審査の結果の要旨

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Dissertation Title:

Sustainability outcomes of eco-industrial park development in China: evidence from cases in Beijing and Tianjin

Industrial parks in China produce more than 60% of the national industrial output, and account for approximately 70% of the national energy consumption and 72% of greenhouse gas (GHG) emissions. To mitigate the negative impacts of industrial production the Chinese government initiated the eco-industrial park (EIP) programme in 2001. Entities within EIPs seek to reduce resource consumption and waste/pollution generation by forming industrial symbiosis to reuse and recycle material and energy by-products. The first national demonstrative eco-industrial parks (ND-EIPs) were approved for upgrade in 2001, and as of August 2020, 59ND-EIPs were operational (with another 48under development).

However, the drivers, stakeholders, regulations, and standards for the EIP programme have not been critically analysed. On the other hand, led by the Ministry of Environmental Protection (now the Ministry of Ecology and Environment), there have been revisions on the guidelines for EIP development.

However, the unbalanced focus of the guidelines is being criticised. For example, 12 out of 15 environmental indicators are related to eco-efficiency. There has been much research on the impacts of EIP upgrade, but the outcomes of several impacts are inconclusive. EIPs' temporal performance trends, environmental quality change, and social impacts are still rare in the literature. Among the 41 papers with specific indicators studied, only one mentioned a health aspect considering the fact that industrial parks attract people to work and live in them. As a result, the actual sustainability outcomes of EIP development and operation are still not clearly known.

The aim of this research is to explore the sustainability performance of EIPs, and especially whether the upgrade to EIP status improves sustainability. The specific focus is on two EIPs, the Beijing Economic and Development Area (BDA), and the Tianjin Economic and Development Area (TEDA). The objectives of this research are:

1) To identify the drivers, key institutional aspects and major challenges of the EIP programme in China;
2) To outline the sustainability performance of the case study EIPs for a series of sustainability aspects and indicators over time;
3) To assess whether the upgrading to an EIP improves the industrial parks' sustainability performance;
4) To offer policy implications and recommendations on how to improve the EIP programme.

For objective 1), an institutional analysis was conducted to identify and synthesize key aspects, including organizational and legislative formations, based on key policy documents and an extensive narrative-based review of the peer-reviewed literature. The results suggest that many stakeholders, including governments on varying administrative levels, enterprises, academics, industrial associations, and international funders, are involved in EIP development and operation, with the main drivers of EIP development anchored on the desire to sustain economic momentum without overburdening the environment, and the effort to reduce production costs and maintain

economic competitiveness. The approach of EIP development in China is top-down, evidenced by the legislation of various regulations, and the verification and entitlement process for EIPs.

For objective 2), through an extensive literature review on national guidelines for EIP programme, similar initiatives, such as green, and low-carbon industrial parks, and international frameworks, while considering data disclosure patterns of Chinese industrial parks, and being informed by data availability of selected case study EIPs, an indicator framework comprised of seven economic, 18 environmental, and seven social indicators is constructed, of which eight environmental indicators are on eco-capacity to balance indicators on eco-efficiency. These indicators cover aspects of economic output, employment creation, economic output efficiency, resource use, resource use intensity, resource reuse and recycling, waste and emissions, environmental quality, livelihood, and social services provision. Based on data availability, the trends of these indicators are identified for the period as early as 1987 to 2016, which encompasses the upgrade period for both EIPs (TEDA started upgrade in 2004, and 2009 for BDA; TEDA was verified in 2008, and 2011 for BDA).

Multi-Criteria Decision Analysis (MCDA) is utilised to test the overall sustainability of the case study EIPs across years using two tests, one with all indicators aggregated, and the other non-scale indicators aggregated to eliminate size and scale biases. Requirements in technical guidelines issued by the government are used as the difference threshold, otherwise, a 5% difference is assumed. Equal weights for sustainability pillars, and equal weights for indicators within each pillar are applied. MCDA shows that generally BDA improved its overall sustainability when all indicators were aggregated and considered. However, its sustainability worsened gradually when only non-scale indicators were aggregated and analysed. For environmental aspect, regardless whether it is the test with all indicators aggregated, or only non-scale indicators aggregated, BDA's environmental performance declined invariantly. For TEDA, regardless of the combination of indicators, its sustainability mostly improved gradually. However, for both EIPs, 2010 is exceptional in that it tends to be outperformed by at least one of the earlier years in all tests. Sensitivity analysis reveals that except for TEDA with non-scale indicators, the resulting ranks of all other tests are sensitive to changes in the weights of indicators.

For objective 3), time series analysis methods with varying tests are used to evaluate whether the upgrading to an EIP improved sustainability performance. The methods are:

i) Causal Impact: testing if EIP upgrade causes significant impacts compared to a baseline covariate. For comparison, another industrial park in the same city, and the industrial/urban data of the same city are used as covariates. Two tests for each covariate are conducted to examine whether and when the upgrade has effects on the parks' sustainability with the years the upgrade started and the years of verification as the intervention points.

ii) Interrupted Time Series: testing if EIP upgrade creates significant effects compared to the previous trend of the same indicator. In addition to setting the years of the start of upgrade and verification as intervention points, a test of gradual effect was added to this method.

The results show a mixed picture for different indicators.

i) Worsened indicators

Both EIPs have more indicators that deteriorated rather than improved in Causal Impact analysis. Economic output, economic output per employee, energy use per unit area, and healthcare coverage rate tend to be worse in tests for BDA. For TEDA, economic output, economic output per employee, economic output per unit area, freshwater use, and land use mostly performed worse in all tests. In Interrupted Time Series analysis, BDA worsened in economic output, economic output per employee, energy use per unit economic output, freshwater use

per unit economic output, greenhouse gas emissions, and wastewater indicators. In contrast, only economic output, economic output per employee, and greenhouse gas emissions show deterioration in more than two tests at TEDA.

ii) Improved indicators

BDA shows better performance in economic output per unit area, monthly payment per employee, land use, and pension coverage compared with another industrial park in Causal Impact analysis. On the other hand, it has better employee number, reclaimed water sales, wastewater treatment capacity, healthcare coverage, pension coverage and compulsory education enrolment compared to the test of the industry/urban data of Beijing as covariate. Results are similar in Interrupted Time Series analysis.

TEDA improved in employee number, wastewater discharge per unit area, affordability of housing, and compulsory education enrolment compared to another industrial park in Causal Impact analysis, while it has better monthly payment per employee, reclaimed water sales, wastewater discharge per unit area, and compulsory education enrolment compared to the industry/urban data of the city of Tianjin as covariate. In Interrupted Time Series analysis, energy use per unit area, waste heat use, and amount of wastewater discharge improved.

Based on a synthesis analysis linking existing literature, four main factors that potentially influence the patterns of the change of the indicators are identified, namely, a) the economic and industrial structure of the EIPs, b) expansion of the EIPs, c) external pressure, and d) national and regional policies relevant to the two cities.

For objective 4) research suggests that EIP upgrade does not always translate into positive sustainability outcomes for many indicators with varying test methods. There is little knowledge about the actual environmental quality change, and social impacts of EIPs, possibly due to the omissions of eco-capacity and relevant indicators incurrent standards. Main policy implications for the better implementation of the EIP programme include (a) filling in the gaps in, and lack of adherence to EIP guidelines, standards and assessment frameworks, particularly in environmental quality and social impact aspects; (b) integrating wider socio-ecological systems into the implementation of industrial/urban symbiosis as more non-industrial activities grow in and surrounding the EIPs; (c) policies on land use, and social services provision should be better designed to reflect the carrying capacity of the environment, and the wellbeing of the employees and residents; and (d) improving data disclosure, its consistency and quality, which enables further research and evaluation for knowledge generation.

Portions of Chapter 1 and 3 have been published as a joint paaper (Journal of Cleaner Production) by the student (Hongru Hong) and the PhD supervisor (Alexandros Gasparatos). Chapter 4-5 will also be submitted for joint publications between the two authors. In all cases the student undertook the majority of the research activities, in particular designing the research approach, collecting the data, analyzing the data and writing the original versions of the manuscripts. The supervisor provided feedback and recommendations throughout these activities.

This committee unanimously agreed to award the degree of Doctor of Sustainability Science.

よって本論文は博士（サステイナビリティ学）の学位請求論文として合格と認められる。

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