Journal of Cleaner Production 17 (2009) 653–661

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Eco-industrial park development in Rio de Janeiro, Brazil: a tool for sustainable development

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ARTICLE INFO

Article history:
Available online 19 December 2008

Keywords:
Eco-industrial parks
Sustainable development
Industrial ecology
Industrial symbiosis

ABSTRACT

The development of eco-industrial parks (EIPs) is an emerging concept that is being spread worldwide as a new industrial model that can reconcile the three dimensions of sustainability: social, economic and environmental. In Rio de Janeiro, Brazil, EIPs were launched through formal legislation as a means to foster sustainable development and to ameliorate the distress caused by unplanned urban and industrial development. The objective of this study is to present and analyze the development of EIPs in Rio de Janeiro, focusing on two of the initiatives launched. We argue that Rio de Janeiro has the potential for developing a sustainable industrial system through EIP implementation, but the continuity of EIPs will only be successful if there is convergence of interests among the actors involved.

1. Introduction

The concept of sustainable development[1] gained worldwide recognition in 1992 at the World Environment and Development Conference (ECO-92), during which many socio-environmental directives were established. These directives called for the adoption of sustainable development principles by the participating nations, in other words, the adoption of political and management strategies that focus on balancing environmental integrity, social equity and economic efficiency, the three "Es" of sustainability [1].

Despite its increased prominence in recent years, sustainable development still faces a number of challenges, both in developed and in developing and newly industrialized nations (DN/NIN). Even with international and government institutional efforts it has proven hard to transform the sustainable development concept from rhetoric into reality. The emphasis has been on the linkages between the economy and the environment, with much less attention being paid to the social or community dimensions of sustainability.

The establishment of eco-industrial parks (EIPs) is a concept that is being spread in many nations as a new industrial model that can reconcile the three dimensions of sustainability, as it reorganizes industrial practices and activities in order to meet sustainable development goals. This mutual benefit to the community, economy and environment is clearly stated in the definition of the EIP concept.

An EIP is defined as "*a community of manufacturing and service businesses located together on a common property. Member businesses seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of individual benefits each company would realize by only optimizing its individual performance. The goal of an EIP is to improve the economic performance of the participating companies while minimizing their environmental impacts. Components of this approach include green design of park infrastructure and plants (new or retrofitted); cleaner production, pollution prevention; energy efficiency; and intercompany partnering. An EIP also seeks benefits for neighboring communities to assure that the net impact of its development is positive.*" [2]. This definition is broadly accepted by major authors in the eco-industrial development field [3–6].

In North America and Europe there are many EIP projects being implemented, many of them already operating. In the USA, classic examples found in the literature are Brownsville/Matamoros, Texas/Mexico; Chattanooga, Tennessee; Civano, Arizona; Fairfield, Maryland; Burlington, Vermont, Londonderry, New Hampshire; Phillips Eco-Enterprise Center, Minnesota; Red Hills EcoPlex, Mississippi, etc. [7–9]. In Canada we can mention Alberta Industrial Heartland, Alberta; Bruce Energy Center, Ontario; Burnside

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[1] Brundtland Report – *Our Common future* – definition (World Commission on Environment and Development, 1992). In this definition the term "Sustainable Development" in itself links the two concepts of "environment" and "development", and it refers to "development seeking to meet the need of the present generation without compromising the ability of future generations to meet their own needs. It aims at assuring the ongoing productivity of exploitable natural resources and conserving all species of fauna and flora."

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doi:10.1016/j.jclepro.2008.11.009

Industrial Park, Nova Scotia; Montreal East, Quebec; Sault Ste. Marie, Ontario; Vancouver, British Columbia; etc. (see Refs. [9,10]).

Finally, in Europe, major initiatives are Bioenergie und Rohstoffzentrum Dormagen, Germany; Closed Project, Tuscany, Italy; Crewe Green Business Park, Cheshire, United Kingdon; Karlsruhe EIP, Germany; Eco-park Moerdijk, Netherlands; Eco-park Oulu, Finland; Ecosite du Pays de Thau, France; EcoTech Centre, UK; Environment Park, Italy; Folkecenter for Renewable Energy, Denmark; Hartberg Oko Park, Austria; London Remade Eco-Industrial Site, UK; Parc Industriel Plaine de L'Ain, Lyon, France; Styrian Recycling Network, Austria; Rotterdam Harbour Industrial Ecology Project, Netherlands; Stockholm Environmental Science Park, Sweden; and Sustainable Industrial Park, UK [11]. In Oceania, the first EIP planned is in Australia, the Synergy Park [12].

In the same way as in developed nations, the EIP concept is being spread in developing and newly industrialized nations (DN/NIN) as a way to foster sustainable development. In some Asian and Latin American nations, the rapid industrialization process has increased resource consumption and environmental degradation [13,14]. In these nations, particularly in China [13,15], Singapore [16], Thailand [17], South Korea [18,13], India [19,20], Colombia [21], Puerto Rico [22,23,14] and Brazil, among others, EIPs are being considered a possible way to overcome environmental damage and at the same time to improve industrial and community economic and social welfare and development. Other Asian nations that are implementing EIP initiatives are the Philippines, Indonesia, Malaysia, Japan, Taiwan, Vietnam, Singapore, and Sri Lanka [13,24].

In Brazil, the state of Rio de Janeiro is struggling to find alternative ways to realize sustainable development. Facing a negative heritage of unsustainable economic growth experienced in the last twenty years, Rio de Janeiro's development reflects a picture of high urban and industrial concentration, an increasing number of land conflicts, the construction of important highways and infrastructure projects and deterioration of major environmental areas. The industrial settlement in Rio de Janeiro reflects its disorderly development, shown by tightly clustered industries outside industrial zones, as well as the occupation of industrial zones for other purposes, mainly residential [25].

In addition, the absence of proper integrated waste management practices instead of only end-of-pipe solutions has contributed to severe environmental damage. This situation prompted the state government to launch the EIP program as a means to foster sustainable development, to ameliorate the environmental, economic and social distress caused by unplanned urban and industrial development.

2. Industrial ecology and industrial symbiosis: key concepts underlying the eco-industrial park idea

Industrial ecology (IE) has emerged over the past years as a potential guide to create opportunities for improving environmental and business performance, and for restructuring the industrial system in compatible fashion with notions of sustainability. Frosch and Gallopoulos [26] first discussed the concept of industrial ecology in 1989, in the article "Strategies for Manufacturing". IE looks at the flows of natural resources from extraction through manufacturing, product use, reuse, and return to the environment and examines the combined effect of all these steps on the environment [27]. As Gertler [28] states, if materials were cycled through industrial systems as they are in natural ecosystems, then the byproducts of one process would become the feedstock of another and the concept of waste would cease to exist. The current production process, particularly in DN/NIN, usually does not take IE principles into consideration, resulting in wasteful natural resource consumption and in major environmental and social damages [12].

Cleaner production (CP) is a field of research and practice that overlaps with IE, sharing common objectives and principles (see Refs. [29–35] for details). As Pauli [35] said "The ultimate goal of CP is thus zero waste. This moves industry from pollution prevention and control into the new paradigm that is to become the industry standard. Clusters of industries, where the waste of one is input for the other, will emerge as the solution." IE and CP can be considered the foundations for EIP.

Since the introduction of IE and CP, the industrial symbiosis (IS) concept has been put in a new perspective. The term "symbiosis" designates relationships in nature in which at least two otherwise unrelated species exchange materials, energy or information in a mutually beneficial manner, thus taking advantage of synergies [36].

Chertow [5], in her article "Industrial Symbiosis: literature or taxonomy" defines the concept of IS as: *"Industrial symbiosis, as part of the emerging field of industrial ecology, demands resolute attention to the flow of materials and energy through local and regional economies. Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity."* The success or failure of IS depends on the industrial mix, byproduct availability, resource demands, management structures, institutional linkages and the regulatory climate [28]. EIPs are a major application of the IE and IS concepts.

The classic example of IS found in the literature is Kalundborg, in Denmark (see Ref. [28] for a detailed history). As Sterr and Ott [37] stated, Kalundborg's symbiosis was driven by market forces. The physical linkages and economic feasibility resulted from bilateral agreements without participation of external forces. This initiative illustrates that industry can coexist with nature in a more benign manner, generating bottom-line benefits for industries, the surrounding community and the environment.

In recent years, attention to EIP development has grown among governments, academia and industries in many countries. The major force behind the EIP idea is that it yields better economic, environmental and social results than do industries acting independently. As an EIP is planned, designed and operated, its main characteristics are built. The literature emphasizes waste exchange as a major feature of EIP development. This is an important element, but if the goal is sustainability a more comprehensive perspective involving economic, social and ecological aspects is necessary [5,15].

Based on particular local conditions, an EIP may yield major benefits for the community, environment, business and government, as described by Lowe [2], Schlarb [6] and Mitchell [38]. These benefits [2,6,38] are incentives for industries to start the process of improving their market image, competitiveness and environmental performance. Superior environmental performance can result in greater cost competitiveness and boost revenues for industries that are part of the EIP, and thus drive more wasteful competitors out of business [4].

EIPs exist in many forms [5]. A distinction should be made between eco-industrial parks (EIPs) and eco-industrial networks (EINs). As Starlander [36] explained, in an EIP industries are concentrated in industrial clusters, while in EINs the industries involved are spread over a region. Hence, EIPs entail a much higher degree of geographic proximity, and some sort of coordination of the tenants. On the other hand, EINs are considered as providing increased synergy possibilities, as they allow for a greater diversity of actors, and as a consequence a greater diversity of byproducts and wastes. Regarding EIPs, a distinction should be made between EIPs that are built in an existing industrial district, thus with existing industries, where some sort of relationship already exists, and EIPs that are planned and developed from scratch (greenfield development).

3. EIP development in Rio de Janeiro: success or failure?

3.1. Rio de Janeiro's industrial settlement

Development, generally meaning industrialization, is a priority for developing nations (DN) and newly industrialized nations (NIN). However, development is usually linked to economic growth, which is given a higher priority than preserving the environment and natural resources.

As in many DN/NINs around the world, industrialization has brought wealth and development to Rio de Janeiro state; however it has also brought many externalities. One of these externalities is the high level of industrial concentration, resulting in increasingly urban concentration, the damage and destruction of many environmental areas and in a high level of soil, air and water pollution [39].

The Rio the Janeiro Metropolitan Area (RJMA)[2] is the state region in which the majority of the industries are located. The data presented in Table 1 compare RJMA and RJ state in order to show its relevance to the state's economic development.

Table 1 shows that 74% of RJ state's population and 65.9% of its GDP are concentrated in an area corresponding to 10.7% of the state's landmass.

The RJMA Industrial Zoning System was established by State Law 466 in 1981, which defined and delimited three different categories of industrial zones: Strictly Industrial Usage Zones (SIUZ), Predominantly Industrial Usage Zones (PIUZ) and Diversified Usage Zones (DUZ). According to a study conducted by Rio de Janeiro Federal University and the Brazilian Institute of Municipal Administration (COPPE–UFRJ–IBAM) [39], RJMA has 56 industrial zones, 11 of which are SIUZs and the remaining 45 are PIUZs.

According to records of the Rio de Janeiro Information and Data Center [40], Rio de Janeiro state has a total of 21,787 industries; out of which 14,158 are transformation industries,[3] as shown in Table 2. Considering just the transformation industries, 9544 are located in RJMA, meaning that 65% of the transformation industries are located in an area corresponding to 10.7% of the entire state. Regarding the state's breakdown of industrial sector activities, 28% are chemical industries, 24% are metallurgical and the remaining 48% are distributed among other industrial sectors. In RJMA, 18% are chemical industries, 13% are metallurgical firms and the remaining 69% are distributed among other industrial sectors. Table 3 gives an overview of this distribution in the state and in RJMA.

As Magrini and Montez [25] explain, only 20% of RJMA's transformation industries (1908 out of 9544) are located inside the 56 industrial zones. This heavy industrial concentration outside the industrial zones (80%) is compromising the region's environment and the community wealth. RJMA's industrial settlement configuration reflects its disorderly development, shown by tightly clustered industries built outside industrial zones, and the use of areas defined as industrial zones for other purposes, mainly residential.[4] Problems related to industrial location in RJMA can be attributed mainly to incapacity of public policies, fragmented administration and the high and largely unregulated urban population concentration, typical of developing nations. As a result, RJMA is facing serious environmental problems that are not only affecting people's quality of life but also inhibiting the region's development.

Table 1
A comparison between RJ state and RJMA.

	RJ State	RJMA	RJMA/RJ state (%)
Municipalities	92	17	18.5
Area	43,864.3 km^2	4688.5 km^2	10.7
Population	14,961,513	11,078,208	74
GDP	R$ 220 million	R$ 145 million	65.9

Source: Ref. [40].

The COPPE–UFRJ–IBAM [39] study indicated the following results: 9 zones showed prospects for industrial expansion, 17 offered no prospects for industrial expansion and 30 still offered possibilities for expansion, but are dependent on environmental/urban planning and/or location related aspects. Reversing this scenario is surely a long-term process. However, one possibility would be to reshape these 39 industrial zones to convert them into EIPs, as shown in Table 4. The diversity of existing industries would facilitate the development of possible synergies.

The heavy industrial concentration in RJMA has also resulted in an increase in the amount of byproducts and wastes generated. How to better dispose of waste economically without degrading the environment is another problem. The lack of sufficient public funds, waste inventory and waste management and treatment practices, particularly by small and medium sized (SMS) industries, severely limits the range of options. Proper waste management practices could help to protect the environment and when properly planned, could save considerable disposal fees. It is worth mentioning that the only industrial landfill and industrial waste incinerator in the state is owned by Bayer Corporation, located in Belford Roxo municipality.

In 2005, the report entitled "Brazilian States' Solid Waste Panorama" [41] revealed that 87% of Rio de Janeiro state's industries have problems in managing solid waste and that only 39% of them make use of waste from other industries. The total amount of hazardous industrial waste generated in Rio de Janeiro state has reached 293,953 metric tons a year and non-hazardous industrial waste 5,768,562 metric tons a year [41].

The above picture demonstrates that Rio de Janeiro state's "industrial scenario" is eroding, not only the physical environment but also the foundation for production and thus the basis for growth. This is emphasized by the realization that the environment is increasingly a competitive factor in location decisions. The question is how to improve natural resource protection, community well being and at the same time to maintain economic development.

Even if only in the long run, a mechanism should be implemented to reshape RJMA's industrial settlement configuration and to improve its environmental quality and the community's wealth. As previously stated, one possible alternative would be the development of EIPs. Two possibilities in this respect are the conversion

Table 2
Rio de Janeiro industries by sector.

	Industrial sector				
	Mineral extraction	Transformation	Public utility	Construction	Total
Rio de Janeiro State	522	14,684	373	6208	21,787
RJMA	178	9544	201	4053	13,976

Source: Ref. [40].

[2] The RJMA was created in 1974 by State Law 20. The municipalities that are now part of RJMA are: Duque de Caxias, Itaboraí, Magé, Nilópolis, Niterói, Nova Iguaçu, Paracambi, Rio de Janeiro, São Gonçalo, São João de Meriti, Belford Roxo, Mesquita, Japeri, Queimados, Guapemerim, Seropédica and Tanguá. [40].

[3] The transformation industrial sector is composed of: chemicals, metallurgy, pharmaceuticals, foods and beverages, transportation material, printing, rubber products, machinery and equipment, textiles, wearing apparel, non-metal products, plastic products, medical equipment, hygiene products, electro electronic material, wood and furniture, pulp and paper, bijouterie, phonographic products, and footwear [33].

[4] A common pattern is for *favelas* (shantytowns) to arise around industrial areas, or be interspersed among them.

Table 3
Major industrial sector activity distribution in RJ state and in RJMA.

Transformation industries		
Industrial sector	RJ state, percentage of total	RJMA, percentage of total
Chemicals	28.15	18
Metallurgy	24.17	13
Pharmaceuticals	6.21	69
Foods	5.98	
Beverages	5.82	
Transportation material	5.64	
Printing	4.41	
Rubber products	3.20	
Machinery and equipment	2.76	
Sundry industries	2.66	
Non-metal products	1.91	
Plastic products	1.52	
Medical equipment	1.44	
Hygiene products	1.43	
Textiles	1.07	
Clothing	0.95	
Electro electronic material	0.79	
Wood and furniture	0.75	
Pulp and paper	0.52	
Bijouterie	0.49	
Phonographic products	0.08	
Shoes	0.06	
Total (14,684)	100	100

Source: Ref. [40].

of extant industrial zones into EIPs and planning new industrial zones at greenfield sites based on industrial ecology and EIP principles and strategies. EIPs would help society make progress toward sustainable development by increasing productivity of resource use, lowering natural resource consumption, by-products and waste disposal, lowering pollution, opening employment opportunities while increasing industries productivity, competitiveness and community quality of life.

3.2. EIP development in Rio de Janeiro state

More recently, the Rio the Janeiro state government, looking for possible solutions to the disorderly industrial settlement of RJMA and for possible ways to minimize waste management problems, inspired by international experiences, began to consider EIPs as a possible strategic planning alternative to achieve sustainable development.

The first such state government initiative was the promulgation of State Decree 31,339 in June 2002, setting up the Sustainable Eco-Industrial Development Program – Rio ECOPOLO (EIP). The program's major goal is "the achievement of sustainable development by minimizing the impact of industrial activity on the environment, improving economic performance and community well being". According to the decree, the long-term results to be achieved were:

- "The development of social, environmental and economic tool in order to promote sustainable development;
- Community quality of life and environmental conditions improvement;
- Industrial settlement improvement, considering the adoption of environmental management strategies and cleaner technologies;
- Public–private sectors partnership;
- Promotion of eco-efficiency and cleaner production practices, instead of end-of-pipe solutions, to optimize utilization of resources in the production process;
- Increase in RJ state industrial competitiveness, and
- Higher quality jobs and increased income generation as a result of investments".

As a financial incentive, the decree created a financial fund called the Economic and Social Development Fund (FUNDES), giving special financial incentives to industries interested in engaging in the EIP program. Based on this decree, the Rio de Janeiro Environmental Protection Agency (FEEMA), in partnership with the state government, Rio de Janeiro Federal University (UFRJ), and community and private sector institutions like the Rio de Janeiro Industrial Federation (FIRJAN), developed the EIP program's planning characteristics and goals. These are shown in Table 5 below.

The first EIP initiatives to be launched as pilot projects were selected from the industrial zones that showed prospects for industrial expansion. Initially, three industrial zones were selected to be converted into EIPs: Santa Cruz, Campos Elísios and Fazenda Botafogo. Later a fourth pilot project was implemented – Paracambi – the only one to be developed at a greenfield site. The three others are industrial zones in operation, which are adapting in order to convert into EIPs.

Today, five years after EIPs were launched, the state government, its major stakeholder, has withdrawn the program. Changes in political administration and public agency leadership interrupted public sector participation. As often happens to other public sector programs in the state, when political leadership changes, good programs and ideas do not always last. It should be noted, however, that the decree is still valid, but EIP development is now a private sector led initiative, since the new state government has not given continuity to the program.

So far, the Santa Cruz, Campos Elísios and Fazenda Botafogo pilot projects are still evolving by themselves, without the public sector support. Even FEEMA is no longer supporting EIP development. At the Paracambi EIP, since the area selected is owned by the local government, there is still public sector support. However, since it was launched, at the end of 2002, very little has been done. Since the beginning of 2006, the local government, in partnership with

Table 4
RJMA industrial zone expansion possibilities.

RJMA industrial zones		
Industrial zones expansion possibilities		Solution
Zones with prospects for industrial expansion	9	Convert this zones in EIP
Zones with possibilities for industrial expansion but dependent on environmental/urban planning and/or location related aspects	30	
Zones no prospects for industrial expansion	17	
Total	56	

Source: Ref. [39].

Table 5
Characteristics and goals of the EIP program in Rio de Janeiro.

Characteristics and Goals of EIP Program in Rio de Janeiro
Adoption of sustainable development practices.
Political influences determining major decisions.
Partnership of public sector, private sector, community and academia.
Adoption of environmental management practices.
State government and agencies giving the private sector the necessary support.
Fiscal inducement.
Public support to existing industrial zones in order to convert to EIPs.
Incentives to national and international industries to join the program.
Environmental regulation compliance.
Environmental settlement rearrangement.
Implementation of eco-efficiency and cleaner production practices.
Increase in industries' competitiveness.
Higher quality jobs, increased income generation and community well being.

Table 6
Santa Cruz EIP.

Industry/industrial sector	Byproducts	Jobs	Environmental achievements
Aciquimica industrial Ltda/recycling of non-metal scrap	Manganese sulfate; zinc, copper oxide; steam, wastewater	60	Air monitoring system, effluent treatment station (ETS), underground water monitoring system
Basf S.A. transnational/chemical industry	Solvents, acids, desiccants	277	Responsible care program, emergency control system, ETS, waste sorting and recycling
Casa da Moeda do Brasil/Brazilian banknote printing and coin minting	Ink sludge, galvanic sludge, plastic, paper, metal plates/dies	1975	ETS, plastic, paper, metal plate/die recycling, environmental training program
Ecolab chemical Inc/hygiene, sanitary products	Acetone, ethanol, acids, paper, cardboard, packing	125	Paper recycling, emergency control system, solid and liquid effluent treatment
Fabrica Carioca de.Catalisadores S.A/ petrochemical	Contaminated gas emission, effluents with ammonia and sodium compounds, sludge	220	Environmental, health and safety program, gas emission control system, ISO 9001, 14,001 certified, emergency control system
Gerdau – Cosigua S/A/steel mill	Iron scrap, metal slag, air particulates, oil	1700	Metal scrap recycling and reuse, 97.2% water reuse, ETS, environmental management system (EMS), air quality monitoring system
Usina Termoelétrica de Santa Cruz/electricity (natural gas power generator)	Solid waste, sludge, solid, gas and liquid effluents, ash, sulfur particulates	230	Air quality monitoring system, EMS, environmental, health and safety program, energy cascading
Latasa Ltda/aluminum – metallurgy	Aluminum slabs, other byproducts, VOCs emission, liquid effluents	136	Environmental, health and safety program, ISO 9001, 14,001, OHSAS 18,001, water reuse, aluminum slabs 100% recycled
Morganite do Brasil Ltda electronic equipment	Solvent, metal scraps	78	ISO 9001 certified, waste recycling program
Novartis Biocências S.A/pharmaceutical, baby accessories and food products	Solvents, hydraulic fluids, chemicals, plastics, paper, cardboard, glass	365	Solvent reuse; plastic, paper, cardboard, glass recycling; ETS, EMS
NUCLEP S.A/heavy nuclear-electric equipment, components	Grease, oil, sludge	530	ISO 9001, ASME, CENEN NE 1.16 certified, ETS
Pan Americana chemical S/A/chemical products	Aluminum, cardboard packing	58	Bureau Veritas QS, Responsible Care, ISO 9001/14,001 certified, ETS
SICPA chemical Brasil Ltda/paints and varnishes	VOC (volatile organic compound), effluents	240	Bureau Veritas QS, ISO 9,001 certified, EMS, VOC reduction system
Valesul Alumínio S.A./metallurgical (aluminum and aluminum alloy metallurgy)	SO particulates, dust, water with oil, spent pot lining (SPL), aluminum dregs	616	ISO 9,001, 14,001, BS 8800, OHSAS 18,001, aluminum recycling, air quality MS, SPL reuse as a energy generator

Rio de Janeiro Federal University (COPPE–UFRJ), is developing a Paracambi EIP planning study. COPPE–UFRJ was selected due to its experience and knowledge regarding the RJMA industrial zoning system and due to other studies conducted regarding the possibilities of developing EIPs in Brazil.

We have selected two EIP pilot projects to describe their current development stage and future perspectives: Santa Cruz EIP, an existing industrial zone; and Paracambi EIP, the one that is being completely planned.

3.2.1. Santa Cruz eco-industrial park

Santa Cruz was the first EIP to be launched in RJMA. In September 2002, the fourteen Santa Cruz Industrial District industries located in Santa Cruz municipality signed an agreement with the state government and FEEMA in order to be part of the Eco-Industrial Sustainable Development Program (Rio ECOPOLO).

The Santa Cruz industries are in full operation. It is expected that the conversion of this industrial district into an EIP will result in social, environmental and economic advantages to the parties involved. Table 6 gives a brief overview of the Santa Cruz EIP industries, their sector and major byproducts, number of employees and some of their environmental achievements.

The industrial diversity shown above and the existing organizational relationship are positive factors driving possible implementation of EIP strategies in Santa Cruz, such as: byproduct and waste exchange; energy efficiency; water reuse; and sharing of information, human resources and services such as training, canteen, recreational facilities, common warehouse facilities, transportation, marketing services and cooperation between the actors involved.

In order to make the EIP program feasible, an action plan defining the Santa Cruz EIP's main goals was developed. These goals, based on the information available in the Santa Cruz EIP Sustainability Report [42], are briefly described in Table 7.

Since 2002, the number of industries holding ISO 14,000 environmental certification has increased. Many industries have found that environmental management practices do not increase costs and liabilities, posing a barrier to economic development. Just the opposite; they can yield positive economic, environmental and social returns [43].

Unlike the experience in other places in the world, AEDIN did not have problems to encourage industries to make their input and output flows available [43]. The byproduct and waste inventory database was to be the first step to enable implementation of byproduct and waste synergies [43].

Since 2002, some of Santa Cruz EIP's initial goals have been implemented: environmental practices; development of an

Table 7
Santa Cruz EIP's main goals.

1. Byproduct and waste management program: implementation of a central waste and effluent treatment station serving the whole park; development of waste inventory; identification of possible synergies, reuse and recycling possibilities.
2. Implementation of environmentally sound production practices, instead of end-of-pipe solutions.
3. Recruitment of new industries, to achieve the right mix to facilitate industrial synergies.
4. Air quality monitoring system: development of an integrative system to monitor regional air quality, which is a major problem for the industries to get their environmental licenses.
5. Rainwater and surface runoff monitoring system.
6. Development of an environmental management plan.
7. Compensatory measures: planting native species in order to reestablish the site's ecological balance.
8. Incentives to environmental initiatives in the park's surrounding area.
9. Ensuring compliance to environmental regulations.
10. Information, training and service sharing.
11. Community socio-environmental initiatives: recycling program, social and educational programs.
12. Energy efficiency, water conservation, environmental research and educational programs.
13. Creation of a centralized management association, the Santa Cruz EIP Management Association (AEDIN).

Source: Ref. [42].

Table 8
Paracambi EIP byproduct and waste matrix.

	Byproduct and waste																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Textile mills	GR	GR	GR	GR	G				GR						G		
Wire manufacturing		G			G	G	G	G	GR						G		
Marble processing									G					G			
Paint manufacturing		G		G	G		G		GR	GR	R				G		
Plastic recycling					R						G						
Electroplating		GR	G	GR	G				GR	R		G					
Steel slab manufacturing		GR	R		G	GR	G	G	GR			R			G		
Plastic Manufacturing					R				G								
Co-processing	R	R	R	R	R	R	R		R		R		R		R		G
Cement Manufacturing		R						GR	R				GR	R		R	R

G – byproduct and waste generator; R – possible byproduct and waste receiver; and G/R –generator and receiver of by product and waste.
1. Textile scrap, cotton fibers; 2. Solvents; 3. Acids; 4. Inks and pigments sludge; 5. Plastic bags, unidentified plastic scraps, polypropylene, polyethylene, pellets, film scrap; 6. Metal scrap; 7. Used iron, aluminum, lead, zinc, copper, steel and other non ferrous metals; 8. Ash containing metals; 9. Oil and wax; 10. Chemicals (ammonia, sodium hydroxide, chloride); 11. Plastic resin, acrylic, vinyl; 12. Exotic and Precious Metals (cobalt, nickel, mercury, gold, silver); 13. Cement kiln dust; 14. Marble dust and scrap; 15. Paper, loose paper waste, baled paper waste, paperboard, corrugated cardboard; 16. Sludge containing metals, solvents, ink pigments, acids, oils, chemicals; and 17. Co-processed by products and dust.

environmental management plan; planting native species; incentives to the local community to develop environmental initiatives in the park's surrounding area; compliance with environmental regulations; information and some service sharing, like canteens and recreational areas; community recycling program; social and educational programs; and finally the existence of a central management association, AEDIN, coordinating the whole program [43].

Despite the increasing awareness of sustainable development among the parties involved, much still needs to be done. For example, the byproduct and waste inventory has been concluded, but no waste exchanges have taken place. The lack of public and institutional commitment to promote the EIP's dissemination is making it hard for the Santa Cruz EIP to evolve the way it was initially envisioned only with the industries' support and work. The lack of knowledge and familiarity with the EIP concept and the possible benefits resulting from its implementation is also making the process slow.

3.2.2. *Paracambi eco-industrial park*

Located in the northwest part of RJMA, Paracambi municipality is small, with a population of approximately 41,000 people and an area of 180 km^2 (3.7% of RJMA area and 0.4% of the whole state area). It is 80 km from the city of Rio de Janeiro [44].

The Paracambi EIP, locally launched by Municipal Decree 937/2002, is being planned in a land area acquired by the local government of 2439 km^2, with the intention of occupation by large and medium industries. Site selection was based on possible economic development and strategic land planning possibilities. The site offers excellent transport connections both to the north and south of the country; and water, electricity and natural gas supply are available.

Unlike the state government, the local government is committed to the EIP's development by financially supporting the park's urban planning and infrastructure development (water, electricity, piped gas, sewage treatment station). To stimulate industrialization and capital investment and to encourage industries to relocate to the EIP, a municipal law (Law 552/2002) was enacted, granting financial incentives and tax exemptions.[5] These incentives were expected to bring to the municipality a diversity of new industries; opening new paths to economic development, innovation and job creation.

As previously stated, the Paracambi EIP is being planned at a greenfield site, since 2006 with the support of COPPE–UFRJ, which is responsible for developing its planning study. This study is being designed in order to help industries, which are looking for ways to cut costs and reduce the consumption of natural resources and the discharge of waste, the community, which is looking for a more sustainable future by identifying ways to protect the environment, improve its quality of life, and the local government, which is looking to advance the municipality's socioeconomic development. A project team was assembled bringing researchers from different backgrounds to work in the planning study. These researchers are providing overall project management, guidance, and technical assistance in developing and designing the planning study. The project goals would be achieved by a reduction in natural resources consumption, maximum use of natural resources and minimum discharge of waste in the environment due to byproduct and waste synergies, reuse and recycling of materials among EIP industries, energy efficiency maximization; multi-level use of water and shared use of infrastructure and services.

Based on EIP ecology principles, industries are being selected looking for possible byproduct and waste synergies. The two major industries existing in Paracambi are being considered as potential partners: a textile mill and a wire manufacturer. In addition, the Paracambi government is in negotiation with four industries to engage in this project: a marble finisher, plastics recycler, paint manufacturer and an electroplating facility. Based on the industrial sectors mentioned, a study was conducted by the COPPE–UFRJ researchers, seeking possible synergies.

The COPPE–UFRJ plan for the Paracambi EIP focuses on creating linkages among the six industries of interest, and between these and new ones drawn to the EIP. A search, looking for possible synergies, was conducted in major databases. The EPA software Facility Synergy Tool (FaST) was a major tool used in this search. The output materials mainly consist of solvents, oils, scrap metal, metal-bearing sludge, paint sludge, acids, ash, plastics in general, paper, cardboard, paint pigments and textile scraps. Based on these findings, focusing on local socioeconomic development, on higher resource efficiency, in lowering pollution levels and on minimizing natural resource consumption, this study recommended locating four additional industries in Paracambi EIP: a steel slab manufacturer, a plastic manufacturer, a co-processing facility and a cement manufacturer. The co-processing facility would act as the anchor industry [45].

[5] In Brazil, the Federal Constitution spells out the taxing powers of the municipalities, states and federal government. The main municipal taxes are service tax and urban property tax. Other municipal revenues come from revenue transfers from the state and federal governments.

In order to demonstrate possible synergies, a matrix was developed, showing the industries' byproduct and waste outputs and potential synergies. Table 8 presents the preliminary result of this matrix.

The matrix above demonstrates that the industrial mix suggested would have potential for developing byproduct and waste synergies, as most of the byproducts and wastes generated would potentially be reusable by the industries suggested. Plastics, solvents, oil, scrap metal, paper, ash containing metals, co-processed byproducts and ash are the ones with major exchange possibilities. In the future, synergies with industries located in nearby municipalities could also be considered.

Regarding water conservation, the possibility of gray water and rainwater recapture and reuse by office or industrial buildings is being considered. The increase in water use efficiency by closing the water reuse loop (water cascading) would reduce pure water consumption in the EIP, as different needs require different levels of water quality. This practice is already being applied in Brazil with major success stories [46]. Regarding liquid industrial effluents, the suggested is to implement a common effluent treatment station (ETS) located inside the EIP, responsible for treating the effluents originating from the industries and other EIP buildings.

Regarding electricity, the region has power available through the grid. A reduction in power consumption by increasing overall energy efficiency is feasible with the use of more efficient technologies and energy conservation methods. Possibilities being considered include: use of alternative sources, inter-plant energy flow, facility design, the use of better industrial equipment, co-generation and the use of renewable energy sources, which is encouraged by the Brazilian government [46].

Besides synergies, water and energy considerations, strategies regarding resources and processes, consideration is going to other possibilities, such as: an integrated information system allowing for communication, control and exchange of information within the park; transportation and shuttle services; and employee benefits, leisure areas and canteens. The COPPE–UFRJ study also suggested the introduction of a common warehouse facility. The resulting benefits would be reduced operational costs, shared logistics and more control of vehicle movements in and out of the EIP [12].

The site development, landscape and building design would incorporate sustainable architecture and landscape principles, such as preservation of natural site features, indoor air quality, solar lighting, energy conservation, natural ventilation, water reuse, use of recycled or renewable construction materials, etc. Environmental and social issues would be considered up front in the design process, at the same time as the functional space needs are planned. The possibility of having ISO 14,000 certification and an umbrella license for the whole park would enhance industries' market image and facilitate access to new market niches. Educational and training sections emphasizing sustainable development practices and EIP principles would also be essential for employees and community members. Table 9 summarizes the main elements being suggested by the COPPE–UFRJ planning study for Paracambi EIP.

The Paracambi planning study will help society to make progress toward more sustainable development, as it aims to achieve economies of scale, reduce industrial costs, increase their competitiveness, minimize environmental impacts, waste discharge and natural resource consumption and depletion resulting from the industrial activities, and finally improve community life quality. Therefore, we expect that the EIP tenants would be guided by a common vision of sustainable development, being committed to ongoing economic, social and environmental improvement.

As previously stated, the Paracambi EIP study is in its initial planning phase. Since 2002, when it was launched, this study has been the first attempt to plan this EIP. Much work still needs to be done. So far, our project has no specified detailed data, indicators and benchmarks in relation to water, energy, byproduct and waste minimization. The effectiveness of this study has not been evaluated; consequently some of its suggestions regarding sustainability could wind up not being implemented.

Table 9
Elements suggested for Paracambi EIP.

Elements	Description
Site selection	Local government ownership.
Local public sector × university	Partnership in developing the EIP planning study.
Industrial mix selection	FaST (US-EPA), recruitment of industries committed to high resource efficiency and low pollution emissions.
Industrial mix	Textile mill, wire manufacturing, marble processing, plastics recycling, paint manufacturing, electroplating facility, steel slab manufacturing, plastic manufacturing, co-processing facility, cement manufacturing.
Byproducts and wastes exchanged	Textile scrap, cotton fibers; solvents; acids; inks and pigments sludge; plastic bags, unidentified plastic scraps, polypropylene, polyethylene, pellets, film scrap; metal scrap; used iron, aluminum, lead, zinc, copper, steel and other non ferrous metals; ash containing metals; oil and wax; chemicals (ammonia, sodium hydroxide, chloride); plastic resin, acrylic, vinyl; exotic and precious metals (cobalt, nickel, mercury, gold, silver); cement kiln dust; marble dust and scrap; paper, loose paper waste, baled paper waste, paperboard, corrugated cardboard; sludge containing metals, solvents, ink pigments, acids, oils, chemicals; co-processed by products and dust.
Landscaping and site planning	Existing ecosystem preservation and incorporation into the design of landscaping, site orientation (north), micro-climate consideration, native species preservation. Financially supported by the municipal government.
Transportation Connections	Major interstate connections to the north and south of the country (Rio de Janeiro and São Paulo – BR 116, RJ 127, RJ 465).
Public Transportation	Effective transportation services available (rail services, bus services).
Infrastructure	Financially supported by the municipal government (power, piped gas, water, sewage). Following high performance resource efficiency standards.
Sustainable architecture and process engineering	Adoption of sustainable and advanced methods and technologies for pollution prevention, energy efficiency, water reuse. Consideration of life cycle of materials and buildings, balancing economic and environmental needs. Utilization of renewable energy and materials.
Common spaces and services	Integrated information system, transportation and shuttle services, employees leisure areas and canteens, restaurants, health center, emergency response center, offices for firms providing common support services to the industries, auditorium and meeting rooms, marketing and management services, common warehouse facility, common effluent treatment station, common waste management and distribution facility, common solvent recycling facility, common oil recycling facility.
Surrounding community	Strong linkage to the surrounding community through economic development, social and environmental programs (educational programs, employment opportunities, income generation, quality of life improvement).

3.3. Analysis of EIP development in RJMA

Considering what has been presented so far regarding EIP development in RJMA, particularly in Santa Cruz and Paracambi EIPs, the specific features, successes and failures that are driving this initiative, an SWOT profile (strengths, weakness, opportunities and threats) was generated. This SWOT is presented in Table 10 and can be used as the basis of goal setting, strategy formulation and implementation of EIPs in RJMA.

Table 10
SWOT analysis.

Strengths	Weakness
Predominance of the private sector in the planning and implementation of EIPs. In the RJMA, EIP pilot projects are being managed by the private sector with no public sector input or participation, except from Paracambi.	The promulgation of State Decree 31,339/2002, initially was a strength, but it became a weakness. The private sector became engaged in this program considering that the state government and public agencies, would act in partnership, which ended up not happening.
The existing organizational relationship in the Santa Cruz EIP helped the industries to overcome initial barriers. The high group and management organization capacity, centralized in AEDIN, were positive factors.	Lack of state government and public agency support: as previously stated, the state government withdrew its support for the EIP program. Changes in political administration and public agency leadership interrupted public sector support. The EIP program is not the first program to be launched in Rio de Janeiro as a tool to promote political careers, nor will it be the last one. Government and public agencies need to play a key role to lead sustainable development initiatives, not look to personal promotion.
Industrial sector diversity would open up new paths to innovation, education and cooperation, leading to an increase in sustainable development awareness among the actors involved. The extant industrial sector diversity in the Santa Cruz EIP would allow the development of byproduct and waste synergies in the near future, besides services and process sharing. In Paracambi, the industrial mix was selected looking for possible byproduct and waste synergies.	Inertia and lack of capacity and bureaucracies of the public institutions, particularly in Paracambi.
Human resources availability: there are plenty of unemployed and qualified workers throughout the RJMA.	Lack of familiarity and knowledge of the concept and potential benefits resulting from the implementation of EIPs. Even though these concepts are spread worldwide, industries and communities are inexperienced with this terminology, hampering the development of both the Santa Cruz and Paracambi EIPs. Informative sessions and meetings would be helpful in order to spread these concepts. Lack of knowledge of the opportunities existing in inter-firm collaboration – most industries look to see what they can do by themselves, without realizing opportunities resulting from cooperation. Lack of funding, subsidies and investment capital might prevent EIP dissemination, particularly regarding SMS industry participation, as these industries usually need greater financial support.
Opportunities	**Threats**
Development of a specific EIP development strategy and methodology for Rio de Janeiro state, considering that it has different political, economic, environmental and natural resource constraints in comparison to developed nations.	Conflict between economic growth and sustainable development. As the public sector is no longer supporting EIP development, the industrial sector may prefer the conventional gains of economic development instead of the possible gains promised by EIPs.
Learning from international EIP experiences: Rio de Janeiro's EIP program can learn from other nation's research, projects, initiatives, solutions and mistakes.	The existing mechanisms and legislation punishing industries that harm the environment, such as mandatory control measures, stiff indemnification for environmental harm, the threat of criminal prosecution of administrators, according to Federal Law 9965/1999, may discourage industries from making their material and waste flow transparent.
Competitive advantages for participating industries: improved economic efficiency, higher return on investment (ROI), increased environmental performance and reduced production costs.	Strategies and methodologies that were adopted by developed nations may result in project failure when transposed to the RJ. It is necessary to conduct site-specific exploration and develop a specific methodology for EIP development.
An EIP label may be created and used as a marketing tool, leading to enhanced market image, increased market share and new market niche access.	Deficiencies of long-term planning might become a problem. EIP development is a long-term planning process that requires cooperation, commitment and trust among all actors in order to succeed, and industries usually think in the short term. Lack of trust – in Paracambi, since the industries being considered do not know each other, they might be unwilling to put their business at risk by depending on others or by sharing knowledge. Education would be needed to overcome this barrier.

4. Conclusion

Inspired by experiences in Europe, North America and Asia, EIPs were launched in Rio de Janeiro as a potential environmental planning strategy to foster sustainable development and to improve the degraded urban and environmental condition existing in the RJMA. From what has been accomplished to date, EIPs are at an early stage of development. Unlike what was expected, collaboration among governments, private institutions and industries, communities and academia, although a central issue to EIP development, has not evolved the way it should have. Changes in political administrations and public agency leadership caused the state government to withdraw EIP support, so the EIP idea has not become the environmental planning strategy for sustainable development that was expected.

Based on our findings, this study suggests that the following points should be considered regarding EIP development in RJMA:

- Collaborative behavior among the actors involved is central to EIP development. Governments, public agencies, private institutions, industries, communities and academia need to cooperate, in real partnership, in order for EIPs to become the environmental planning strategy for sustainable development that RJ needs to overcome the environmental and social distress caused by unplanned urban and industrial development.
- Byproduct and waste exchange development is a long-term process that happens after other EIP elements are already introduced.
- Trust needs to be developed between industries and park management before economic cooperation can be established.
- Community participation in the early EIP planning process is critical to avoid misunderstandings, share responsibilities for ongoing development and build trust and community support.
- The role of government (federal, state, and local) is important in the area of environmental licensing (umbrella licensing), disseminating the EIP concept and principles and in providing the necessary legal support.
- Government and public agency incentives can help industries to continuously improve their environmental and social performance.
- The following RJMA social, environmental and economic problems need to be considered: unsustainable urban development, severe environmental damage, scarce natural

resources, unsustainable economic growth, incontrollable population growth, poor or non-existent waste management practices, poverty and misery.
- Environmental and social development must be done jointly with economic development, following the same path.
- Community and industry education is needed to support EIP development.
- Public sector incentives are needed to encourage the development of recycling programs, to help poor communities to enhance income and consequently their quality of life.
- Rio de Janeiro has different political, social, economic, cultural and environmental constraints compared to other regions of the world. Therefore, it is necessary to conduct site-specific exploration and adapt the EIP principles and characteristics developed worldwide to Rio de Janeiro's reality in order to develop its own strategy and methodology for EIP development.

Thus, considering that five years have gone by since the EIP program was launched in Rio de Janeiro, very little has been done. Rio de Janeiro has the potential to create a sustainable industrial system in the near future. However, the continuity of EIPs in the RJMA will only be successful if we have a convergence of the actors' interests, to build a cooperative network to achieve sustainable development.

This article seeks to present what has been accomplished to date in EIP development in RJMA. Just as in many other regions around the world, EIP development in RJMA still has many challenges to overcome.

Acknowledgements

We wish to thank Suzanne Giannini-Spohn, Ph.D., of the U.S. Environmental Protection Agency, who made the EPA's software Facility Synergy Tool (FaST) available for this study.

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