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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.

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, 2011). 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

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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 effect at the EIP systems level?*

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 et al., 2007; Geng et al., 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 A.

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

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