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Process analysis of eco-industrial park development—the case of Tianjin, China

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Abstract:

The variety of successful and unsuccessful eco-industrial parks (EIPs) have evoked a discussion on “how to intervene in the process of transforming an industrial park to an eco-industrial park”. This study presents a process analysis approach that enables analysts to trace and structure the key activities that influence changes in an EIP system. This approach rests on five key activities that affect EIP changes and development: (1) institutional activity (2) technical facilitation (3) economic and financial enablers (4) informational activity and (5) company activity. Applying this lens to a Chinese EIP, Tianjin Economic-technological Development Area (TEDA), allowed us to build a structured database of activities to analyze its eco-transformation. In TEDA, institutional activity shapes the institutional arrangements that are pivotal for enabling and shaping the eco-transformation. Company activity has less influence on the system than the other key activities. Informational activity is vital to build trust and relationships. In a long time-span, TEDA transformed from a planned EIP to a planned and facilitated EIP, where the local authority acts as a coordinator and as a facilitator. The process analysis approach is amenable for an institutional environment other than the Chinese context because it results in a structured and documented analysis that is open to adjustment, expansion and critique.

Keywords: eco-industrial park, industrial symbiosis, process analysis, circular economy, Tianjin Economic-technological Development Area (TEDA)

1. Introduction

The most famous eco-industrial park (EIP), Kalundborg in Denmark, demonstrates the feasibility of
reconciling a profit orientation with environmental performance. Due to water scarcity, six major companies in Kalundborg spontaneously formed a symbiotic network that is deeply embedded in the regional context. In recent years, EIPs have become a policy-driven attempt to apply the principles of Industrial Ecology in specific locations (Gibbs, 2009) to reduce the environmental impact of industrial activities. The worldwide boom of EIP practices has been evidenced in the National Industrial Symbiosis Program (NISP) in the UK, the regional synergies in the Australian mineral industries and the Circular Economy program in the Chinese industrial park (Mirata, 2004; van Beers et al., 2007; Yuan et al., 2006). Meanwhile, the abandoned projects in the US have revealed that regulatory and management complications may exist when realizing EIPs. Overemphasis on the technical aspects of matching material flows appears not sufficient to facilitate the emergence of symbiotic networks. Indeed, barriers created by existing regulations and distrust among actors have hindered the establishment of synergy in many US EIP projects (Gibbs and Deutz, 2007; Heeres et al., 2004). The variety of successful and unsuccessful cases raises the question “how to examine the determining factors of existing EIP cases and how to explore developmental paths for future EIPs”.

The underlying idea of an EIP is industrial symbiosis (IS) that aims to engage otherwise separated industries in a collective approach to reduce their environmental impact (Chertow, 2000). It involves physical exchange of materials and by-products, shared management of common utilities and infrastructures for water, energy and waste (Chertow, 2000; van Berkel, 2009). Analysis of worldwide EIPs has revealed that most of the eco-initiatives have been deployed to transform already existing industrial parks (Mathews and Tan, 2011b). In this article, the term “eco-transformation” is used to designate industrial park revitalization and transformation in accordance with IS principles. Eco-transformation of industrial parks does not come about overnight. Rather, it is a process that spans years and unfolds in a wider socio-technical context wherein changes emerge from the co-evolution of technology, institutions and social systems (Chertow, 2000; Dijkema and Basson, 2009). Many scholars have sought to understand the patterns and mechanisms for EIP inception and development over time, based on the experiences from various historical and current cases. However, a knowledge gap remains: how to trace the determining factors that unfold over time and elicit their integrative
Thus, this research aims to develop a generic approach which allows analysts (1) to structure the key activities that influence changes of EIP systems, and (2) to track the process of the system development over time.

This article will unfold as follows. Section 2 introduces process analysis and how it can be adapted to study an EIP’s development. Such an approach requires a set of indicators to detect the key activities from the events in a given time span. Consequently, a literature review is provided on the topics of EIP and IS, which culminates in a list of the key activities that promote or hinder the development of an EIP. Meanwhile, a set of indicators is identified to trace these activities over time. In section 3, the approach is applied to an ongoing case – the Tianjin Economic-technological Development Area (TEDA) in China. The authority of TEDA initiated the eco-transformation in 2000 as one of the earliest participants in the China National EIP Program. The overview of this national program has been discussed (see (Fang, 2007; Geng, 2009a; Mathews and Tan, 2011)). And this article focuses on the practice at the park level. Evidence shows that IS networks are indeed emerging in TEDA, stimulated by several institutional and management instruments (Shi et al., 2010). Thus, TEDA’s eco-transformation during the last decade provides real-life lessons to uncover insights as to how EIP development can successfully evolve. Section 3 first details how the process analysis approach is used and the necessary data has been collected. Subsequently, the approach is applied to make sense of the transformation process of the TEDA case. In the fourth and concluding section, the research findings and insights are discussed and their wider implications are addressed.

2. Process analysis of an EIP system

2.1 Analysis of EIP

Generally, chronological narrative analysis is used to describe the process of EIP evolution. Ehrenfeld and Gertler (1997) analyzed the evolution of company interdependence at Kalundborg from 1959 to 1993 in terms of business interests, organizational arrangements, technical factors and regulations. A discontinuous three-stage IS model was extracted by Chertow and Ehrenfeld (2012) (i.e., sprouting,
uncovering, embeddedness and institutionalization). This three-stage model was subsequently used to examine ten industrial ecosystems (Chertow and Ehrenfeld, 2012). Doménech and Davies (2011) explored the main mechanisms that forge trust and embeddedness during the three IS stages: emergence, probation, and development and expansion. They then characterized three cases (including Kalundborg, NISP, and Sagunto) to examine the trajectories of their embeddedness in IS networks (Doménech and Davies, 2011). A cross-case study was made by Mathews and Tan (2011) through discussing the drivers and inhibitors in an evolutionary framework. These authors analyzed in detail what happened in various IS projects during a period. Their work, however, points out a knowledge gap: how to trace the determining factors unfolding over time and elicit their integrative effect at the EIP system level. Furthermore, narrative analysis is context-specific, which lacks a generic approach to discern the determinants for success and failure. It is limited to extract the patterns for comparison and generalization.

### 2.2 Process analysis

Process analysis aims to capture and explain the different types of forces and mechanisms that can influence the evolution of a firm or a network of firms (Poole et al., 2000). In this article, process analysis is adapted to better understand the drivers of change of an EIP, and how changes unfold over time. A *Process* is defined as a sequence of events that describe how things change over time (Ven and Poole, 1995). The point of process analysis is to obtain meaningful insight into the changes unfolding over the duration of a central subject’s existence (Poole et al., 2000), here being an EIP. In process theories, the event is used as the appropriate meaningful unit by which change can be detected (Poole et al., 2000). Activities in a certain subject are mapped as events. Thus, a historical database is constructed in which all relevant events related to a specific developmental process are mapped (Hekkert et al., 2007). Hence, development and change can be studied by analyzing the sequence of events (Poole et al., 2000). The advantage of event analysis is that rich qualitative information about the development processes can be obtained. Furthermore, the structured and quantitative characteristics are useful to interpret and compare case studies. As Poole et al. (2000) emphasized, the goal of the process approach is to develop explanations with more general applicability; in the
meantime, it stresses the systematic investigation and evaluation of narrative explanation. Process analysis was used to collect the events and study the Dutch stimulation program for EIPs (Boons and Spekkink, 2012). The data were employed to test the theory of institutional capacity for IS. Their work has inspired us to use process analysis to analyze the changes during the eco-transformation of industrial parks from a system perspective.

2.3 Towards a lens on EIP development

The study of EIP development requires us to tailor process analysis. We first need to develop a framework that consists of the key activities as variables that determine the development of EIP/IS, and specify the corresponding indicators for each variable. Second, the framework is applied to detect the events from the empirical data to build the database. Then the system analysis of EIPs’ development is delivered based on the main events description and event sequence analysis.

A literature study has been conducted to identify the determining factors that promote or prohibit an EIP’s evolution. We searched item “eco industrial park symbiosis” for journal articles in Hub-SciVerse, which spans ScienceDirect and Wiley-Blackwell. The results included 167 articles in the subject areas: Environmental Sciences, Energy, Agricultural and Biological Sciences, Social Sciences, Economics and Econometrics and Finance, Business and Management and Accounting, and Decision Sciences. After initial inspection, we identified 46 articles that address drivers and barriers of EIPs/IS projects. A comprehensive overview of the determining factors is extracted and given in Appendix 1.

The classification criteria of the factors are based on review-type articles. Mirata (2004) categorized the determining factors for IS networks into technical, political, economic and financial, informational, organizational and motivational. Sakr et al. (2011) classified the EIP success and limiting factors as symbiotic business relationships, economic value-added, awareness and information sharing, policy and regulatory frameworks, organizational and institutional setups, technical factors. When comparing the drivers and barriers of Australian IS projects, van Beers et al. (2007) used six categories including economics, information availability, corporate citizenship and business strategy, region-specific issues, regulation, and technical issues. Considering the need for mutual-exclusiveness of the criteria, we
concluded that the determining factors elicited from the literature review best fit the classification criteria by Mirata (2004). Consequently, we use the following criteria in our tailored process analysis approach for EIPs: 1) institutional activity, 2) technical facilitation, 3) economic and financial enablers, 4) informational activity and 5) company activity. The next section further details the lens on these five groups of key activities.

2.3.1 Institutional activity

Having an appropriate institutional setting in a region is one of the most important elements for IS programs (Mirata, 2004). Ehrenfeld and Gertler (1997) pointed out that policies may enable or preclude EIP development. In many EIP cases, policy interventions motivate the development of new EIPs or the transformation of existing industrial areas (Boons et al., 2011; Lehtoranta et al., 2011; Mathews and Tan, 2011b). Examples are the national level EIP program in China, NISP in the UK, and the special industrial park in Ulsan, South Korea. The formal institutional regime consists of laws and regulations (e.g., environmental protection law and water quality standards). Policies and guidance can create appropriate conditions that enable infrastructure sharing and company interaction, which increases the synergy opportunities (Gibbs et al., 2002; Mirata, 2004). If strict environmental regulation is in place, the financial burden imposed on resource consumption and waste disposal urges companies to reduce and recycle their waste and by-products. Regarding the policy direction, Chertow (2007) argued that for self-organizing or planned EIPs, three policy ideas can move IS forward: 1) bring to light kernels of cooperative activity that are still hidden; 2) assist the kernels that are taking shape; 3) provide incentives to catalyze new kernels by identifying “precursors to symbiosis”. When investigating the evolution of Kalundborg, Ehrenfeld and Gertler (1997) and Desrochers (2001) highlighted that the flexibility of regulatory requirements on performance standards is the key to stimulate companies to innovate and explore creative arrangements to meet pollution-reduction targets. In contrast, regulatory requirements may preclude the material exchanges due to high transaction costs or inflexible planning (Geng et al., 2009b; Mirata, 2004). Additionally, regular monitoring and evaluation of EIPs is necessary to ensure that ecological and economic goals are reached (Geng et al., 2009a).
2.3.2 Technical facilitation

The second criterion is the availability of infrastructure for pooled use and joint management of resources (Chertow et al., 2008). Besides, information and communication technology (ICT) tools also may facilitate the realization of potential synergies. Although the type of specialized infrastructure depends on local industrial characteristics, the regional public utilities (e.g., co-generation and wastewater plants) can play the role of anchor tenant, around which the main material and energy flows of a regional industrial system could be arranged (Korhonen, 2001). Lastly, ICT can support IS networks through information acquisition and analysis of material flows for potential synergies, and for monitoring the performance of the network (Mirata, 2004).

2.3.3 Economic and financial enablers

Economic benefit is the main driver for the emergence of IS/EIP projects (Ehrenfeld and Gertler, 1997; Lehtoranta et al., 2011; Roberts, 2004; Tudor et al., 2007). Companies may hesitate when considering the transaction cost and risk in symbiosis projects. Subsidies and funds can stimulate the collaboration, and guide the adopting technologies and infrastructures. And market-driven actions, such as price mechanisms for energy and resources, are crucial to make symbiosis economically attractive (Desrochers, 2001; Ehrenfeld and Gertler, 1997; Mathews and Tan, 2011b). Mirata (2004) reviewed the fiscal incentive policies relevant for IS programs in the UK, viz. landfill taxes and climate change levies. The former provides incentives to reduce and recover waste streams and to find alternative ways for waste treatment. The latter provides tax reductions or exemptions for inter-organizational synergies such as co-generation. And heat, steam and waste as defined by statute are non-taxable carriers of energy (Mirata, 2004).

2.3.4 Informational activity

During the eco-transformation of an industrial park, information is essential to identify and establish various types of synergies (Heeres et al., 2004). Absent or incomplete information may lead to difficulties even when companies share one geographical space (Tudor et al., 2007). First, professional knowledge may be lacking to turn waste into a profitable product (Chiu and Yong, 2004). Second,
while companies may know what by-product exchanges they are engaged in, they do not have complete information about who their neighbors are, what industry and activity they are engaged in, and thus what by-products they may have or need (Chertow, 2007). In the context of EIPs, three aspects of informational activity are involved: 1) dissemination and training, to generate a common understanding of IS; 2) networking activity, to engage companies in and to collect the information for potential synergies; 3) feasibility studies, to analyze potential synergies. Informational activities may benefit from the input of coordination bodies, such as entrepreneurs association and non-governmental organization (NGO). Coordinators can catalyze IS through organizing training or workshops and research on IS feasibility and thereby engage key parties. Frequent encounters can reduce “mental distance” and cognitive barriers (Mirata, 2004; Roberts, 2004; Sterr and Ott, 2004). Even if actors decide not to pursue a joint project, their thinking may have changed to give preference to IS projects when the conditions for a partnership are favorable (Paquin and Howard-Grenville, 2009).

2.3.5 Company activity

The bottom-line of industrial symbiosis is company participation in the exchange of physical by-products and utility sharing (e.g., steam, wastewater treatment and joint provision of ancillary services) (Chertow et al., 2008; Tudor et al., 2007). Heeres et al. (2004) compared the Dutch and North American EIP projects and concluded that active company participation is crucial for success, as the EIP plans are ultimately implemented by companies. Companies must invest time, money and other resources in IS projects. Trust and willingness to participate often determine whether the initiatives can eventually lead to the implementation of an IS project (Gibbs and Deutz, 2007; Mirata, 2004). The main reasons for Kalundborg’s success are the “culture of cooperation”, the “short mental distance” and a shared cooperative attitude (Ashton, 2008; Ehrenfeld and Chertow, 2002; Gibbs and Deutz, 2007; Sterr and Ott, 2004). Self-organization by companies for IS is a pivotal factor for the emergence of symbiosis possibilities, and appears to be the missing link in many unsuccessful planned EIP (Chertow, 2007; Gibbs and Deutz, 2005).

2.4 Approach to identify the key activities for event tracking
Above, we have summarized our findings from a literature review and grouped the results into institutional, technical, economic and financial, informational and company activity. As we are interested in the process of EIP development, we use a list of indicators (see Table 1) to represent what drives the changes of an EIP, in order to identify these activities from empirical material. The set of indicators as a minimum should cover the determining factors under each subject of the key activity in Appendix 1. The institutional activities concern formal institutions such as regulations, laws, planning and evaluation, as well as informal institutions like voluntary agreements or shared norms. For technical facilitation, we focus on the public utilities such as co-generation plants and wastewater recycling plants. Regarding economic and financial enablers, although the funding sources of companies are diverse, we pay particular attention to local government’s subsidies and funds for encouraging companies to join symbiosis networks. The informational activity can be mapped through the number of training sessions, feasibility studies, workshops and networking events. And we use the started IS projects to map the events about company activity. Finally, the participation in the information exchange and information disclosure can be counted as a proxy, because these imply willingness of companies to engage in IS projects.

The framework can help detect the events from raw data (e.g., news, archives and interviews) related to EIP/IS development. Once a related event appears, it will be counted with value 1 in this type of key activities. The events are stored in a historical database to create a time series. Consequently, the trends of the 5 key activities influencing an EIP’s development are illustrated and analyzed. Through this approach, the process of EIP’s development is tracked and systematically analyzed over time. The approach requires case study to testify whether it is adequate, which will be presented in the next section.

3. Case study on process analysis about the eco-transformation of TEDA

3.1 Method of applying process analysis and data collection

In the following sections, the approach outlined above is used to illustrate TEDA’s development and to analyze its evolution process. First, we describe the milestone events that had profound impacts in
terms of institutional activity, technical facilitation, economic and financial enablers, informational activity and company activity. Second, a system analysis is presented based on the database that has been compiled by collecting historical events from 2000 to 2011. The database is setup in accordance with the indicators in Table 1. Data collection follows Hekkert et al. (2007) who tracked events reported at the system level. Thus, we focus on the data sources available to give us information at the park level of TEDA’s eco-transformation. These include news and annual reports of TEDA from 2000 to 2011, mainly from the websites of TEDA government (http://www.teda.gov.cn), TEDA’s Eco-center (http://www.ecoteda.org), and TEDA’s Environment Protection Bureau (EPB) (http://www.teda.gov.cn/html/hjbhj/portal/index/index.htm). The events are counted over time with the same weight and plotted in the figures. The trends of the 5 key activities through time are analyzed to explain the dynamics of TEDA’s eco-transformation. Moreover, during data collection in the field, we conducted seven semi-structured interviews with the key departments in TEDA. These interviews lasted 1-3 hours and the findings largely served as triangulation of data obtained by other means (yearbooks, policy documents, our measurements of the key activities). The interviews also provided necessary background information about the drivers and barriers during TEDA’s eco-transformation. Appendix 2 gives an overview of the departments and positions of the respondents and questions in the interviews.

3.2 General introduction of TEDA

Tianjin Economic-technological Development Area (TEDA) was established in 1984 as one of the first Chinese national level economic development zones. Connected with Tianjin Port, TEDA’s developed land occupies approximately 98 km$^2$, including 46 km$^2$ of industrial area and an employed population of 484 thousand. In 2010, TEDA’s GDP was RMB $^{1}$ 154.586 billion, an increase of 25.1% compared with the previous year (TEDA, 2010a). In total, TEDA has approved 4,870 foreign companies involving US$ 62.207 billion of project investment, and 9,546 domestic-funded enterprises with a total registered capital of RMB 177.069 billion (TEDA, 2010a). As a mixed industrial park with diverse industries, TEDA has seven main industries and their relative share is shown in Fig. 1.

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$^1$ RMB is the currency of China. 100 RMB is approximately equal to 16 US dollar.
TEDA’s eco-transformation dates back to the year of 2000 when TEDA started to prepare for the ISO14001 certification. The diversity of industries brings TEDA the possibility of by-product exchanges as well as the challenges to connect different types of companies. Furthermore, Tianjin City relies on external energy and resources. Consequently, TEDA also suffers from the same problems, especially water scarcity. Considering the growing demand for resources from the rapid economic growth, it is indispensable to reduce and recycle energy, water and resources. After years of effort, TEDA was nominated as a National Pilot Industrial Area for Circular Economy in 2005 and it became one of the first three National Demonstration EIPs in 2008. Utility sharing has gradually increased in regional water supply and co-generation. Moreover, a symbiosis network of by-product exchanges is emerging. During TEDA’s eco-transformation, various activities and changes took place in terms of institutional intervention, infrastructure provision and actor participation, which will be discussed in the following sections.

3.3 Description of main events

3.3.1 Institutional activity

TEDA’s Administrative Committee (AC) (set up in 1984) is accredited by the Tianjin municipal government. The AC is in charge of administrative management, the drafting and supervising local regulations. Besides, it is also responsible for the auditing of investment projects, the planning of infrastructures and public utilities, and setting infrastructure charges. The multiple roles as a substitute local government give TEDA’s AC considerable institutional capacity for economic development and environmental issues.

Various administrative instruments, including national laws, have stimulated TEDA’s eco-transformation since 2000. Table 2 records the institutional activities stimulating EIP practices from 2000 to 2010 in TEDA and at the national level, respectively. At the park level, the institutional arrangements involve planning, incentive policies, monitoring and evaluation, which is in line with the goal of EIP and national laws. The focus in TEDA switched from using public utilities to companies’ spontaneous IS behavior. Due to the worsening environmental situation and water scarcity, in 2000
TEDA initiated the regional ISO14001 certification and adopted its main principles on reducing sewage discharge and air pollution. When the first wastewater reclamation plant was operated, TEDA’s AC formulated two measures: exemption from the sewage disposal fee in 2000; encouragement for the use of new water sources in 2002. According to these measures, if a company’s wastewater meets the Grade II national standards or if its wastewater is reused, the company is exempt from the sewage disposal fee (1 RMB/ton) (TEDA, 2002b). Furthermore, recycled water is 20% cheaper than tap water. These measures thus stimulate companies to improve their wastewater treatment and to use recycled water. In 2009, 25.29% of discharged water was recycled (Eco-center, 2010).

Life cycle use of materials and industrial symbiosis have been clearly proposed since 2002 in TEDA’s National Level EIP Development Planning. This plan prioritized the complementary projects for closed-loop industrial chains on electronics and telecommunications, machinery manufacture, food and biomedicine (TEDA, 2004). In addition, environmental infrastructure projects were initiated, which involves the regional water cycle system and a co-generation plant. Moreover, due to the absence of national regulations on non-hazardous industrial waste, an eco-labeling management system was launched in 2005 to reduce solid waste. Companies that generate, recycle or treat solid waste can set up a waste management system and have it evaluated. If it passes the assessment, the company will receive an eco-management label as a certification (TEDA, 2007). Apart from the goal of solid waste reduction, the eco-labeling management system also traces the solid waste flow to search suitable waste recyclers and the effective transport routes.

Although crucial regulations had been implemented for closed-loop chains and IS, many problems still persisted. For instance, the efficiency of energy utilization was low. 60% of the steam condensation water could be reused for heat energy instead of being discharged. The reclamation of materials was constrained by imperfect information and insufficient information services (TEDA, 2006b). Considering these shortcomings, the Implementing Plan for the TEDA Circular Economy Pilot was promulgated in 2006. Following the main IS principles, this plan emphasized on optimization of energy structure, reclamation of regional steam condensation water, and the establishment of an
information platform for solid waste management. Furthermore, it stressed the incentive mechanisms to mobilize companies to disclose environmental information and join the IS network (TEDA, 2006b). In retrospect, these new goals paved the way for IS-type projects. A company obtaining the eco-management label for 3 consecutive years can receive a reward of RMB 30,000. Additionally, monitoring and evaluation have been strengthened since 2007. TEDA’s EPB regularly publishes the names of companies that fail the requirements for pollution discharge.

The transition of China’s national environmental policies also have impacts on TEDA’s development. As the Cleaner Production Promotion Law was formulated in 2003, the shift from end-of-pipe to source control and life cycle management has been strengthened (Zhang and Wen, 2008). Besides, the national EIP standards and the Guide for Planning and Construction of EIPs provide a clear definition of IS and the associated regulatory instruments in the following domains: wastewater treatment and recycling, solid waste disposal and reclamation, and energy cascading. Furthermore, the Circular Economy Promotion Law (2009) states that the development of a green-field (building new parks with ecological principles) and a brown-field industrial parks (revitalizing existing industrial parks) should follow the 3R principles: Reduce, Reuse and Recycle through the approaches of closed-loop chains and IS.

3.3.2 Environmental infrastructure facilitation

Several environmental infrastructures were built by TEDA Investment Holding Co. (a state-holding company authorized by TEDA’s AC), according to the instructions of TEDA’s National Level EIP Development Planning (2002) and the Implementation Plan for TEDA’s Circular Economy Pilot Project (2005). The first wastewater reclamation plant was initiated in 2000. By 2007, the regional water cycle system had taken shape. The idea is to integrate wastewater in-situ regeneration, wastewater treatment plants, recycled water and ecological landscape restoration to provide high-quality water to the users in the whole industrial park. Fig. 2 shows the water cycle system and the design capacity of the plants. New Water Sources Plant supplies the high purity recycled water with
the technologies of reverse osmosis and continuous micro-filtration for users demanding water of high purity.

In 2005, Binhai Energy Cogeneration Plants generated 2.04 million tons steam and 95570 kWh electricity (Binhai-Energy, 2005). The main steam users were Toyota, Tingyi Food, Chia Tai Group, Novozymes Biotechnology, Tingjin Food, Nanqiao Oil, Hartwell Textle, Zhongxin Pharmaceutical, Fuji Protein and Idemitsu Lube. Fly ash from the coal-fired production can be completely reused by TEDA Eco-landscaping Development Company. Fig. 3 shows the energy flow of TEDA co-generation plants. The problem of inefficient steam condensate reclamation persisted, however. By the year 2008, only one company reclaimed and transformed the condensate water back to Binhai Energy. The amount was only 7000 tons which accounted for 0.4% of the total steam consumption for industrial production. The rest was all discharged into the sewers. Moreover, only one-fifth of the steam can be consumed in summer, which means a capacity of 800 tons steam per hour is left unused. To improve the efficiency of the co-generation plants, TEDA has listed a number of key projects for condensate water reclamation and thermo electric air-conditioner by waste steam to stimulate companies and investors.

3.3.3 Economic and financial enablers

To further trigger and foster the spontaneous IS activities, since 2007 subsidies and funds have been provided for new water sources, reduction of resource and energy, and reclamation of solid waste. TEDA's AC issued the Provisional Regulation for Promoting Energy-saving, Cost-reducing and Environmental Protection in 2007. According to this guidance, a special fund of RMB 1 hundred million per year is provided to promote the usage of new water sources, by-product utilization and energy-saving projects. Fig. 4 shows the amount of funds for environmental protection projects in 2007, 2008, 2009. In 2009, the total funds grew by 86% compared with 2007. And a total of 143 environmental projects were funded. The number and amount of funds on energy-saving projects is also growing. As shown in Fig. 5, from 2008 to 2009, the total number of funded projects on energy-saving increased from 6 to 95 and the amount of the funds grew by 83.6%. Furthermore, in order to
encourage environmental data disclosure among companies, in 2010 TEDA’s AC awarded RMB 30,000 to every company that kept publishing environmental information for 3 consecutive years.

3.3.4 Informational activity

In April 2004, a Waste Minimization Club (WMC) was established in TEDA. As a NGO, the WMC was a sub-project of the EU-China Environmental Management Cooperation Program (EMCP) (2003-2005). The EMCP aimed to enhance company environmental awareness and to provide relevant knowledge and technology for facilitating waste exchange and recycling. The point of the WMC is to foster spontaneous action among pioneer companies through profitable waste minimization, and then to gradually expand the effect to the whole industrial park. Although TEDA’s AC provides only limited funding, the committee promises not to intervene during the projects. While the EMCP was running, experts organized by the EU and TEDA selected one company each month and investigated the efficiency of its energy and water usage. Then potential solutions were discussed with the company to minimize waste. From July 2004 to March 2005, the WMC’s first term attracted 10 companies (e.g., Lafarge-Aluminates and GlaxoSmithKline). A total of 52 low/free-cost solutions were proposed to realize waste heat recovery, the reduction of energy/water/raw materials, waste recycling, and pollution treatment (Zhang et al., 2007). The payback period for most of these was less than a year. Table 3 shows the results of the first term of WMC: the total capital saving was approximately RMB 8.8 million. TEDA WMC is still active even though the EMCP has ended. It is a platform for training and knowledge dissemination about waste minimization and IS. A problem, however, is that the main participants are either the leading or the problematic companies. How to attract the average companies to expand the good practices remains an issue (Zhang et al., 2007).

To trace TEDA’s solid waste flow, a Solid Waste Management Information System (SWMIS) was developed by the EPB and EMCP group in 2004. It provided an online questionnaire for a waste information database. In addition, the online system can also analyze the data to assist the waste trade market. Also, several workshops were organized by the EPB to train companies to use the online system. During the EMCP, SWMIS implemented online surveys twice in 2004 and 2005, respectively.
The surveys involved 62 solid waste producers (accounting for 85% of this type of companies in TEDA) and 57 recycling companies (Zhang et al., 2007).

In early 2010, another coordination body, TEDA’s Low-Carbon Economy Promotion Center (called TEDA Eco-center) was set up by TEDA’s AC. The center is a hub to explore and disseminate knowledge and information about IS, energy saving and environmental protection. It is responsible for engaging stakeholders to join eco-oriented business projects and to assist companies to identify synergy possibilities (TEDA, 2010a). The Eco-center hosts the Industrial Symbiosis and Environmental Management System Program under the EU Switch-Asia Project since 2010. Matchmaking workshops are the main platforms to discover potential synergies and company communication. At the workshops, participants are asked to fill in forms about their by-products, waste and spared resources. Afterwards, the Eco-center analyzes the data and identifies potential synergies. In this way, suppliers and receivers of materials can be connected. Additionally, the Eco-center provides consultancy services for alternative eco-solutions. Meanwhile, information about by-products, solid waste and waste energy can be better traced. By the end of 2011, TEDA’s Eco-center had organized 6 match-making workshops and 8 IS conferences (Eco-center, 2011). It also undertakes training and educational services in collaboration with research institutes.

3.3.5 Company activity

Four recycling companies settled in TEDA in 2006, attracted by the large volume of solid waste from electronics and telecommunications, and the automobile industries. Taiding (Tianjin) Environmental Technology mainly works on e-waste recovery with the treatment capacity of 30,000 tons/year. Tianjin Toho Lead Recycling reuses the lead from battery manufacturing and auto parts to produce lead alloy. From 2008 to 2010, Tianjin Toho recycled 30,000 tons of lead waste in TEDA (TEDA, 2010a). The scrap steel produced by Toyota is disassembled by Tianjin Fengtong Recycling and then sent to Tianjin Rainbow Hills Cast Iron to make casting (TEDA, 2011b). The casting is reused by Toyota to produce grinding tools for auto parts. Thus, scrap steel is reclaimed as a resource in the automobile industrial chain.
Since the IS program (within the EU Switch-Asia Project) was launched in 2010, 536 companies within TEDA have been recruited in IS events. In 2010 and 2011, 13 and 14 by-product exchange projects have been completed, respectively. These involved packaging waste, scrap iron, wastewater treatment and waste oil. All synergies were one-to-one matches. Table 4 shows the environmental and economic results of these synergy projects. Meanwhile, the number of companies who publish environmental information was 14, 26, and 29 in the years of 2008, 2009, 2010 (EPB, 2012).

However, one drawback of the strong government involvement in the IS project was that some companies only passively participated in the beginning (Sun et al., 2011). Many companies would have preferred to use existing logistics relationships for waste disposal rather than exchange their by-products or recovered resources, because the profit margins of these synergy projects are lower. Since company managers have been trained in traditional business models, their interest to join IS events has often been limited.

3.4 System analysis

The system analysis is based on the event sequence analysis of the 5 key activities. Basically, the years 2000-2005 were the initial era of TEDA’s eco-transformation with the themes of cleaner production, ISO14001 and construction of environmental infrastructures. The era was characterized by the fact that IS-related company activities were not very significant (see Fig. 10). During this era, the emphasis of the planning and guidance was on intra-firm cleaner production, building water treatment plants and co-generation plants, and connecting the industrial chains. Infrastructures were mainly launched before 2006 (see Fig. 7). Fig. 8 indicates that in this era few events related to economic and financial incentives targeting encouraging company activities, except for the WMC funding in 2004. The informational activities were at a stable and low level (Fig. 9) of no more than 5 events per year. Unlike the culture of cooperation in Kalundborg, the companies in TEDA lacked of inter-firm
communication most of the time (Sun et al., 2011). Furthermore, in this period there was no main coordinating body that could have improved the situation of incomplete information and fostered the dissemination of IS-related ideas to a wider business community. Consequently, by-product exchange and information disclosure were not substantial (Fig. 10). This type of events appeared only about 10 times per year.

The tide seems to have changed since 2006 when the Implementation Plan for TEDA’s Circular Economy Pilot was carried out. In this emerging era, IS-related company activities increased markedly (Fig. 10) and physical synergies gradually emerged. Prevalent institutional incentives triggered companies to spontaneously share information and to join the IS network. Fig. 6 shows a trend of growing institutional activity, which implies a positive governmental involvement in building up the institutional environment for IS in TEDA. The monitoring and evaluation of the environmental impacts were also strengthened (see Fig. 6). The companies that failed the evaluations could be deprived of preferential policies. As the new environmental infrastructures were launched, more and more companies began to use recycled water and steam subsidized by TEDA’s AC. The special funds in 2007 for environmental protection projects and energy saving gave an additional impetus to company participation. Ever since, the economic incentives have been consistently strengthened (Fig. 8). Financial rewards were also given to companies that continued publishing their environmental information. Meanwhile, the coordinating body, TEDA Eco-center, functioned as a broker to provide the information and knowledge essential to build new IS relationships and to identify the potential synergies. These developments explain the growth in Fig. 9 of informational activities since the establishment of the Eco-center in 2010. The number of events in 2011 increased by 85% compared with those in 2009. The awareness of IS and the inter-firm communication was enhanced through several conferences and training organized by the Eco-center. Meanwhile, as economic incentives were offered, companies were encouraged to consider alternative solutions for solid waste reclamation and wastewater treatment. Fig. 10 indicates that a surge of company activities occurred in 2010 on physical synergies, information exchange and disclosure. Networking activities created more opportunities for by-product exchanges, and strengthened the common understanding.
agreements were achieved for by-products and waste exchange. These successful practice led more company activities to join the IS program.

In spite of the progress in TEDA, no small number of barriers remains. In the interviews with local authorities and coordinators in TEDA, two main difficulties for TEDA’s eco-transformation were mentioned:

1. As a mixed industrial park, TEDA has a large number of companies from diverse industrial sectors who produce different types of waste. This is a consequence of the unplanned industrial structure of TEDA since its establishment in the 1980s. The fragmented industrial composition limits the possibilities for connecting industrial chains. The strategy of closed-loop chains was tried through inviting companies to settle down in TEDA, aiming to reclaim the waste in the industrial chains. This enforcement to create closed-loop chains may have had a short-term effect, but in reality the links did not evolve in a natural way, which resulted in incompatible and unstable couplings.

2. There is no landfill tax nor Extended Producer Responsibility for general industrial waste in China, which results in a lack of pressure and motivation for companies to reduce, reuse and recycle. In addition, the current environmental regulation has an institutional barrier as it lacks of practical and standardized instructions. The regulations on industrial waste classification and reclamation are not systematic. And the immature market of waste recycling is taken by unqualified recyclers.

To overcome the first barrier, TEDA is operating the IS program in order to engage companies from various sectors in a symbiosis network that is flexible and can increase cooperation. The economic and environmental benefits from by-product exchange projects can be quantified and traced by TEDA’s Eco-center. The combination of closed-loops within chains and networks of synergies between chains may be a solution for the eco-transformation of mixed industrial parks. Regarding the second barrier, TEDA can only guide companies to join the IS network through incentive policies and dissemination at the park level, the effect of which is still limited. The central government should issue clear and
specific regulations to promote waste reclamation and waste recycle market. The relevant laws will also need to be strictly enforced.

TEDA’s eco-transformation reveals a typical government-driven model in China where planning comes first, accompanied by other supporting policies (e.g., infrastructure services and economic incentives). Fig. 11 and Fig. 12 indicate the relevant actors mentioned above in 2000-2005 and 2006-2011. The arrows show how the actors influence each other in terms of institutional activity, technical facilitation, economic and financial enablers, informational activity, and company activity regarding IS (interpreted as material flow and energy/water flow). As revealed by these two figures, the role of TEDA’s AC varied in different phases. It initially concentrated on planning and building infrastructures through investments and subsidies. Then the goals shifted to the incentive policies for IS and the evaluation and monitoring. The coordinating bodies in the business community and government, such as the WMC and the Eco-center, provide platforms for communication and consultation to assist policy implementation. Especially the Eco-center, as shown in Fig. 12, plays the role of catalyst in generating a common understanding on eco-solutions. Fig. 11 and 12 also show how the main IS activities expanded over time from only utility sharing to more actual by-product exchanges and information sharing. Some companies in TEDA gradually evolved into material supplier, recycler and receiver. These findings suggest that the intervention at the park level can indeed facilitate the eco-transformation of industrial parks (e.g., adjustment of industrial structures, eco-labeling, rewarding solid waste reduction). However, TEDA, like many other EIPs, is also influenced by national institutional arrangements. Although current environmental and energy laws in China provide directive goals and guidance, the specific regulations have not been established yet. In other words, the gap between “what to do” and “how to do it” still needs to be bridged. Only a systematic institutional framework can thoroughly change the activity patterns toward actual eco-industrial development.

4 Discussion

4.1 Reflection on the approach
Process analysis has provided a novel view to grasp EIP development and to learn lessons from a historical case that continues to develop. By applying the framework, we assembled a database from individual events that enabled us to make a system analysis. We learned that understanding the eco-transformation of industrial parks requires dynamic systems thinking. When steering the eco-transformation, the strategies and decisions should be underpinned with a holistic understanding about what drives the transformation by what mechanisms, and how various drivers and mechanisms interact. We have deconstructed this web of drivers and mechanisms in five key activities: institutional activity, technical facilitation, economic and financial enablers, informational activity and company activity. The development in TEDA across the years has shown that each of these five activities does matter, but not equally in every phase. In this particular case, company activity was relatively weak compared with the others and the role of public authority was strong and dominant. In different phases, the intensity of various activities changed and the contributions made by various actors to these activities also varied. Across the board, a close reading of the qualitative and quantitative data indicates that TEDA shifted from a planned to a more facilitated model, with a positive outcome for the EIP’s performance. It thus appears that one can draw valuable lessons from mapping the events using the approach we developed. Across case studies, one can check if similar or different patterns can be established, whether similar mechanisms and drivers have led to different outcomes. Eventually, EIP management can be compared and appropriately selected. Only when the mechanisms that determine changes have been captured and understood can we give underpinned policy advice on how to steer the system.

4.2 Scope and applicability

The scope of this research has limitations. Our focus is on a regional industrial park, hence the technical facilitation focuses on public utility projects for co-siting. For cross-regional programs, such as NISP, technical facilitation may involve the use of ICT tools. Moreover, the TEDA case shows that company activity does not have as much influence at the system level as the other key activities. It seems that company activity is an outcome that is co-shaped by the other four. This explains that the developed framework is suitable for analyzing both planned and facilitated EIPs. In more self-
organizing environments, however, such as Kalundborg, company activity does play a vital role in driving the whole system and it changes the causal relationships between the key activities. Therefore, a next step should be to further validate and adjust the framework through applying it to other EIP cases in China and in other institutional and physical contexts.

TEDA’s trajectory has shown a transition from “a planned EIP” to “a planned plus facilitated EIP”. Government planning came first, and it soon was accompanied by supporting policies. In the initial era, networking utilities were provided for water and energy utilization. Several goals were set to guide the EIP’s continuous development, such as closed-loop chains and industrial symbiosis. Moreover, the coordinating body created by the local authority strengthened the common understanding of IS business and promoted the spontaneous collaborative behavior among firms. Such an actor can integrate the information streams of local waste, water, energy and by-products. The coordinator can offer technical and consultancy services to uncover and foster synergy possibilities. It also provided decision-making advice to the national government to adjust the wider institutional framework in desirable ways. This strengthens the argument made by Chertow et al. (2012) that the top-down planned EIP model which stresses matching flows alone is less successful. The key is to stimulate firms to join and accept shared behavioral norms and a common understanding, which facilitates the continuous inter-firm exchanges and the resource conservation.

TEDA’s approach is driven by public policy in the sense that it reveals the primary focus on institutional activity and the relative weakness of company activity. TEDA reflects a wider Chinese tendency that lets public authorities take a leading role in EIP development. However, it would be premature to assume that the same tendency exists or even should exist in other national and regional contexts. In terms of the systems approach laid out in this article, one could argue that the set of five activities to analyze EIPs around the world are likely to remain the same (therefore more or less “universal”), but their relative importance in general and the developmental phases can be different from that of TEDA. Subtle differences may already exist among various cases in China, where the national institutional framework is largely the same. Different contexts such as those in Denmark or the US are likely to show different interrelations and importance of the activities throughout
development stages. Consequently, drawing policy lessons (Rose, 1993) regarding the successful intervention in eco-transformation from Denmark to China and transplanting institutions from Kalundborg to TEDA or vice versa cannot be underpinned by scientific evidence yet in this research. In other words, before policy recommendations can be formulated for a given case based on the lessons from another one, more research and analysis is needed on how institutional specificities, local preferences and the physical context (Jong et al., 2002) affect the five key activities and what the implications are for policy transferability.

5 Conclusion

We have adapted the methodology of process analysis to deconstruct the mechanisms of eco-transformation and how the changes of an EIP unfold over time. An approach has been developed rooting in process analysis, industrial symbiosis and socio-technical systems to trace the five key activities that drive the evolution of an EIP. The structured process analysis approach directs one to bring together qualitative information about the events in an EIP system and their sequence over time. The database thus built allows one to quantify trends of the key activities.

The approach was applied to the TEDA case in order to analyze TEDA’s eco-transformation between 2000 and 2011. The application of the analytical approach was examined through the case study. Overall, the five key activities sufficiently cover the main determining factors during an EIP’s development. Thus we conclude that the process analysis approach led to a structured and documented analysis that is open to adjustment, expansion and critique. These characteristics make the approach amenable for an institutional environment that differs from the Chinese context, as the relative importance of the five key activities and the recommended policies can be different. Through developing a systemic analytical framework, a major step has been taken to deconstruct EIP development and to enrich our understanding about the underlying mechanisms and drivers of eco-transformation. Further work is required to flesh out how this framework is to be deployed or adjusted in the different institutional contexts. Comparative analysis may provide clues on the possibilities, limitations and pre-conditions for transferring policy recommendations across borders.
Acknowledgments

The authors would like to thank Frank Boons and Wouter Spekkink for inspiring discussions on process analysis of industrial symbiosis. We are indebted to four anonymous reviewers and to Elias de Valk for discussing the function of innovation systems approach. We greatly appreciated the hospitality and assistance received from TEDA’s Eco-center and TEDA’s Environmental Protection Bureau staff. This work was supported by the Next Generation Infrastructures Foundation (http://www.nextgenerationinfrastructures.eu/).

Reference

A CCEPTED MANUSCRIPT

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Highlights

- We develop a process analysis approach which can structure the key activities influencing changes in eco-industrial park systems, and track the dynamic process of the system development over time.
- The literature review is provided to generate five key activities determining the development of an eco-industrial park as well as the indicators for tracing these activities through time.
- Applying the approach to the case study, we analyze the evolution process of Tianjin Economic-technological Development Area in China from 2000 to 2011.
- Using the process analysis approach leads to a structured and documented analysis that is open to adjustment, expansion and critique.
- Conclusions are drawn on the approach application and the determinants for successful eco-transformation of industrial parks.
<table>
<thead>
<tr>
<th>Determining factors</th>
<th>References</th>
<th>Classified as key activities</th>
</tr>
</thead>
</table>
| • Detailed and flexible planning for medium and long-term goals.  
  • EIP promoters (authority) provide guidance and put frameworks in place to encourage interaction among companies.  
  • Institution set-up encourages green business activities to identify potential synergistic partners.  
  • Voluntary agreements with a group of member companies. | (Chertow, 2007; Chiu and Yong, 2004; Costa et al., 2010; Desrochers, 2001; Ehrenfeld and Gertler, 1997; Fang et al., 2007; Gibbs and Deutz, 2007; Lehtoranta et al., 2011; Mathews and Tan, 2011a; Mirata, 2004; Park et al., 2008; Pellenborg, 2002; Roberts, 2004; Shi et al., 2010; van Beers et al., 2007; Zhang et al., 2010) | Institutional activity (park-level) |
| • Evaluation and regular monitoring to ensure ecological and economic goals.  
  • Environmental assessment. | (Côté and Hall, 1995; Geng et al., 2009a; Geng et al., 2008; Mirata, 2004; Zhang et al., 2010) | |
| • Public policy targets and intervention for IS program.  
  • Policy makers (regional and national governments) provide guidance and put frameworks in place to encourage interaction among companies.  
  • Government provides rewards for the best practice and announces the names of the companies that fail to meet the requirements for IS.  
  • Standards (about EIP, reused and recycled products).  
  • National environmental laws and regulations.  
  • Market-driven actions (e.g. enhancing private property rights; making due allowance). | (Boons, 2008; Chertow, 2007; Chiu and Yong, 2004; Côté and Smolenaars, 1997; Fang et al., 2007; Geng et al., 2009b; Heeres et al., 2004; Lehtoranta et al., 2011; Mathews and Tan, 2011a; Park et al., 2008; Tudor et al., 2007; Yong, 2007; Yuan et al., 2006; Zhang and Wen, 2008) | Institutional activity (regional/national) |
| • Infrastructures and cost efficient technologies (water, waste disposal, energy cascading and co-generation, ICT tools, service, transport) for enabling industrial symbiosis. | (Chertow, 2007; Chiu and Yong, 2004; Côté and Cohen-Rosenthal, 1998; Grant et al., 2010; Heeres et al., 2004; Mirata, 2004; Park et al., 2008; Shi et al., 2010; Tudor et al., 2007; van Beers et al., 2007; Wang et al., 2006) | Technical facilitation |
| • Subsidies, special funds and investment.  
  • Profits from symbiotic operation. | (Chiu and Yong, 2004; Côté and Smolenaars, 1997; Ehrenfeld and Gertler, 1997; Jacobsen, 2006; Lehtoranta et al., 2011; Tudor et al., 2007) | Economic and financial enabler |
| • Preferential tax policies for environmental projects and equipment about energy saving and waste reduction.  
  • Price reforms for resources (e.g. preferential fee for reused water/increasing charges for disposal of wastes).  
  • Low-cost of waste disposal/low price for utility resources/high landfill tax. | (Costa et al., 2010; Côté and Cohen-Rosenthal, 1998; Geng et al., 2009b; Mathews and Tan, 2011b; Park et al., 2008; van Beers et al., 2007) | |
| • Inter-firm networking organized by coordination bodies.  
  • Activities for reducing the “mental distance” and cognitive barriers through workshops, training, conferences, dissemination.  
  • Information gathering (basic company | (Chertow and Ehrenfeld, 2012; Chertow, 1998; Chiu and Yong, 2004; Côté and Cohen-Rosenthal, 1998; Côté and Smolenaars, 1997; Geng et al., 2009b; Gibbs and Deutz, 2005; Heeres et al., 2004; Lowe, 1997; | Informational activity |
<table>
<thead>
<tr>
<th>Information, capacities, resource streams, materials, by-product and etc.).</th>
<th>Mirata, 2004; Mirata and Emtairah, 2005; Park et al., 2008; Roberts, 2004; Sakr et al., 2011; van Beers et al., 2007; Zhang et al., 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconnaissance teams to identify the kernels of symbiosis.</td>
<td></td>
</tr>
<tr>
<td>Collective problem definition and feasibility research for potential synergetic partnership.</td>
<td></td>
</tr>
<tr>
<td>Collaboration on the exchange of energy, raw materials, water and by-products.</td>
<td>(Ashton, 2008; Chertow and Ehrenfeld, 2012; Chertow, 1998, 2007; Côté and Hall, 1995; Côté and Cohen-Rosenthal, 1998; Doménech and Davies, 2011; Gibbs and Deutz, 2005, 2007; Heeres et al., 2004; Jacobsen, 2006; Mathews and Tan, 2011a; Park et al., 2008; Pellenbarg, 2002; Sakr et al., 2011; Tudor et al., 2007)</td>
</tr>
<tr>
<td>Exchange information for potential synergy opportunities.</td>
<td></td>
</tr>
<tr>
<td>Reuse and recycle by-products or waste.</td>
<td></td>
</tr>
<tr>
<td>Trust and cooperation between companies and between companies and government.</td>
<td></td>
</tr>
<tr>
<td>Anchor tenant participation as a “magnet”.</td>
<td></td>
</tr>
</tbody>
</table>

**Appendix 1. Key activities from the literatures for driving the changes of an EIP system**
| Positions and departments of respondents | 1. The Director of TEDA’s Environment Protection Bureau  
2. Two representatives of TEDA’s Administrative Committee  
3. One representative of TEDA’s Public Utilities Bureau  
4. The director and one project manager of TEDA’s Eco-center  
5. One representative of the policy research group |
| --- | --- |
| Interview questions | • How do you interpret EIP or IS based on the work of your department?  
• How do you incorporate and implement the principles of EIP in your work? Can you give some concrete examples?  
• What are the main drivers and barriers during TEDA’s eco-transformation?  
• What are the difficulties of your department to carry out the EIP-related work?  
• When you work with companies, how do companies response to EIP principles? What are the incentives or difficulties of companies to reduce waste or exchange by-products? |

**Appendix 2. Titles and departments of interviewees and the questions for interviews.**
<table>
<thead>
<tr>
<th>Key activities</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institutional activity</td>
<td>• Policies, regulations, planning, voluntary agreement and evaluation for EIP/IS (+1)</td>
</tr>
<tr>
<td>Technical facilitation</td>
<td>• Projects of infrastructures and utilities for enabling IS (+1)</td>
</tr>
<tr>
<td>Economic and financial enabler</td>
<td>• Financial incentives (funding and subsidies) (+1)</td>
</tr>
<tr>
<td>Informational activity</td>
<td>• Training and educational programs (+1)</td>
</tr>
<tr>
<td></td>
<td>• Feasibility/assessment research projects (+1)</td>
</tr>
<tr>
<td></td>
<td>• Workshops, conferences, seminars and forums for networking (+1)</td>
</tr>
<tr>
<td>Company activity</td>
<td>• IS projects started (+1)</td>
</tr>
<tr>
<td></td>
<td>• Join the information exchange activities for seeking synergy partners (+1)</td>
</tr>
<tr>
<td></td>
<td>• Environmental information disclosure (+1)</td>
</tr>
</tbody>
</table>

Table 1. Framework for identifying the events of key activities
<table>
<thead>
<tr>
<th>Year</th>
<th>Institution</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEDA</td>
<td>2000 TEDA Regional ISO14001.</td>
<td>Incentive policy</td>
</tr>
<tr>
<td></td>
<td>2000 Measures for exempting from sewage disposal fee (On trial).</td>
<td>Incentive policy</td>
</tr>
<tr>
<td></td>
<td>2002 Measures for encouraging new water sources (On trial).</td>
<td>Incentive policy</td>
</tr>
<tr>
<td></td>
<td>2005 Eco-labeling management system for industrial solid waste.</td>
<td>Incentive policy</td>
</tr>
<tr>
<td></td>
<td>2006 Implementing Plan for TEDA Circular Economy Pilot.</td>
<td>Planning</td>
</tr>
<tr>
<td></td>
<td>2007 The Guide for TEDA Environmental Information Disclosure. And the Catalogue for TEDA Environmental Information Disclosure, including government information disclosure, company voluntary and compulsory information disclosure.</td>
<td>Monitoring and evaluation</td>
</tr>
<tr>
<td></td>
<td>2007 Provisional Regulation for Promoting Energy-saving, Cost-reducing and Environmental Protection.</td>
<td>Incentive policy</td>
</tr>
<tr>
<td></td>
<td>2007 Initiated to quarterly publish the companies who failed the requirements for pollution discharge.</td>
<td>Monitoring and evaluation</td>
</tr>
<tr>
<td></td>
<td>2010 Provisional Measures on the High Energy Users in TEDA.</td>
<td>Monitoring and evaluation</td>
</tr>
<tr>
<td>National</td>
<td>2003 Cleaner Production Promotion Law.</td>
<td>Law</td>
</tr>
<tr>
<td></td>
<td>2003 Environment Impacts Assessment Law.</td>
<td>Law</td>
</tr>
<tr>
<td></td>
<td>2004 Law on the Prevention and Control of Environmental Pollution by Solid Wastes.</td>
<td>Law</td>
</tr>
<tr>
<td></td>
<td>2006 National Standards for Eco-industrial Parks (On trial) (Revised in 2009).</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td>2008 Guild for Planning and Construction of Eco-industrial Parks.</td>
<td>Planning</td>
</tr>
<tr>
<td></td>
<td>2009 Circular Economy Promotion Law.</td>
<td>Law</td>
</tr>
</tbody>
</table>

Table 2. Main institutional activities stimulating EIP at TEDA and national levels
<table>
<thead>
<tr>
<th>Themes</th>
<th>Raw materials</th>
<th>Fuel</th>
<th>Gas</th>
<th>Steam</th>
<th>Electricity-saving</th>
<th>Water-saving</th>
<th>Total capital saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving Results</td>
<td>1034.44 t/a</td>
<td>108 t/a</td>
<td>2340 m³/a</td>
<td>1191.69 t/a</td>
<td>593.87 10⁴ kWh/a</td>
<td>24.42 10⁴ m³/a</td>
<td>880.48 10⁴ RMB</td>
</tr>
</tbody>
</table>

Table 3. Results of materials and energy saving from the first term of TEDA WMC (Zhang et al., 2007)
<table>
<thead>
<tr>
<th>Number of recruited companies</th>
<th>Number of synergies</th>
<th>CO$_2$ reduction (10,000 tons)</th>
<th>Landfill diversion (10,000 tons)</th>
<th>Raw materials reduction (10,000 tons)</th>
<th>Revenue increase (RMB 10,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>536</td>
<td>27</td>
<td>1.1</td>
<td>0.3</td>
<td>0.3</td>
<td>552</td>
</tr>
</tbody>
</table>

Table 4. The environmental and economic results of the synergy projects within Switch-Asia Project by 2011. Data source: (Eco-center, 2011).
Fig. 1. The proportion of the industries in TEDA by 2010. Data source: website of TEDA Government
Fig. 2. TEDA’s water cycle system. The treatment capacity is the design capacity. Source: (TEDA, 2007b).
Fig. 3. Energy flow of TEDA co-generation plants. Source: (Shi et al., 2010; TEDA, 2008)
Fig. 4. Funds for environmental protection projects from TEDA’s Administrative Committee. Management projects include cleaner production verification, ISO14001 certification, environmental labeling product certification, national environment-friendly company, ecological management logos for industrial waste, and annual corporate social responsibility reports or environment reports. Engineering projects include situ sewage reuse, resource comprehensive utilization, flue gas desulphurization and demonstration project. Data source: (TEDA, 2010b). Unit: RMB $10^4$. 

![Graph showing funds for environmental protection projects](image-url)
Fig. 5. Number of energy-saving projects funded by TEDA's Administrative Committee. Data source: (TEDA, 2010b). Unit: RMB \(10^4\).
Fig. 11. TEDA’s system structure in the initial era (readers are referred to the online version of this article for colorful figure)
Fig. 12. TEDA’s system structure in the emerging era (readers are referred to the online version of this article for colorful figure)