEM

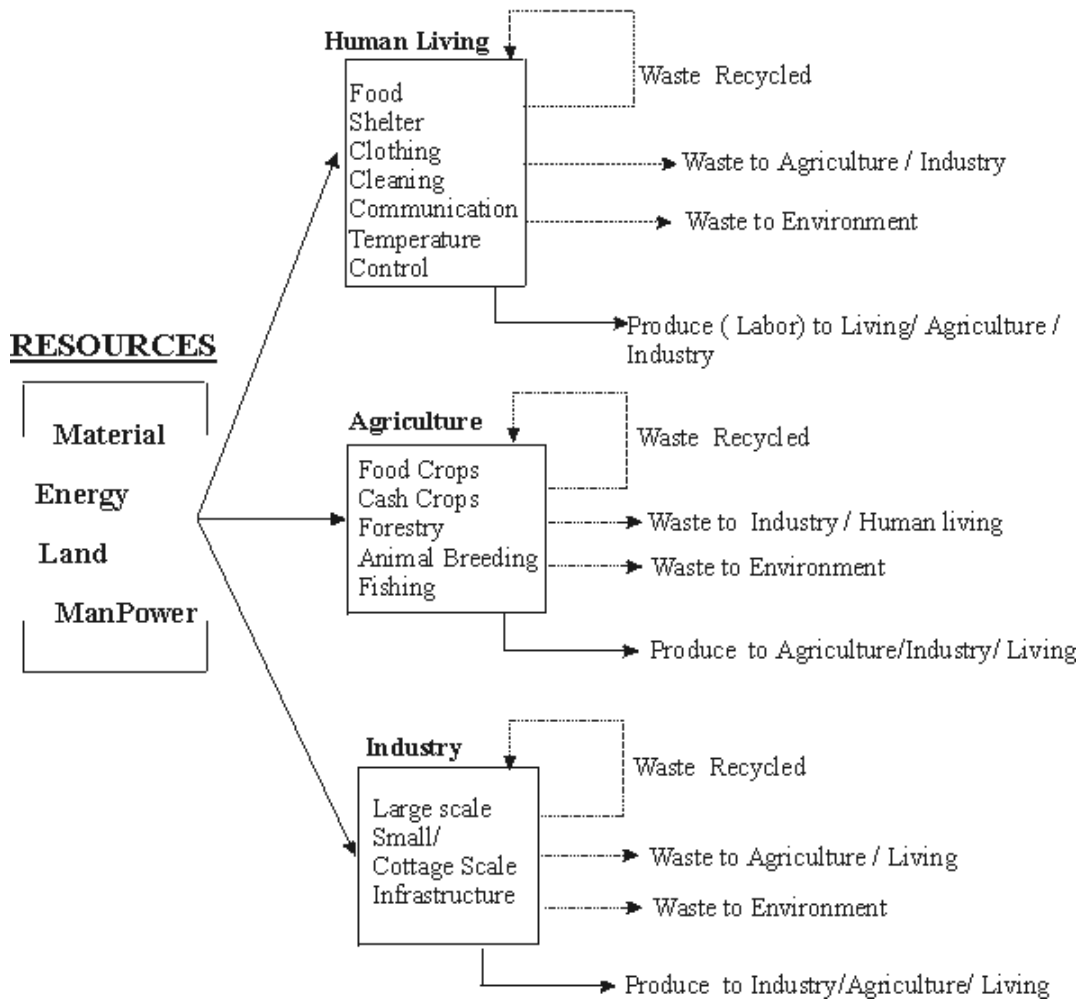


Figure 6

- by recycling the wastes so that the same quantity of resources are made to perform their function many times before being discarded into the environment, thereby increasing the productivity of the resources
- by substituting with a resource whose efficiency is better and hence its use and the consequent flow of wastes to the environment is minimal.
- by substituting the use of such a resource with one whose availability is "interminable" (at least from the human perspective), such as solar or wind energy
- While discussing the subject in the context of a developing country, three aspects of the issue need to be separately addressed:
 - The total quantity of resources
 - The method of use of the resources
 - The impact of the method of use and disposal on the local population and ecosystem.

Total Quantity:

Although the per capita consumption of individual resources in a developed country like the US may be far greater than in a developing country like India, the sheer size of population in India makes the quantities large enough to cause concern. Secondly, the quantities of different

resources used in a resource-starved economy should be viewed as a proportion of the total per capita availability of the resource in the region.

Method of Use:

The method of use of different resources in a developing country is very different from that in a developed country. Very often, the processes adopted in the developing countries in the use of resources in households, agriculture or industry are outdated and are wasteful. Their scales of operations being small, it is difficult to adopt better methods, which are often capital intensive.

The use of these resources is also very dispersed over very large number of points, which makes control difficult. For example, in many parts of India, coal is used as a fuel in households, in a number of very small/ cottage industries as well as in the large industries. As the number of usage points is too large, any monitoring or control of the use of coal is fairly complex.

Impact on the local Environment:

The impact of the use and disposal of materials in a developing country could be quite different from that in a developed country. This is partly because of a lesser awareness of issues concerning health hazards, inadequate systems of law making and enforcement and lack of a proper civic infrastructure.

Regional Resource Flow Analysis (RRFA)

As mentioned earlier, to understand the flow of resources in a selected geographical region, the preparation of a Regional Resource Flow Diagram as shown in Figure 1, could be useful. This would show clearly the quantitative inputs of resources into the selected region and outputs from the region, both as wastes to other geographical regions for reprocessing or as waste to the environment, in addition to the end products for sale or consumption.

A figure such as this would immediately give a detailed quantitative account of the flows of different resources in the area. Without such an analysis, it is often difficult to get a quick assessment of the issues of importance in the area. This is particularly so in a developing country where many of the resources are used by a number of small and cottage sector industrial units or in households. Since the use of these resources is distributed over a large number of points, the consumption of the resources is often not obvious. For example, it is easier to notice and estimate the volume of waste in a large waste dump rather than litter in a city, although the litter when collected could be twice as voluminous as the dump.

If it is required to establish priorities for action, from the point of view of development fund requirement, the first step could be to prepare a Regional Resource Flow Diagram, which would clearly indicate the resources that are of significance in the region. Since the consumption figures of all the resources are clearly quantified, it will be easy to assess the relative importance of any resource in the region.

Against each resource which is an input into the region, the only questions that needs to be asked are:

1. "Is the resource scarce in the region?"
2. "Is the availability of the resource likely to be a problem in the future"
3. "Is the use of the resource likely to do any damage to any other resource?"
4. "Can the resource be more profitably utilized in the sphere/segment or can it be put to more profitable use?"

The case study of the Tirupur industrial cluster, presented above, serves as an example of the use of this method as a planning tool.

Redefining Problems

Once a quantitative analysis is available of the "flows" of different resources in the region, it may be necessary to redefine problems from the perspective of resource utilization. For example, it is often said that the liquid effluent from a particular industry does not meet the norms laid down. The same issue could be redefined to say that the industry is using water (which is often a scarce resource) and the effluent from the industry is spoiling another resource of the region (it could be land, or ground water, for example). The reason for such a redefinition is that if the effluent is not affecting any other resource of the region, it is not of much consequence and hence not a major problem. However, if the resource that the industry is using is a scarce resource and if the industry is causing damage to another scarce resource in the region, it needs immediate attention. Hence problems have to be viewed specific to a location.

The case study of the leather tanning industry in Tamil Nadu, highlights this issue. The case study is also illustrative of how redefining a problem can change approaches to development planning.

Setting Priorities:

Based on a study of a Regional Resource Flow Diagram, it is possible to identify and prioritize the resources, which need more detailed attention.

If the analysis of the regional resource flow has to translate into an action plan, priorities have to set for action. If action is to be initiated, the aspects that need to be studied are:

- Is action needed?
- Which particular sector needs it?
- Is action possible?
- The consequences of any action.

While setting priorities, it is necessary to prioritize areas where action will yield results. Hence the results indicated by a Regional Resource Flow Diagram may need to be read in conjunction with many other factors. Some of the factors for consideration are listed below:

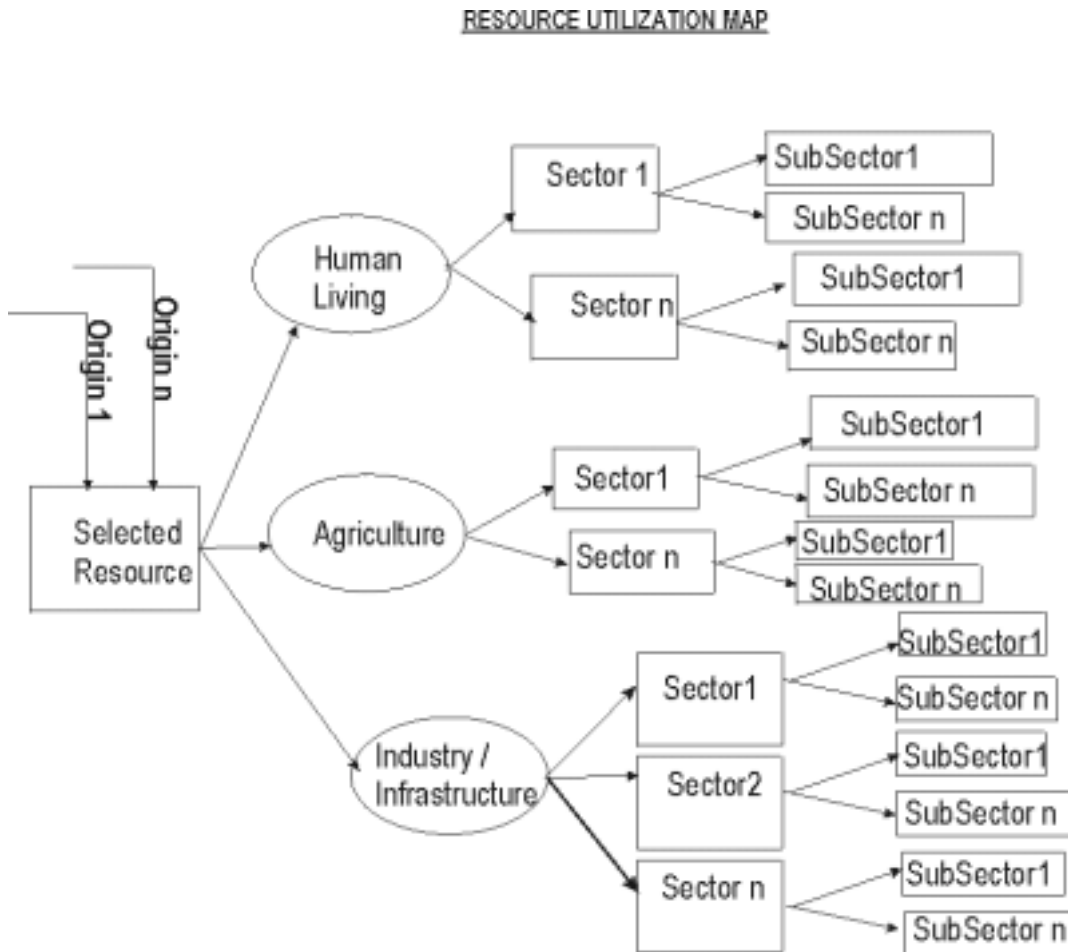
1. The Government Policy and the legal framework
2. The ease of availability of different materials in the region
3. The relative importance of the produce of the region for the state/ country
4. The price sensitivity of the produce of the region
5. Financial health of the industry
6. The taxation system and the system of industrial financing
7. The costs of production of businesses and the relative importance of the costs of different materials in the operation
8. The investments in production capacity build up, the economies of scale and the relative cost of pollution prevention or abatement
9. The level of technology and the attitude to acceptance of new technologies
10. The inter-relationships within the different economic/ business entities in the region and the role of "opinion leaders" who could influence change
11. The society and its influence on the economy of the area including the presence of environment activists, attitudes of labor, work ethics etc
12. The relationship of business with the community

Resource Utilization Map (R U M)

Having set priorities and selected the resources for closer scrutiny, it is necessary to analyze in greater detail, how the particular resource, which has been selected as a priority is used in the identified region. The questions that need to be answered are:

- Who are the people using the resource?
- Can the usage be optimized?
- Can the users find an alternative resource?
- Can the resource be harnessed in a better way (water harvesting techniques, for example)
- Can the users be removed from the system or region?

Figure 7: Resource Utilization Map



Preparation of a Resource Utilization Map on the lines depicted in Figure 7 could provide a coherent framework to answer these questions.

It is important to understand as much as possible the behavior of each category of users of the resource: what they use it for and how much they use. This understanding could be used effectively to plan strategy to optimize the use of a resource.

Any Strategic Resource Management Plan needs to take into account the following elements:

1. A very clear definition of objectives
2. Possible options to achieve the goal
3. Optional action plans
4. The cost assessment of each action plan & time frame
5. Likely consequences/ results of each option
6. Evaluation of options
7. Selection of a specific action plan
8. Setting time-bound action goals
9. Evolving a system of evaluation of progress

A clear definition of objectives can be aided with the help of the figures generated through the RRFA and the RUM. What could be interesting in the context of Industrial Ecology would be to discuss the kind of strategy options that are generated.

Possible Strategy Options

1. Use Resources, Which Are Wasted (Close the Material Cycle)

A study of Figure 1 (Regional Resource Flow Diagram), gives a lead to the quantity of different resources that are put out to the environment from a given geographical region. This data could be used to develop new economic activity or an industrial undertaking, which would make use of these wastes. As mentioned earlier, especially in developing countries, as the usage of the different materials is spread thinly over many points, the wasted resources are often not very obvious (as was shown in the case study of the textile cluster in Tirupur).

There is another example from the city of Chennai in South India. The action by the city administration, is an example of how the wastes are identified and channeled as a resource for another economic activity. Some of the industries have been asked to recycle the city's sewage to cater to their water requirements. This has partially solved the problem of the treatment of the sewage as well as taken care of the fresh water requirements of the industries. The cost of the sewage treatment has been internalized in the operations of the industry.

2. Plan Integrated "Closed Material Cycle" Economic Activity

If a new industrial area or an industrial estate is planned (for example), it may be possible to plan the types of industries that are set up in such a way that the waste of one unit of in the area is a feedstock of another unit. Hence the individual industries in the cluster become partners in a quasi-closed cycle. This replication of the Kalundborg model is attempted in the planned Eco Industrial Parks (EIP) or Networks (EIN).

3. Reduce Or Eliminate Utilization Of Selected Critical Resources

Reduction in resource consumption could be achieved by either a change in technology or by improving efficiency with the same technology. A good example of changing technology to eliminate use of a material is the Chlor Alkali industry. The industry has progressively shifted from the old mercury cell process to the membrane technology which has not only eliminated the use of mercury but has also proved to be more economical. Similarly, waste minimization programs could be specifically planned to achieve clearly laid down targets for the region.

4. Recycle Materials within The Same User Sector

A targeted industry could recycle their own wastes, which will help them reduce their use of resources. The generation of methane from the wastes in a distillery to completely take care of their own energy need is a good example of this method. The Government of India has made it mandatory for the distilleries to install methane generation plants to minimize the industry's energy needs.

5. Strategically Relocate Industries Which Use Up Critical Resources

Due mainly to historical reasons, many industries grow in area where their resource requirements are quite incompatible with resource availability in the region. Very often, since resources are not costed on any rational basis (other than the capacity of the citizenry to pay), the industry continues to survive. In that case, it may be necessary to relocate the industries in such a way that they find a new source to meet their resource requirements.

CONCLUSIONS

We feel that the case studies presented above, and the methodological concepts derived from them, offer a number of perspectives for policy makers:

- This methodology is intended to allow developing countries to map flows of materials through their entire economic system. This will show what the critical resources are.
- From such a model, the loose ends are very obvious and immediately give an indication of unused or under-utilized resources.
- In specific instances, this information can be used for planning integrated industrial complexes
- This methodology is relevant for various scales: local, regional, national.
- Such studies of different activity groups can be aggregated to provide an overall picture of material flows in a region. Based on this, the planners can consider promotion of industries in specific sectors which would optimize the use of critical resources.
- Information and understanding generated by material flow analysis can be used as a tool for planning socio-economic development. Such a tool can be useful for either local and regional Government, or for international development agencies and financial institutions.

Finally, from the point of view of the business, such case studies serve two purposes. Firstly, they can offer new options for the industries who are under great pressure from the Government authorities charged with controlling environmental pollution. Secondly, these can expose the companies to the larger picture and made them aware of the total quantum of materials used in a cluster, a zone or a region. As large numbers of small manufacturers use the materials, an aggregation such as shown, can be revealing and may become a catalyst for action. Even more importantly, such data can reveal new business opportunities. Also, the knowledge of the opportunity for better use of resources could become of interest to the companies, in the context of globalization and increasing competition from neighboring countries.

REFERENCES

- (1) United Nations Environment Programme and World Business Council for Sustainable Development: Cleaner Production and Eco-efficiency - Complementary Approaches to Sustainable Development. UNEP / WBCSD, 1998.
- (2) Allenby, Braden R.: Industrial Ecology - Policy Framework and Implementation. Englewood Cliffs, N.J., Prentice Hall, Inc., 1999.
- (3) Allenby, Braden R. and William E. Cooper: Understanding Industrial Ecology from a Biological Systems Perspective. Total Quality Environmental Management. Vol. 3, N° 3, pp. 343-354, 1994.
- (4) Graedel, Thomas E.: On the Concept of Industrial Ecology. Palo Alto, CA, Annual Review of Energy and the Environment, Vol. 21, pp. 69-98, 1996.
- (5) Frosch, Robert A. and Nicholas E. Gallopoulos: Strategies for Manufacturing. Scientific American, Vol. 261, No. 3, pp. 94-102, September 1989 (Special Issue on «Managing Planet Earth»).
- (6) Allenby, Braden R. and Deanna J. Richards(eds.): The Greening of Industrial Ecosystems. Washington, D.C., National Academy Press, 1994.
- (7) Frosch, Robert A.: Toward the End of Waste: Reflections on a New Ecology of Industry. In: Technological Trajectories and the Human Environment, edited by J. H. Ausubel and H. D. Langford. Washington, DC, National Academy Press, 1997.
- (8) Ayres, Robert U. and Leslie W. Ayres: Industrial Ecology. Towards Closing the Materials Cycle. Cheltenham, UK, Edward Elgar, 1996.
- (9) Erkman, Suren: Industrial Ecology: An Historical View. Journal of Cleaner Production, Vol. 5, N° 1-2, pp. 1-10, 1997.
- (10) Baccini, P. and P. H. Brunner : Metabolism of the Anthroposphere. Berlin, Springer Verlag, 1991.
- (11) Brunner, Peter H. and Paul Baccini : Regional Material Management and Environmental Protection. Waste Management & Research, Vol. 10, pp. 203-212, 1992.
- (12) Stigliani, William and Stefan Anderberg: Industrial metabolism at the regional level: The Rhine Basin. In: Industrial metabolism: Restructuring for sustainable development, edited by R. U. Ayres and U. E. Simonis. Tokyo, United Nations University Press, 1994.
- (13) Adriaanse A. et alia : Resource Flows: The Material Basis of Industrial Economies. Washington, DC, World Resources Institute, 1997.
- (14) Gertler, Nicholas and John R. Ehrenfeld : Industrial Ecology in Practice. The Evolution of Interdependence at Kalundborg. Journal of Industrial Ecology, Vol. 1, N° 1, pp. 67-79, 1997.
- (15) Nemerow, Nelson L. : Zero Pollution for Industry. Waste Minimization Through Industrial Complexes. New York, John Wiley & Sons, 1995.

(16) UNEP : The Environmental Management of Industrial Estates. UNEP-DTIE Technical Report N° 39, Paris, 1997.

(17) Fritz Balkau : Managing Environmental Issues in Industrial Estates: An Application of Industrial Ecology, August 1997. Source: www.uneptie.org/ipman/papestat.html.

(18) Ray Côté and Fritz Balkau : Environmental Management Systems for Industrial Estates - A Discussion Paper, April 1999. Source: www.uneptie.org/ipman/emspap.html.

(19) Ernest A. Lowe, Steven R. Moran and Douglas B. Holmes : Eco-Industrial Parks - A Handbook for Local Development Teams. Oakland, CA, Indigo Development, 1998. (<http://www.indigodev.com>)

(20) Erkman, Suren and Ramesh Ramaswamy: Industrial Ecology as a Tool for Development Planning. Case Studies in India. New Delhi and Paris: Sterling Publishers, forthcoming (2001).