Doctoral Thesis

博士論文

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

（中国におけるエコ・インダストリアル・パークの建設がもたらす持続可能性の変化：

北京と天津での事例研究）

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Abstract

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.

However, the drivers, stakeholders, regulations, and standards for the EIP programme have not been critically analysed. On the other hand, the unbalanced focus of the governmental 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. 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;
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 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.

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. 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 performance of different aspects 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 economic performance when all indicators were aggregated and considered. However, its economic aspect worsened gradually when only non-scale indicators were analysed. For environmental aspect, regardless whether it is the test with all indicators, or only non-scale indicators, BDA's environmental performance declined invariantly. For TEDA, regardless of the combination of indicators, its economic aspect mostly improved gradually. The negative environmental aspect of TEDA fluctuated when all indicators were considered, but it improved when considering only non-scale indicators. Both EIPs' social aspect fluctuated throughout the years. 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, namely Causal Impact and Interrupted Time Series with varying tests are used to evaluate whether the upgrading to an EIP improved sustainability performance. For Causal Impact analysis, 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. For Interrupted Time Series analysis, in addition to setting the years of the start of upgrade and verification as intervention points, a test of gradual effect was added.

The results show a mixed picture for different 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.

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 with the industry/urban data 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 of climate and geographic conditions, 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 actual environmental quality change, and social impacts of EIPs, possibly due to the omissions of eco-capacity and relevant indicators in current standards. Main policy recommendations for the better implementation of the EIP programme include (a) filling in the gaps in EIP guidelines and assessment frameworks, particularly in environmental quality and social impacts, and evaluation methods, and strengthening monitoring after verification; (b) integrating wider socio-ecological systems into the implementation of industrial/urban symbiosis as more non-industrial activities grow; (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, to enable further research for knowledge generation.

Acknowledgements

At this end of the three years and nine months journey, or longer if the contemplating and application processes were considered, it is fitting for me to take this opportunity to express my heartfelt appreciation to those who have helped me along the way. I could not have finished this Doctorate course without you.

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Finally, I want to give thanks and praise to the triune God, the creator, sustainer, and restorer of this universe, whose call to care for the creation has inspired me to do this research. All praises to Him! Amen.

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List of Abbreviations

ASD	Agenda for Sustainable Development
BDA	Beijing Economic-Technological Development Area
BND	Binhai New District
CI	Causal Impact
CO_2e	Carbon dioxide equivalent
EIP	Eco-industrial park
EPA	Environmental Protection Agency (existed until 2007)
FDI	Foreign direct investment
GHG	Greenhouse gas
GIS	Geographic Information System
IAV	Industrial added value
IPCC	Intergovernmental Panel on Climate Change
IPUU	Industrial processes and product use
ITS	Interrupted Time Series
LCA	Life Cycle Assessment
MCDA	Multi-Criteria Decision Analysis
MEE	Ministry of Ecology and Environment (founded in 2018)
MEP	Ministry of Environmental Protection (existed between 2007 and 2018)
MIIT	Ministry of Industry and Information Technology
MOE	Ministry of the Environment of Japan
MOF	Ministry of Finance
MOFCOM	Ministry of Commerce
MOST	Ministry of Science and Technology
NBSC	National Bureau of Statistics of China

ND-EIP	National demonstrative eco-industrial park
NDRC	National Development and Reform Commission
OECD	Organisation for Economic Co-operation and Development
OH&S	Occupational health and safety
RMB	Renminbi (Chinese currency)
SCE	Standard coal equivalent
SDGs	Sustainable development goals
TEDA	Tianjin Economic-Technological Development Area
tsce	Tonne of standard coal equivalent
UNIDO	United Nations Industrial Development Organisation
ZSP	Zhongguancun Science Park

Chapter One

Introduction

1.1 Industrial sector in China

Industrialisation has been one of the main targets of development for China for the last one century (Wen, 2016). In the 1950s, China launched the Great Leap Forward with an aim to catch up with other industrialised countries (Jung and Chen, 2019). Industrial sector then was more inward-looking and with distinct characteristics of planned economy (Onoye, 1982). After China initiative the Reform and Opening-Up policies in the late 1970s, industrial sector has been growing at an unprecedented level and with features different from earlier patterns. In 1984, China set up the first batch of industrial parks in a few coastal open cities[1] as experiment for economic reform, which marks another milestone for the development of industrial sector in China. These industrial parks are normally called the first generation of industrial parks in China (Chen and Ma, 2008) and come under the administration of the Ministry of Commerce (MOFCOM, then Ministry of Foreign Trade) as it deals with cross-border trade. In 1988, some high-tech development parks were built to speed up the industrialisation process with a focus of innovating and utilising advanced technology. These industrial parks are termed second generation industrial parks (Chen and Ma, 2008) and administrated by the Ministry of Science and Technology (MOST, then National Commission of Science and Technology).

Industrial parks in China were founded in line with foreign export processing zone to attract foreign investment and locomote the export-orientated economy of China (Zhao et al. 2014). The first generation of industrial parks often go with names such as Economic and Technological Development Area/Park/Zone, Free Trade Zone, and National Tourism Vocation Zone. The second generation has names like New and High-Tech Industrial Development Area/Park/Zone. For the purpose of this thesis, the first and second generations of industrial parks are conclusively called conventional parks. (Zhao et al. 2014, Chen fand Ma, 2008).

Industrial parks increased rapidly in number reaching 2543 in 2019 (Piatkowski et al., 2019). They are also significant in the Chinese economy. In recent years, industrial parks produce more than 60% of the national industrial output (Fan et al., 2017c), and account for approximately 70% of the national energy consumption and 72% of greenhouse gas (GHG) emissions (Thieriot and Sawyer, 2015). Due to their

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1 Coastal open city in China are Dalian, Qinhuangdao, Tianjin, Yantai, Qingdao, Lianyungang, Nantong, Shanghai, Ningbo, Wenzhou, Fuzhou, Guangzhou, Zhanjiang and Beihai, which enjoy certain policy treatments and preferences in foreign trade.

substantial demands for labour, industrial parks have also been a pushing factor for urbanisation and internal migration in China (Zhao et al., 2014).

Industrial parks have a focus on clustering and developing industrial sectors of manufacturing, construction, and tertiary industry. Agriculture is literally non-existential in industrial parks. As China aims to promote higher value-added and less environmentally burdensome industries (Li and Bao, 2017), industrial parks also act as pioneers in attracting and cultivating high-end industries, such as tertiary industry (Tian et al., 2014).

Nevertheless, most of the conventional industrial parks did not adopt sound pollution prevention measures (Pan et al., 2016), and thus have been linked to high levels of resource depletion and environmental degradation (Liu et al., 2017b). Despite the tighter environmental regulation following the 1989 Environmental Protection Law (Li, 2004), environmental quality has not improved appreciably due to the combined effects of low environmental awareness, outdated technologies, and implementation weaknesses (Zhang and Sun, 1999). In addition, environmental problems in China are complex, with industrial parks being just one of the multiple contributing sources. For example, the prevalence of smog has been linked to coal combustion, motor vehicle emissions and industrial sources (Pui et al., 2014, Wang et al., 2016) , domestic biofuel combustion and biogenic emissions (Liu et al., 2016a), and dust (Liang et al., 2016), among others.

It is neither efficient nor straightforward to tackle pollution sources individually, especially when scattered spatially. Industrial parks offer a great advantage for environmental mitigation efforts in that they have multiple polluters congregated in the same area, which makes easier the promotion and adoption of environmental mitigation technologies. This has been one of the main rationales of a series of environmental investments and national programmes to upgrade conventional industrial parks through the introduction of environmentally friendly technologies.

1.2 Industrial park transformation efforts

Regulations are a straightforward means to manage the operations of industries and individual companies. *"Environmental Protection Law of the People's Republic of China"* (amended for the second time in 2015) is the fundamental ministerial regulation in China. Consistent with the core values of this ministerial regulation, three-simultaneity principle has always been reinforced in its history and implementation, which requires all construction projects to meet the requirements of making sure environmental protection facilities are simultaneously designed, constructed and put into use with the main facilities (State Council, 1998).

There are other basis industrial laws governing the practicalities of industrial activities such as *"Clean Production Promotion Law of the People's Republic of China"* (effective from 2003) , *"Energy Conservation Law of the People's Republic of China"* (effective from 2008), *"Circular Economy Promotion Law of the People's Republic of China"* (effective from 2009) etc.. Parallel with those ministerial or industrial laws are strategic documents issued by the ruling party and the State Council such as *"Opinions on Accelerating the Promotion of Ecological Cultural Construction"* (issued in 2015).

On the other hand, there are programmes initiated to encourage change of operations and behaviours. For example, the Ministry of Ecology and Environment (MEE, then Environmental Protection Agency, EPA) co-operated with MOFCOM and MOST to start a National Demonstration Eco-Industrial Park (EIP) programme in 2001. National Development and Reform Commission (NDRC), the Ministry of Finance (MOF) and another four ministries and bureau also initiated a Pilot Circular Economy programme, covering transformation of key industrial sectors, fields, industrial parks, and cities in 2005. In 2013, NDRC and Ministry of Industry and Information Technology (MIIT) launched a Pilot Low Carbon Industrial Park programme, promoting the decarbonisation of industrial parks. As recent as 2016, MOST began a Demonstrative Innovative Zone programme in line with 2030 Agenda for Sustainable Development issued by the United Nations. These standards have different foci, but all have the intention to catalyse the transformation of the material and energy flows of economic activities from linear to circular, and from individual to symbiotic patterns (Table 1).

This study would focus on the National Demonstration Eco-Industrial Park (EIP) programme as 1) it has a longer history than other programmes enabling more feasible time series analysis, 2) its target, industrial parks have clearly delineated system boundaries, and 3) its transformation is more comprehensive and not limited to one aspect, for example, decarbonisation.

Table 1. programs related to the transformation of the industrial sector

Program	Leading Government Body (and others)	Foci of Implementation	Targets	Status quo
National Demonstrative EIP	EPA (MOFCOM and MOST)	Resource minimisation, waste minimisation. Construction of National Demonstrative EIPs. (EPA et al., 2007)2	Economic and Technology Development zones and High-Tech Development zones	Implemented in 2001, ongoing.
Circular Economy Demonstrative Zone	EPA	Pollution prevention, material circular flow (World Bank, 2007)	Cities and provinces	Implemented in 2002, replaced by Pilot Circular Economy
Pilot Circular Economy	NDRC (EPA, MOST, MOF, MOFCOM and Bureau of Statistics)	Selective of certain industries and sectors, research, pioneer and education purposed. Construction includes 1. demonstrative units of certain industries and sectors, 2. upgrading of industrial parks,3. urban mining and 4. demonstrative cities. (NDRC et al., 2005)	Companies and parks of key industries and sectors, cities and provinces	Implemented in 2005, ongoing.
Pilot Low Carbon Industrial Park	MIIT and NDRC	Selective of well founded, featured, representative and compliant industrial parks for work of 1. Promotion of renewable energies; 2. Decarbonisation of steel, construction material, non-ferrous, petroleum and chemical and other energy intensive sectors; 3. Development of low carbon enterprises; 4. Popularization of low carbon management model of industrial parks feasible in China; and 5. Achievement of leading carbon intensity level in the country, setting examples for decarbonisation of industrial development. (MIIT and NDRC, 2013)	Aim for denomination of 80 low carbon industrial parks. First batch of 39 trial industrial parks was approved in August 2015, second batch of 12 trial industrial parks in December 2015.	Implemented in 2013, ongoing.
Demonstrative Innovative Zone of ASD*	MOST	Regional scale, technology-driven, problem-orientated, wide stakeholder engagement (State Council, 2016; MOST, 2017)	In principle, municipal cities	Implemented in 2016, ongoing.

* ASD is 2030 Agenda for Sustainable Development.

2 As issuing bodies change their titles, contemporary titles of the issuing bodies are used for reference.

1.3 Eco-industrial parks

1.3.1 Definition of EIPs

The National Demonstrative Eco-Industrial Park (EIP) programme envisioned the development of new industrial parks (and the upgrading of existing parks) (EPA et al., 2007) following industrial ecology principles where tenant companies and other organisations work jointly to maximise their environmental, economic and social performance (Lowe, 2001).

The formation of EIP is evidently related to the emergence of "industrial ecology" in the late 1980's and "industrial symbiosis" in the early 2000's (Chertow 2000, Cai et al., 2007). According to policies such as the "*Guide for the Establishment of Eco-Industrial Parks Planning*" (EPA, 2007) and the "*Administrative Measures on National Demonstrative Eco-Industrial Parks*" (MEP et al., 2015), EIPs should utilise a mix of technological, economic and managerial actions to minimise waste production. These actions span three different levels (i.e. individual entity, EIP, city/region) and involve different stakeholders. First, individual entities within EIPs[3] must upgrade their industrial production processes to reduce resource consumption, pollution, GHG emissions, and waste generation, potentially by pre-treating waste for reuse or recycling. Second, individual entities should seek to create symbiotic relationships by reusing and recycling the waste generated within the EIP to reduce transportation costs. Third, cities or broader regions can enter this symbiotic relationship by providing waste as a resource for EIPs or benefiting from EIP waste streams such as residual heat (Geng et al., 2009). Developing and leveraging such "industrial symbiosis" often requires substantial technological advancement and information sharing (Bellantuono et al., 2017). The process of the scaling up of EIPs is illustrated in Figure 1.

3 The term "entities" is used in this paper in the broader sense, to refer to organisations that are not solely commercial enterprises. Many scholars have recognised the need for involving such diverse organisations in EIP processes for administration and information sharing, among others (Yu et al., 2014b).

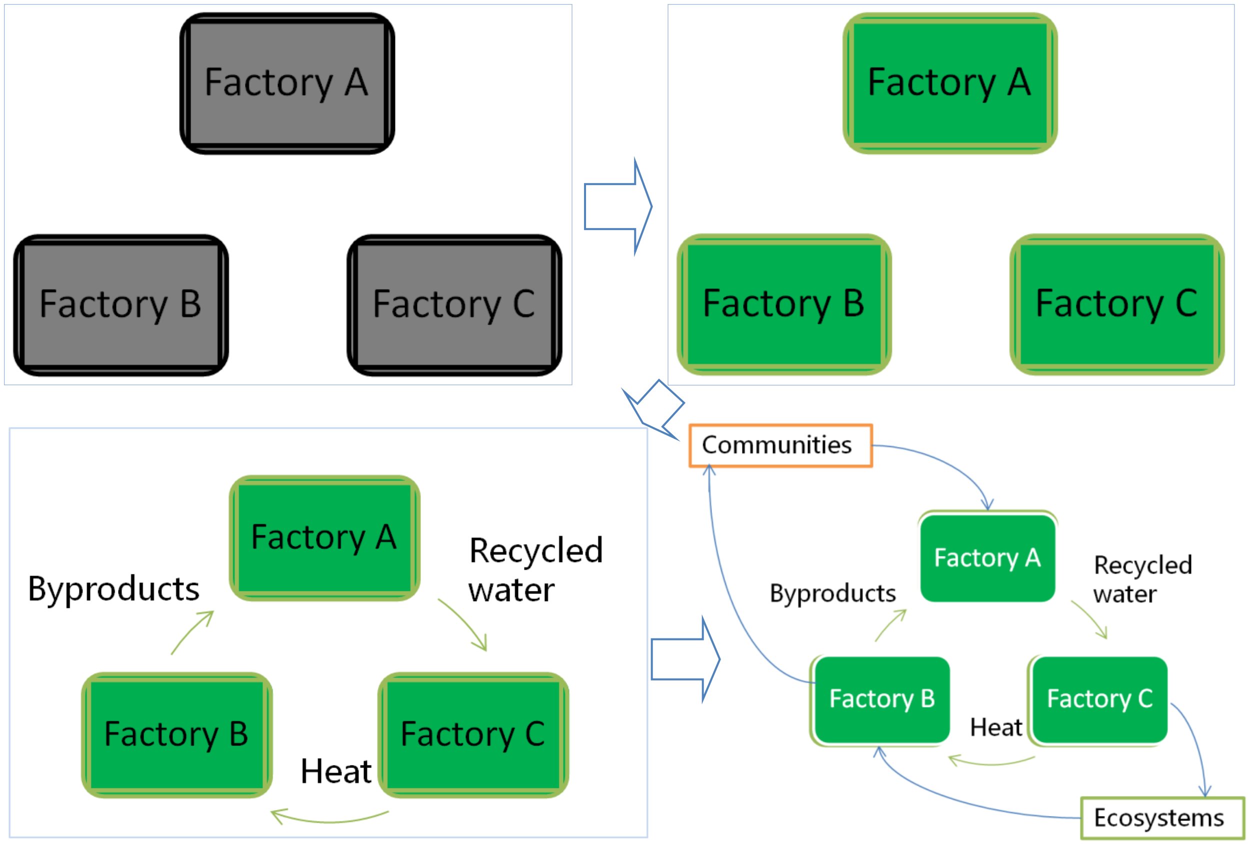


Figure 1: the stages of the development of EIP: stage one, cleaner production at individual entity level; stage two, industrial symbiosis among approximate entities; and stage three, circular economy for the region/city.

1.3.2 Status quo of EIPs in China

The first national demonstrative eco-industrial parks (ND-EIPs) were approved for construction in 2001, and as of July 2020, 59 ND-EIPs were operational (with another 48 under development) that are mostly concentrated in the more developed coastal regions (Figure 2 and 3) (Fan et al., 2017b). EIPs are usually categorised as (a) integrated (i.e. contain entities/operations from several industrial sectors without any of them being dominant); (b) sectoral (i.e. contain a dominant industrial sector, with the entities from other sectors operating around the dominant sector); and (c) venous (i.e. the dominant industrial sector is waste reuse and recycle). Table S1 in the Supplementary Material summarises the main characteristics of ND-EIPs across China. There are also international, provincial-, municipal- and county-level EIPs, although their official titles do not always include the designation "EIP". For example, the Qingdao Sino-German

Eco-park is an international EIP that is a joint venture of the Chinese and German governments. Examples of provincial EIPs include the 20 EIPs verified and denominated by the Jiangxi Province government in 2011.

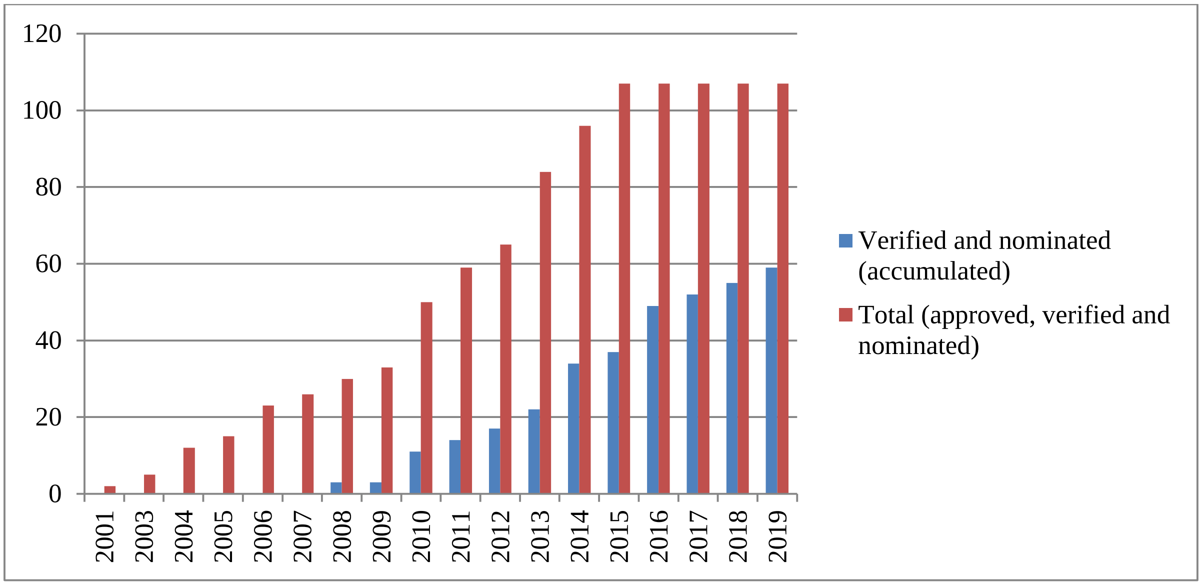


Figure 2: number of ND-EIPs in China

Source: developed with data collected from the Ministry of Ecology and Environment

The above trends clearly indicate the rapid expansion of EIPs in China over the past two decades. Even though EIPs have been implemented in most regions of the world (UNIDO, 2016)4, China is currently perhaps the only country globally that has implemented EIP initiatives at the national level at such a large scale and rapid pace (Liu and Côté, 2017). This make China relatively unique in that it has experienced a large expansion of EIPs through coordinated policy actions, and makes it an illustrative example for other emerging countries that still base their national economy on manufacturing with conventional and outdated technologies that have large negative environmental impacts (Piatkowski et al., 2019).

4 There have been EIP-related studies in very diverse geographical contexts such as, among others, the EU (Susur et al., 2019), Southeast Asia (Pilouk and Koottatep, 2017), Northern America (Heeres et al., 2004; LeBlanc et al., 2016), and Latin America (Elabras Veiga and Magriri, 2009).

Figure 3: distribution of ND-EIPs by type

1.3.3 Economic impacts of EIPs

The most commonly studied economic impacts of EIPs in China include (a) economic performance at the park level, (b) technology adoption, (c) industrial transition, and (d) broader regional economic effects.

For example, for (a), a study of the economic performance of 17 EIPs found that most increased their annual industrial added value (IAV) by at least 17% per year between the year of approval and verification (which often spans a 2-3 years' period) (Tian et al., 2014)5. Fan et al., (2017b) modelled the IAV of 40 industrial parks (including many EIPs) finding that only three of these EIPs had a medium or high IAV per employee. Based on current studies, it is difficult to conclude whether EIPs have better economic performance compared to conventional parks.

Regarding (b), EIPs often adopt and integrate in their processes innovative technologies that optimise product development and resource circulation (Wang et al., 2015). Evidence suggests that by adopting such technologies enterprises engaged in industrial symbiosis can save costs (Childress, 2017) and reinvest in R&D, which further enables them to develop or adopt better technologies (Kor, 2006). Furthermore, some EIPs have attracted many high-tech industries, which sometimes account for >60% of their overall economic output (Zhang et al., 2009). However, there are also many bottlenecks for the adoption of innovative technologies due to efforts to maintain the original symbiotic relationships, lack of financial support, and inability to upgrade the entire symbiosis system (Guo, et al., 2008).

Regarding (c), in an attempt to reduce both the high dependence of some industries on natural resources and high waste generation (e.g. steel production, raw material processing), many EIPs have tried to attract industries with a high value-addition potential and/or industries associated with the tertiary sector (Fan et al., 2017b). However, although a few EIPs have exhibited a steady increase in the share of tertiary industry in their overall economic output, this is not always the case for most parks, with sometimes the opposite effect observed (Tian et al., 2014). This could be partly due to resistance to changes that might affect the current operations (Xiao et al., 2017). For example, it might take a long time to mitigate the disruptions in symbiotic processes as a result of the withdrawal of companies, causing shocks difficult for enterprises and the local economy to withstand (Tian et al., 2014).

Finally, regarding (d), an imperative goal of EIP development is to provide broader economic benefits for their respective regions (Shi and Yu, 2014). It has been estimated that in some regions EIPs can contribute >40% of the regional economic output (Table S1 Supplementary Electronic Material). Some of the larger EIPs such as the Dalian Development Area EIP, Wuhu Economic Development Area National Eco-Industrial Demonstrative Park, and Changsha High-Tech Industrial Area Eco-Industrial

5 It should be noted that the average annual IAV growth for the entire Chinese economy between 2005-2010 (i.e. the assessment period for most EIPs) was 16.7% per year, which was on par with the economic growth for most of the studied EIPs (Tian et al., 2014).

Demonstrative Park have accounted for a significant fraction of the regional economic output (>30%), being major drivers of regional economic development (Table S1 Supplementary Material).

1.3.4 Environmental impacts of EIPs

The most commonly studied environmental impacts include (a) resource use savings, (b) waste and pollution prevention, and (c) land use change and biodiversity loss. Many studies tend to adopt a comparative mindset, contrasting the environmental performance between EIP (Zhang et al., 2009), or with the performance before verification (Tian et al., 2014). However most of these studies report simulations or proxies for the different environmental outcomes, rather than robust baseline analyses based on temporal trends (e.g. Fan et al., 2017b) or directly observed environmental data (Zhao et al., 2008).

Regarding (a), many studies have argued that industrial symbiotic processes within EIPs could offer substantial savings in natural resource use (Han et al., 2016). For example, studies have shown the positive impacts of EIP verification on eco-efficiency, however, at varying degrees (Liu et al., 2018a). Nevertheless, when looking at the absolute amount of natural resource consumption across time, the picture might be quite different. For example, according to Tian et al., (2014), although the resource consumption intensity decreased in various degrees across the 17 studied EIPs, the total resource consumption seemed to increase. It is worth noting that resource use efficiency is one of the main aspects of the Standard for National Demonstration Eco-Industrial Parks (HJ 274-2015) (MEP, 2015). However, improvements in eco-efficiency without considering the total resource consumption and waste generation could raise concerns over the overall sustainability of industrial production in EIPs, and more broadly, industrial activity in China (Yong, 2011). Furthermore, savings can depend on the year and other external factors, which further complicate the picture (Lin et al., 2019).

Regarding (b), EIPs tend to generate less waste than conventional industrial parks, considering the higher rates of material reuse and recycling discussed above. For example, a comparative analysis of 17 EIPs found that, after their approval, six reduced wastewater discharge, eight reduced solid waste generation, and most reduced waste generation intensity. However, more than half of the EIPs generated higher amounts of waste in absolute terms, even after following their approval for EIP construction (Teng and Wei, 2008). Similarly many studies have also found that the cleaner production and industrial symbiotic processes within EIPs could reduce the emission of pollutants and GHGs (Shan et al., 2019), as well as the intensity of these emissions (Yu et al., 2015d). However, according to a longitudinal analysis of the Beijing Economic-Technological Development Area (BDA) EIP, the total carbon emissions actually increased following its upgrading into an EIP (Liu et al., 2014b). It is worth noting that apart from direct effects on pollution reduction, EIPs can also have a rather indirect positive effect by influencing emission reductions in other types of infrastructure, possibly through technology and knowledge spillover effects (Sun et al., 2019).

However, it is not always straightforward to accurately estimate the effects of the actual pollution and waste generation from EIPs (or its benefits), as they are tightly integrated with other activities in the surrounding regions (Section 1). For example, a study on wetland degradation in the coastal district of Binhai found low and constantly decreasing water quality for all 11 rivers, but could not distinguish the actual contribution of the Tianjin Economic Development Area (TEDA) EIP (Meng et al., 2010). Furthermore, EIPs can also have indirect effects on pollution and waste generation, for example, by driving housing construction and catering services operation for laborers and their families (Xie et al., 2018). Many scholars have argued that the circular economy approaches of EIPs should be expanded for surrounding communities (Dong et al., 2017).

Regarding (c), land conversion for industrial use accounted for most of the construction-related land use change in China between 1998 and 2008 (Li et al., 2017). The construction of new EIPs and/or the expansion of existing EIPs require significant amounts of land both directly, e.g. to host the factories (Dennis Wei et al., 2009), and indirectly, e.g. housing and ancillary infrastructure (Luo et al., 2018). If EIPs were constructed in natural areas, or if they did not restore previously degraded land, they could possibly have negative biodiversity outcomes by causing/sustaining habitat loss and change (Liu and Côté, 2017). For example, Tianjin TEDA, one of the major EIPs, was originally constructed on habitats of critical ecological importance such as wetlands (albeit prior to its upgrade to an EIP), possibly having negative and undocumented biodiversity outcomes (Meng et al., 2010). However, it has been suggested that compared to conventional industrial parks, EIPs could cause lower land use change due to higher land use efficiency as industrial symbiosis can allow for space/facility sharing (Yu et al., 2015c), increase proximity of facilities for the exchange of by-products (Lin et al., 2004), and require less landfill space due to waste minimisation (Geng et al., 2012).

1.3.5 Social impacts of EIPs

Considering their substantial economic and environmental impacts (Sections 4.2-4.3), EIPs can have profound societal effects (Huang et al., 2019). However, although most current EIP-related impact assessment and evaluation frameworks acknowledge possible social impacts (UNIDO et al., 2017), the actual empirical peer-reviewed literature about the social impacts of EIPs is surprisingly scarce for China

(Figure 4). This is possibly because the government has not included any mandatory social indicators in its standards (Huang et al., 2019). According to existing frameworks some of the possible social impact categories related to EIP development and operation include health, social services, and social conflicts. Below we attempt to provide some of the possible mechanisms drawing from other studies and reports.

Health and safety impacts are directly linked with the environmental performance of EIPs and the adoption of good production practices (Pilouk and Koottatep, 2017). However, even though it might be intuitive that pollution emission (and their reduction) from industrial activities have ripple health effects in China (Gu et al., 2018), there is little empirical literature addressing the health outcomes of adopting cleaner production processes in EIPs. Some studies have modelled the possible health outcomes through Life Cycle Assessment (LCA) indicators related to the emission of hazardous substances for human health (Wang. et al., 2019). However, there is a lack of studies that assesses the actual causal pathways from emission reduction to health improvements in and around EIPs. The fact remains that as the overall industrial activity and resource use increases (Section 4.2), EIPs could indeed cause negative health outcomes in Chinese cities. It is also worth mentioning that Chinese EIP standards lack provisions for occupational health and safety (OH&S) management systems (Piatkowski et al., 2019).

Even though not explicitly stated in EIP standards, the provision of some level of social infrastructure and services provision (e.g. lighting, security, transportation) is a precondition for the development of industrial parks in China (Piatkowski et al., 2019). Furthermore, measures, plans and websites of many EIPs consulted during the development of this thesis often mention social infrastructure such as hospitals or schools, which are fully or partly developed by the respective EIPs. However, despite the many studies raising the need to develop such services in the context of EIPs in China (Huang et al., 2019), we could not find any studies that had assessed the delivery and quality of such social services.

EIPs entail the construction of major infrastructure and ancillary developments such as roads, and much like other industrial activities, these generate pollution and waste (Section 4.2). Furthermore, much like other industrial activities, they can also be seen as drivers of internal migration (Unger and Siu, 2019). Such processes have been associated with a host of different social conflicts in China (Yang, 2012). However, we could not find empirical studies tracking social conflicts from EIP development and operation in China, potentially due to their omission from the national standard systems (including processes to facilitate community dialogue and outreach) (Piatkowski et al., 2019).

1.4 Research gaps

In the 41 different studies identified, they have mainly focused on the economic and environmental impacts of EIPs, with practically no studies on social impacts (Figure 4). Between them, these studies focused on various EIPs using very different methods, indicators and system boundaries. For example some studies focused on single EIPs (e.g. Yu et al., 2015b) and single impacts (e.g. Geng et al., 2014), or multiple EIPs (e.g. Bai et al., 2014) and multiple impacts (e.g. Yang et al., 2018). Some studies have conducted historical and baseline impact assessments using existing data sets (e.g. Zheng and Peng, 2019), while other studies have estimated potential future impacts using simulations to assess different scenarios (e.g. Pauliuk et al., 2012).

Most studies identified positive impacts from EIPs, but an appreciable number identified both positive and negative effects for the same impact category depending on the EIP, method (e.g. Fang et al., 2017), or scenario (e.g. Zhao and Guo, 2018). Table 2 summarises the outcomes of 41 previous studies on different impacts of Chinese EIPs. Table S2-3 in the Supplementary Material contains more detailed summaries and characteristics for each study.

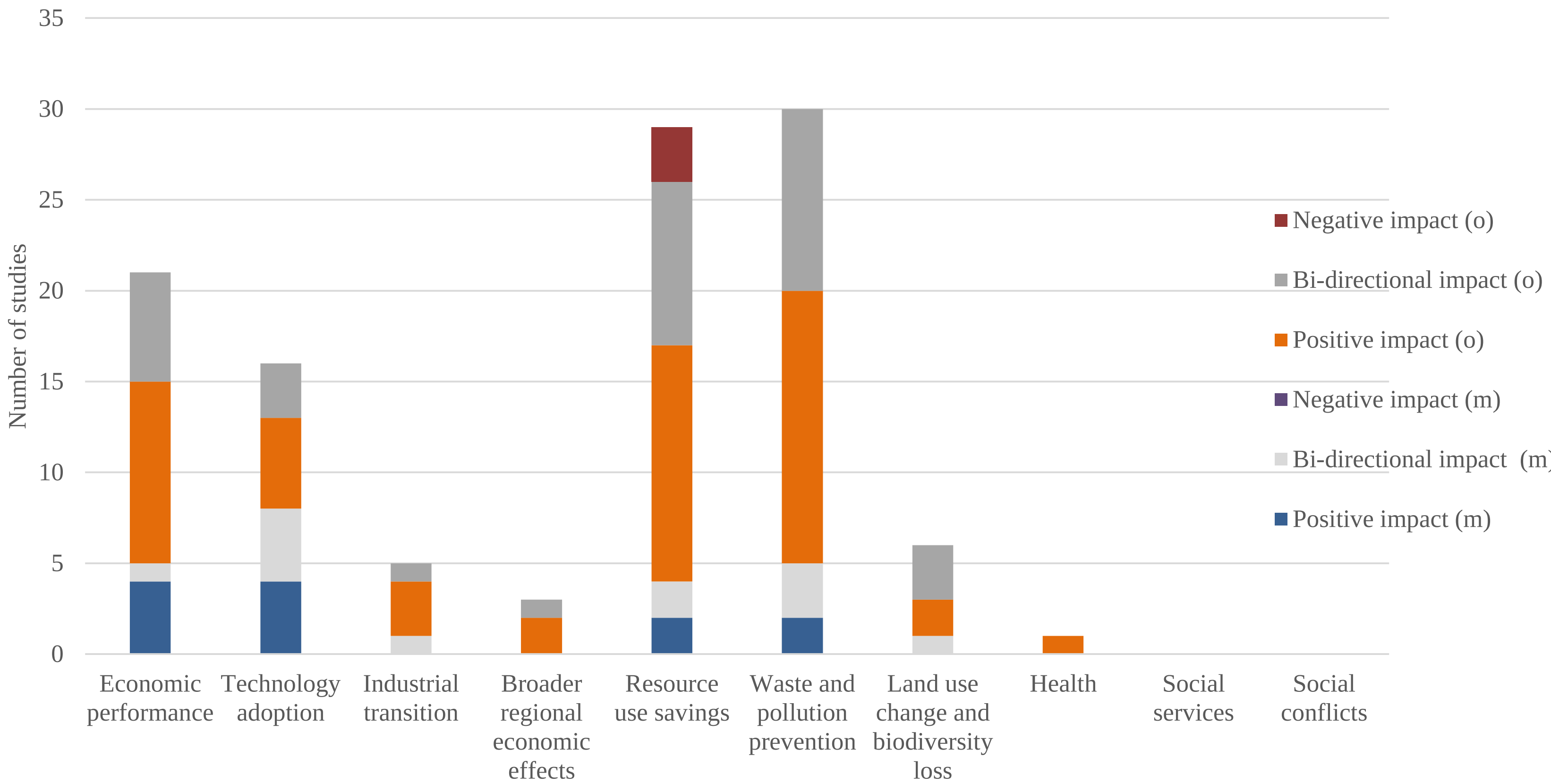


Figure 4: impacts and direction of impact for the reviewed studies

Note: (m) denotes impacts derived from modelled data, and (o) observed data.

Table 2: the outcomes of previous studies on different impacts of Chinese EIPs

Impacts	**Positive impact**	**Bi-directional impact**	**Negative impact**
Economic performance	Teng & Wei, 2008; Zhou et al., 2012; Starfelt et al., 2008; Lin et al., 2004; Fan et al., 2017b; Geng et al. 2014; He et al., 2017; Liu et al., 2018; Shi & Yu, 2014; Tian et al., 2014; Yu et al., 2015b; Yu et al., 2014; Liu et al., 2018; Zheng & Peng, 2019	Bai et al., 2014; Fan et al., 2017a; Fang et al., 2017; Zhang et al., 2009; Yang et al., 2012; Yang et al., 2018; Zhao et al., 2018	
Technology adoption	Zhang et al., 2016; Zhou et al., 2012; Starfelt et al., 2008; Lin et al., 2004; Shi & Yu, 2014; Yu et al., 2015b; Yu et al., 2014; Shi et al., 2010; Li & Zeng, 2018	Tiejun, 2010; Li & Xiao, 2017; Lu et al., 2015; Xiao et al., 2017; Zhang et al., 2009; Yang et al., 2018; Zhao et al., 2018	
Industrial transition	Shi & Yu, 2014; Yu et al., 2015b; Liu et al., 2018	Wang et al., 2013; Yang et al., 2018	
Broader regional economic effects	Yu et al., 2015b; Yang et al., 2012	Zhang et al., 2009;	
Resource use savings	Liang, 2011; Zhou et al., 2012; Fan et al., 2017b; Fan et al., 2017c; Geng et al. 2014; Liu et al., 2018; Shi & Yu, 2014; Sun et al., 2017; Yu et al., 2014; Dong et al., 2016; Shi et al., 2010; Zeng & Shi, 2018; Li & Zeng, 2018; Lin et al., 2004; Zheng & Peng, 2019	Bai et al., 2014; Tiejun, 2010; Fan et al., 2017a; Fang et al., 2017; Tian et al., 2014; Yu et al., 2015; Yu et al., 2015b; Zhang et al., 2009; Yang et al., 2012; Yang et al., 2018; Zhao et al., 2018	He et al., 2017; Liu et al., 2014; Liu et al., 2018
Waste and pollution prevention	Liang, 2011; Starfelt et al., 2008; Fan et al., 2017b; Fan et al., 2017c; Geng et al. 2014; He et al., 2017; Liu et al., 2014; Liu et al., 2018; Shi & Yu, 2014; Sun et al., 2017; Yu et al., 2015; Yu et al., 2014; Dong et al., 2016; Shi et al., 2010; Li & Zeng, 2018; Lin et al., 2004; Zheng & Peng, 2019	Bai et al., 2014; Teng & Wei, 2008; Zhou et al., 2012; Fan et al., 2017a; Fang et al., 2017; Tian et al., 2014; Yu et al., 2015; Yu et al., 2015b; Zhang et al., 2009; Yang et al., 2012; Liu et al., 2018; Yang et al., 2018; Zhao et al., 2018	
Land use change and biodiversity loss	Shi & Yu, 2014; Yang et al., 2012	Shi et al., 2017; Fan et al., 2017a; Fang et al., 2017; Yang et al., 2018	
Health	Li & Zeng, 2018		
Social services			
Social conflicts			

Despite the rapid uptake of this policy and consequent expansion of the academic literature there are still significant knowledge gaps related to EIP development and operation in China, with many scholars raising questions about the verification, operation and performance of EIPs (Fang et al., 2007). For example, there have been strong critiques since the early implementation of EIP policies about the need to expand the sustainability criteria of EIPs to include social aspects related to education, health, and social insurance coverage, among others (Huang et al., 2004). In spite of the development and periodic revision of EIP standards by the Chinese government (Huang et al., 2019), the evaluation of EIP performance is still hotly debated (Liu et al., 2019). Essentially, there are still needs to consolidate and synthesise the current evidence about the main institutional aspects, which influence the operation, sustainability outcomes, evaluation and challenges of EIP development in China.

Another major gap in the academic literature is that most studies seeking to explore EIP sustainability focus on individual or sub-sets of impacts, usually economic and environmental (Hong and Gasparatos, 2020). For example, most relevant studies have focused on economic and environmental impacts such as (a) investment per constructed land, regional economic effect, energy-saving, and GHG emissions (Yang, 2012); (b) technology adoption, and industrial transition (Yu et al., 2015b) (c) resource use, waste and pollution prevention, and land use change (Fan et al., 2017b) (d) GHG emissions (Liu et al., 2014), among others. These studies find a rather mixed picture with EIPs performing well and better than conventional parks for some indicators, and worse for others (Hong and Gasparatos, 2020). However, very few studies have adopted a more comprehensive approach to the sustainability assessment of EIPs, which also includes social impacts. Huang et al. (2004) has been one of the noteworthy exceptions, developing an indicator system to assess EIP sustainability, which included indicators related to education of employees, life expectancy of surrounding communities, and social insurance coverage. However, social impacts have not been integrated into official indicator lists (Hong and Gasparatos, 2020).

A third major gap in the academic literature is the scarce evidence on whether upgrading to EIP status actually improves the sustainability performance. Tian et al. (2014) studied the economic and resource conservation aspects of the development of 17 EIPs, but the time span of their analysis only covers the period being the start of upgrading, to the year the parks were verified. The previous studies mentioned earlier show that bi-directional impacts were frequently observed in case studies. It should also be noted that the time of the implementation of the EIP programme coincides with a period when China undergo drastic socioeconomic changes. Whether EIP development outperforms the trend of the region and nation is rarely studied.

1.5 Aim and objectives

Therefore, to address these research gaps, this study has an overarching aim, which is to evaluate if upgrading to EIP status improves the sustainability performance of industrial parks. With this aim in mind, we lay out four objectives to be answered.

The first objective is to identify the drivers, key institutional aspects, and major challenges of the EIP programme;

The second objective is to outline the sustainability performance of the EIPs for a series of sustainability aspects and indicators over time;

The third objective is to evaluate whether the upgrading to an EIP improves sustainability performance;

The fourth and last objective is to synthesise the evaluation and offer recommendations on how to improve EIPs' performance.

1.6 Originality and Contribution

EIPs have multiple impacts across different dimensions, and they possess unique features in China. However, research gaps in existing literature suggest that some impacts are under-represented in evaluation and comprehension. Therefore, there are needs to formulate an indicator framework that is more comprehensive than previous studies and contextualised into the Chinese situation.

This study develops a comprehensive indicator system based on existing literature, governmental guidelines while considering the data availability of case study sites. We not only include efficiency indicators, such as resource use per unit economic output, or economic output per employee, but also make use of scale indicators to have a fuller picture of the balanced outcomes of EIP development.

This study also applies robust statistical analysis on the sustainability outcomes of EIPs. We not only look at the overall sustainability performance of the case study sites using Multi-Criteria Decision Analysis (MCDA), but also utilizes two types of time series analysis to understand the change of the indicators over time. The first one is Causal Impact (CI) analysis with theoretically justified covariates to understand the temporal change of each indicators compared to the trend of the wider region, and the second one is Interrupted Time Series (ITS) analysis to compare the trend of the indicators after the EIP upgrade and the trend before the EIP upgrade.

Industry is and will continue to be an indispensable component of the human society. Economic growth, industry, innovation, responsible consumption and production, reduced inequalities are among the SDGs (sustainable development goals) to be achieved by 2030. This study contributes to the literature in a few ways. Firstly, it focuses on how responsible production, and innovating the industrial sector could contribute to sustained economic growth by evaluating the transformation of a special kind of industrial player – eco-industrial parks. Secondly, it extends the evaluation of an industrial area to the social aspect, particularly whether industrial development benefits the livelihood of the employees and promotes a more inclusive community. Thirdly, it gives out policy and research implications and recommendations so that future implementation of similar efforts could be benefited from this study.

1.7 Structure of thesis

The structure of the thesis is as below. Chapter Two explains the research approach, study sites, data collection and analysis methods utilised in this study. Chapter Three gives the results of the first objective, i.e., drivers and key institutional aspects of the EIP programme based on institutional analysis. Chapter Four presents the results of the multi-criteria decision analysis to show the sustainability of case study sites over time. Chapter Five gives the results of two temporal analysis on indicators based on Causal Impact analysis and Interrupted Time Series analysis. Chapter Six presents policy and research implications and recommendations based on the analysis from previous chapters.

Chapter Two

Methodology

2.1 Research approach

Based on the research aim and objectives of this study (Section 1.5), the main elements of this study are to understand the sustainability performance of case study EIPs in China over time, and to understand if upgrading to EIP improves the sustainability of the industrial parks. The research approach adopted is explained below.

The concept of sustainability in this research is adopted to be in line with the framing described by Kudo and Mino (2020), especially the keywords of holistic treatment and trans-boundary thinking. Regarding holistic treatment, this research looks at the development of EIP and its impacts from various angles including economic, environmental, and social aspects. Regarding trans-boundary thinking, this research recognises that stakeholders, policies, and actions in and outside of the EIPs interact with each other to shape how EIPs develop. Trans-boundary thinking would also help us to understand what factors influence the trends of aspects and indicators (Section 4.5 and 5.6.2). This concept would be visited and discussed again in Section 6.4.

It should be noted that even though EIPs are supposed to improve the performance of the industrial sector, and some of the elements of the EIP programme should contribute to sustainability, there is no clearly articulated definition of sustainability in the context of EIP development, or how the overall programme is to improve it in regulations and guideline issued by the authorities. Instead, green, low carbon and circular economy are mentioned in the administrative measures (MEP et al., 2015).

Following the concept defined above, in order to understand the sustainability performance of EIPs, proxies such as indicators are commonly used. For example, the effects of EIP upgrade (Wang et al., 2006), the environmental change caused by EIPs (Hsu, 2012), and EIP resilience (Valenzuala-Venegas et al., 2018), among others. Therefore, relevant indicators need to be identified, and this is done by analysing EIPs' impact mechanisms with a comprehensive literature review, which gives a thorough depiction of the impacts of EIPs as described in Section 1.3.

Subsequently, to formulate an indicator framework appropriate for sustainability evaluation, relevant drivers, policies, standards, and processes are studied through an institutional analysis (Section 2.4.1 and Chapter Three), which gives a fuller picture of what the governments, EIP administrations, and other stakeholders expect EIPs to achieve, thus suggesting the focus of EIP development and what indicators might have been neglected. The formulation of an indicator framework is also assisted by visits to case study sites (Section 2.2), and consulting authorities, experts and researchers to get their opinions on potential indicators.

With an initial indicator framework in mind, data availability is another issue to be considered. There is inconsistent data disclosure by Chinese EIPs (MEE, 2018a), as EIPs are often considered as functional city districts (rather than individual administrative areas), and thus there is no binding regulations to disclose socioeconomic data as detailed as administrative districts (Section 2.3). Therefore, data collected and processed are brought into judgment and shaped the formation of the indicator framework (Section 2.3.1). Eventually, a final indicator framework feasible for the research purpose of this study is formed (Section 2.3.2).

Having finalised the indicator framework for evaluation, methods to assess case study sites' sustainability, and to understand the impacts of EIP upgrading has on industrial parks' sustainability are selected and applied. For assessment of case study sites' sustainability performance, Multi-Criteria Decision Analysis is used, which gives the overall sustainability performance change of the EIPs over the years (Section 2.4.3 and Chapter Four).

To have a deeper understanding of the change of individual indicators as a result of EIP upgrading, two time series analytical methods, namely Causal Impact and Interrupted Time Series analyses are utilised. Both methods assume the trend of each indicator to follow a certain pattern based on regression, and test if the trend changes significantly after EIP upgrading (Section 2.4.4 and 2.4.5, and Chapter Five).

Finally, a synthesis analysis considering the results, and potential factors influencing the outcomes are conducted so as to give foundations for policy implications and recommendations, and suggestions for future research (Chapter Six).

The research approach of this study is depicted in Figure 5.

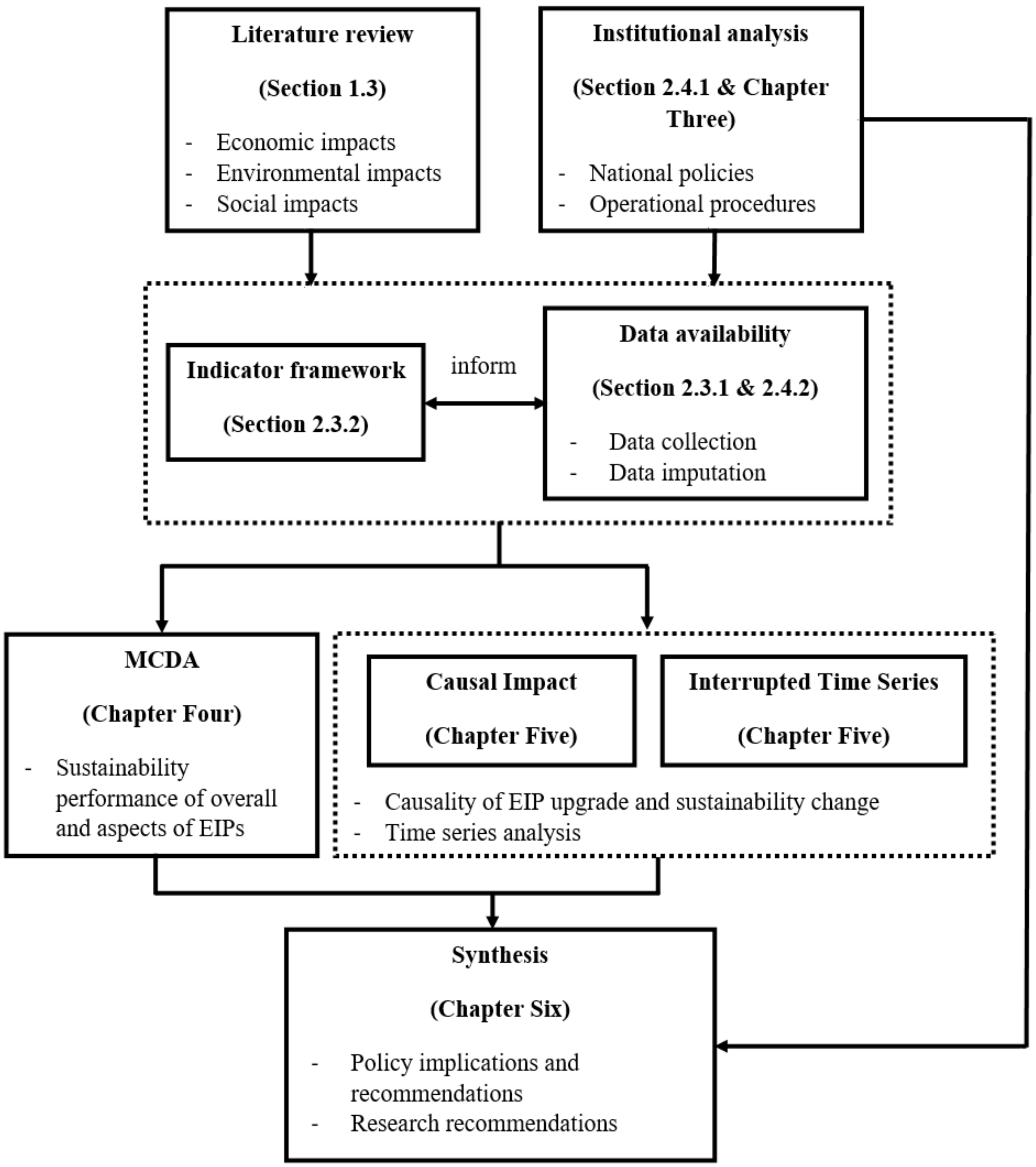


Figure 5. research approach of this study

2.2 Study site

Two EIPs, namely the Beijing Economic-Technological Development Area (BDA), and the Tianjin Economic-Technological Development Area (TEDA) are selected as the case study sites for this study. Data availability for the indicator framework (Section 2.1) and the causality analysis (Section 2.4) assisted this decision. In particular both EIPs (a) have relatively good and consistent data availability for intended indicators; (b) are located in autonomous municipalities, implement the integrated administration commission model, or government-led model (Section 3.3), and thus have similar administrative authority; and (c) are located in northern China (only 150 km apart), have thus have similar climate and conditions for resources supply.

In addition, both EIPs rank at the top of all national industrial parks according to the evaluation conducted by MOFCOM across aspects of industrial base, technological innovation, utilisation of foreign investment, and foreign trade (2018, 2019). BDA ranked the first in the re-examination of national demonstrative EIPs in 2016 (MEE, 2017), and TEDA the third in 2017 (MEE, 2018b). Therefore, the improvement of these two industrial parks upgrading into EIPs should be easier to be observed if present. However, it should be recognised that they cannot represent other EIPs in China as EIPs are diverse in their management capacity, size, industrial composition and so on. Below we introduce these two case study sites briefly.

2.2.1 BDA

BDA was established in 1992 and is located in the southeast of Beijing (Figure 6). In 2016 it had a planned size of 58.8 km^2, an economic output of RMB (Chinese currency) 117,260 million, and over 345,000 employees. BDA was approved for an EIP upgrade in January 2009 and verified as an EIP in April 2011.

Figure 6: location of BDA (boundary as of 2016) in relation to Beijing

It is a sector-integrated industrial park, with its main industries spanning electronics, biopharmaceuticals, automobiles, high-end equipment, internet, and novel energy and environmental protection. BDA’s industrial structure has remained relatively stable during its upgrading into an EIP, and the years following its verification as an EIP.

In summary the contribution of the tertiary sector (i.e. services) increased from 7.7% in 2000 to 31.8% in 2007 and has remained above 30% since (Figure 7). The construction output doubled between 2008 and 2009 but has remained relatively stable afterward (Figure 7).

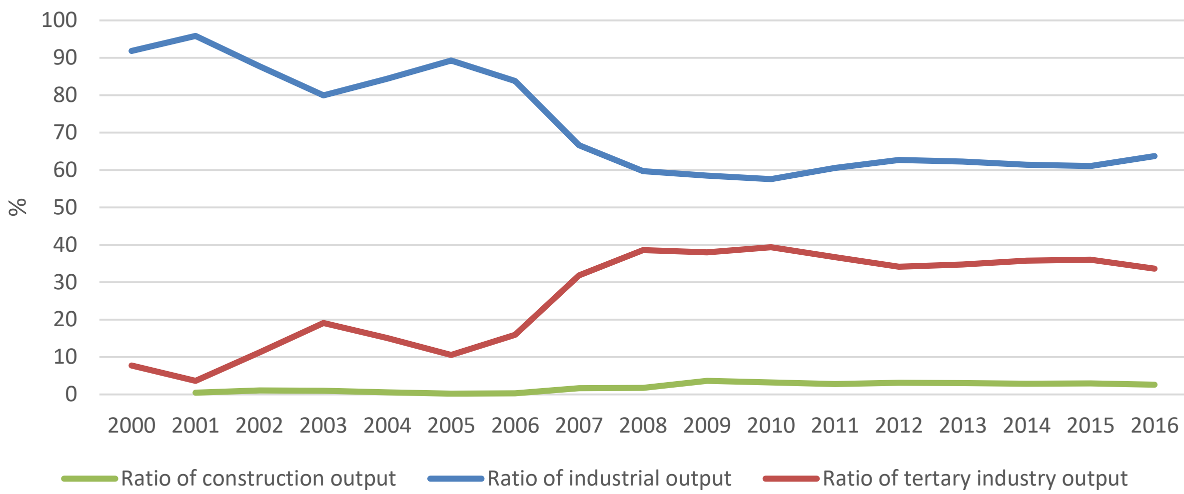


Figure 7. industrial structure of BDA between 2000 and 2016

In terms of its industrial sector, telecommunications expanded significantly between 2004 and 2007 (Table 3), with Nokia becoming by 2010 the main enterprise in BDA and forming an industrial chain spanning R&D, design, supply of parts, logistics, and manufacturing. LCD and OLED display and optoelectronics products manufacturing also grew substantially during this period. Automobile and transportation manufacturing gained it momentum after 2008 as Benz and Beijing Automotive set up a joint venture. Conversely, after a spike in 2004, astronautics output declined sharply since, possibly due to the move of heavy industries away from Beijing during the preparation for the 2008 Olympics.

Table 3. share of economic output of main sectors in BDA

Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Telecom	45.27%	36.04%	67.80%	68.53%	58.32%	-	38.72%	34.84%	50.29%	51.48%	52.01%	50.68%	51.08%	54.27%
Equipment manufacturing	14.20%	16.39%	12.81%	9.94%	5.89%	-	10.64%	10.98%						
Biopharmaceutics	11.16%	5.65%	5.99%	3.81%	2.78%	2.72%	3.62%	3.76%						
Auto and transportation	0.00%	0.00%	0.00%	0.00%	0.00%	-	-	4.79%						
Astronautics	7.53%	23.97%	2.84%	1.79%	1.21%	1.98%	2.34%	-	-	-	-	-	-	-
New energy & new material	2.77%	2.87%				-	-	-	-	-	-	-	-	-
Total manufacturing	80.92%	84.91%	89.44%	84.07%	68.20%	61.43%	62.06%	60.69%	63.33%	65.83%	65.30%	64.25%	63.99%	66.35%

In 2011, BDA and Daxing District reached an agreement to develop in a more integrated way. As a result, BDA does not disclose its industrial output separately by industry sector anymore. However, the four main industrial sectors of telecommunications, equipment manufacturing, biopharmaceuticals, and automobile and transportation manufacturing of BDA remained stable, accounting for about 80% of total industrial output in Daxing District.

2.2.2 TEDA

TEDA is one of the earliest industrial parks in China, established in 1984. It is located on an area that was formerly the mudflats of Bohai Bay in the outskirt of Tianjin City. Originally it consisted of only one zone with a planned size of 40 km^2, but gradually expanded by acquiring or constructing new industrial zones (Table 4). In April 2004, five of its sub-parks were approved for EIP upgrading, and in March 2008 all were jointly verified as an EIP (Figure 8). Subsequently, TEDA expanded to absorb some other industrial parks following the principles of industrial ecology to maintain EIP status. In 2016, its total economic output was RMB 304,983 million and employed over 513,000 people. Its main industries span telecommunications, bio-pharmaceutical, automotive, food processing, petroleum and chemical engineering, equipment manufacturing, astronautics and novel energy and material industries.

Table 4: the expansion of TEDA, and characteristics of each sub-park

Feature / Name	Year of Foundation	Size (planned in km^2)	Formation of EIP	Type/Main Industrial Sectors
TEDA	1984	(411.3)	Upgraded	Sector-integrated
East Zone *	1984	40	Upgraded	Sector-integrated
Yat-sen Scientific Industrial Park *	1993	2.88	Upgraded	Sector-integrated
Microelectronics Industrial Zone *	1996	2.3	Upgraded	Sector-specific
Modern-Industrial Zone *	1996	20.17	Upgraded	Sector-integrated
West Zone *	2003	48	Planned	Sector-specific
Nangang Industrial Zone	2009	200	Planned	Petroleum-chemical, energy, metallurgy and equipment manufacturing
TEDA WIT Valley**	2011 (2003)	5.17	Acquired	Modern manufacturing, new energy and material
South Emerging Industries Zone	2012	26	Planned	Modern manufacturing
TEDA Middle Zone	2013 (2009)	58	Acquired	New energy and material, light equipment, environmental protection
FAW-Volkswagen North China Manufacturing Base	2016	8.78	Planned	Automotive

Note: * Sub-parks verified as EIP in a batch in 2008. ** Year in parentheses is the year of original development before being acquired by TEDA.

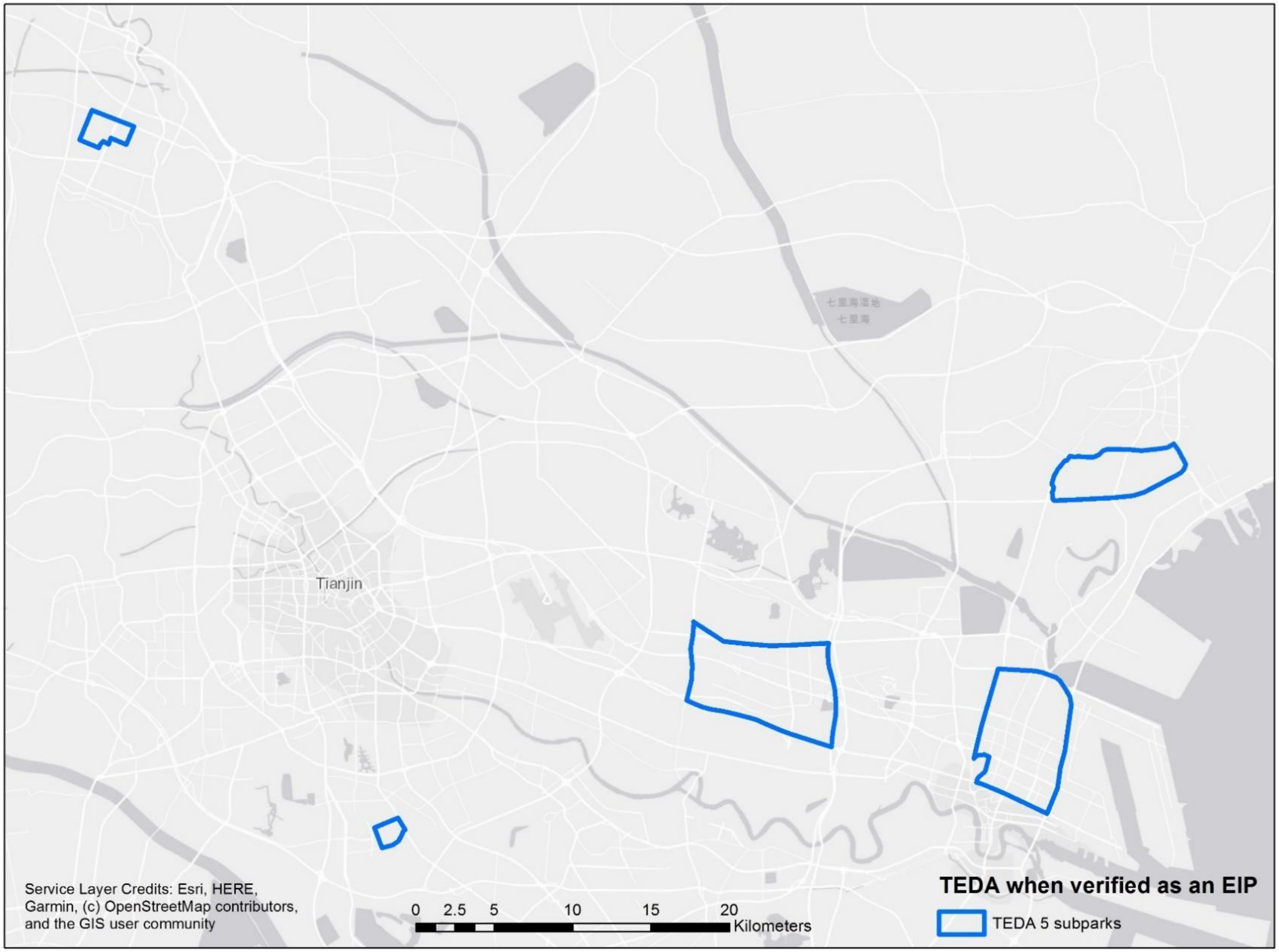


Figure 8. sub-parks of TEDA verified as EIP in 2008 and their locations

TEDA has maintained a strong focus on industrial output in the last a few decades, and the tertiary industry output increased moderately in the last few years while accounting for 29.2% in 2016 (the second highest since 1993) (Figure 9). TEDA also had a relatively stable industrial structure during the period of its upgrade into an EIP, and the subsequent years up to 2016 (Figure 9).

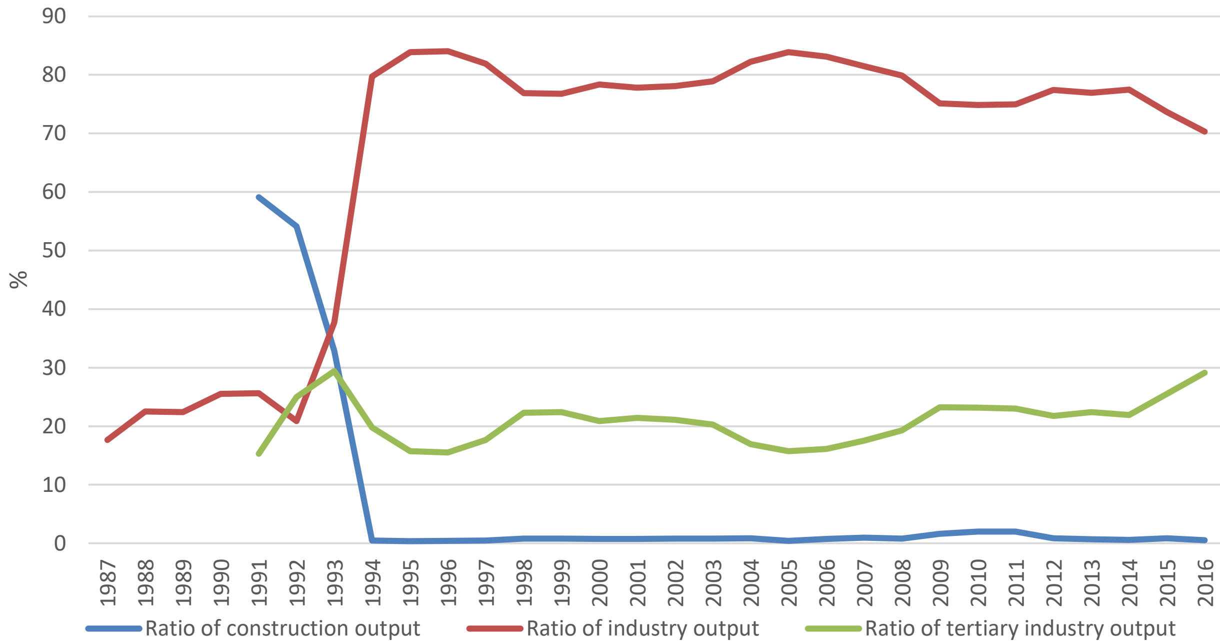


Figure 9. industrial structure of TEDA between 1987 and 2016

During its expansion the TEDA gradually introduced more and more industries. By 2011, its above scale industry 6 was dominated by eight industrial sub-sectors (Table 5). Although the electronics and information sub-sectors accounted for a generally declining share in total output, the absolute output of these sectors nevertheless increased from RMB 51,500 million in 2000 to RMB 211,500 million in 2013, showing a decreasing trend since 2014. The petroleum and chemical engineering sub-sectors share increased by roughly 45% while its absolute output nearly tripled between 2009 and 2016. The absolute output of the equipment manufacturing sub-sector did not change much between 2008 and 2016, however accounting for a decline from 18.2% of total TEDA output to 10.94%.

6 By the end of 2010, the threshold is revenue equal to or greater than 5 million RMB; from January 2011, the threshold is equal to or greater than 20 million RMB (NBSC, 2011)

Table 5. share of above scale industrial output of main sectors in TEDA

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Electronics and information	70.40%	68.70%	68.61%	62.20%	64.00%	62.70%	61.39%	49.10%	38.50%	26.20%	25.20%	25.19%	25.10%	25.23%	21.42%	18.60%	22.86%
Auto	0	0	0	17.00%	17.89%	21.40%	23.40%	32.40%	19.50%	19.40%	20.30%	17.19%	16.60%	14.87%	15.24%	18.90%	21.15%
Equipment manufacturing	0	0	0	0	0	0	0	0	18.20%	16.70%	13.09%	11.60%	10.81%	9.13%	8.79%	8.90%	10.94%
Petroleum & chemical engineering	0	0	0	0	0	0	0	0	0	9.41%	7.59%	8.10%	7.60%	7.29%	12.18%	11.10%	13.64%
Bio-pharmaceutics	0	0	0	0	0	0	0	0	0	2.31%	2.30%	2.00%	2.20%	2.19%	2.21%	2.70%	2.94%
New energy & new material	0	0	0	0	0	0	0	0	0	0	3.71%	4.40%	4.10%	4.43%	4.48%	4.40%	-
Food	0	0	0	0	0	0	0	0	0	0	0	9.19%	9.19%	7.37%	7.82%	7.30%	-
Astronautics	0	0	0	0	0	0	0	0	0	0	0	0.30%	0.10%	0.12%	0.10%	0.10%	-
Other secondary industry	18.39%	22.00%	22.80%	12.20%	10.00%	8.70%	8.80%	10.40%	17.00%	8.10%	5.20%	0	0	0	0	0	-
Total manufacturing	88.80%	90.70%	91.40%	91.40%	91.90%	92.80%	93%	91.90%	93.20%	82.10%	77.40%	78%	75.70%	70.63%	72.24%	72.00%	71.53%

2.3 Data collection

2.3.1 Process of data collection

Data for the different indicators are collected from industrial park annual reports, district annual reports, city reports, Hexun macroscopic data, CNKI, and other official and authoritative documents and reports. This required extensive communication with various departments of the administration commissions of the EIPs, and researchers who have calculated the data of relevant indicators in past research.

Industrial parks in China have clear administrative and geographic boundaries delineated according to city planning. Industrial parks might change their boundaries as city planning is updated. However, data scope of reports is always set in line with the EIP boundaries of the reporting year. As illustrated in Figure 10, a certain EIP located in a certain city might expand gradually, the data scope would be the same as the boundary of the EIP of that reporting year.

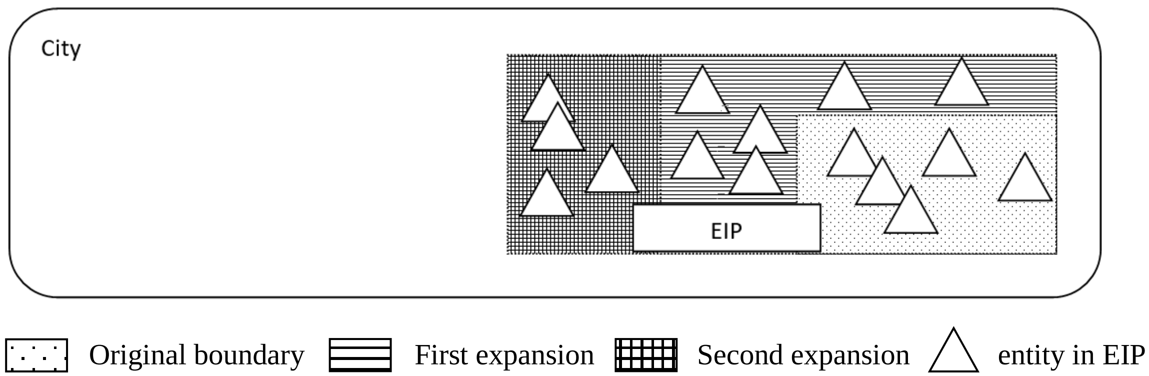


Figure 10. system boundary of study

2.3.2 Final indicator list

Informed by the existing literature (Section 2.1) and data availability of case study site (Section 2.2 and Section 2.3.1), the indicator list is finalised in Table 6. Seven economic indicators, 18 environmental indicators and seven social indicators are identified for this study. As mentioned in Section 1.6, the multi-faceted impacts of EIPs, their uniqueness in the Chinese context, and existing literature suggest a more comprehensive indicator framework specific for the Chinese situation is needed. For instance, one of the unique characteristics of industrial parks in China is that they are not only comprised of industrial facilities and activities, residential areas and activities are also common. Industrial parks attract people to come and work, who consume and push local economies to diversify and expand. For example, for the East Zone of TEDA, there are at least 20 residential compounds with over 174 building accommodating around 180,000 employees. As a result, social impacts and the measurement of them are indispensable for EIP development in China. For this reason, several social indicators are included in the framework of this research.

According to different statistical analytical methods used (Chapter Four and Five), indicators analysed would be adjusted. For example, when using Causal Impact analysis, because the baseline data are of the same city, analysis on ratio of economic output to economic output of city is not performed as this is essentially the same as economic output (with the same denominator), and only monthly payment per employee (inflation adjusted) is used since the inflation is the same for the EIPs and the baseline data.

Table 6. indicator framework for this study

Pillar	Impact	Indicator	Unit	Data source	
				BDA	TEDA
Economic	Economic output	Economic output	RMB 100 million/year (base year 2000)	Basic Data Repository of Macro-Economy and Social Development for Beijing Municipality; Beijing Area Statistical Yearbook; website and annual reports of BDA; Hexun; China Statistics Information Net; World Bank (economic output deflator)	Tianjin Area Statistical Yearbook; website and annual reports of TEDA; Hexun; China Statistics Information Net; World Bank (economic output deflator)
		Ratio of economic output to economic output of city	%		
	Employment generation	Employee number	number of employees		
	Economic output efficiency	Economic output per employee	RMB 10,000/person		
		Economic output per unit area	RMB 100 million/km^2		
		Nominal monthly payment per employee	RMB/employee/month		
		Monthly payment per employee (inflation adjusted)	RMB/employee/month		
Environmental	Resource use	Energy use	tsce*/year	Deloitte Research, 2017	
		Freshwater use	t/year	Website and annual reports of BDA	
		Land use	km^2		
	Resource use intensity	Energy use per unit economic output	kg (SCE)/RMB 10,000		
		Energy use per unit area	tsce/km^2		
		Freshwater use per unit economic output	t/RMB 10,000		
	Resource reuse / recycling	Waste heat use	tsce/year		
		Residual heat reuse ratio	%		

		Reclaimed water sales	t/year	Website of Beijing Yizhuang Water Co., Ltd.; Wang, 2009	
		Reclaimed water sales ratio	%		
	Emissions and waste generation	GHG emissions	t(CO_2e)/year	Calculated (Section 2.4.2)	Calculated (Section 2.4.2)
		GHG emissions per unit economic output	t(CO_2e)//RMB 10,000		
		Wastewater discharge	t/year	Website and annual reports of BDA	Website and annual reports of TEDA
		Wastewater discharge per unit economic output	t/RMB 10,000		
		Wastewater discharge per unit area	t/km^2		
		Wastewater treatment capacity	t/year		
	Environmental quality	Air quality better than level II	days	Beijing Municipal Environmental Monitoring Center	
		Ratio of green area	%	Website and annual reports of BDA	
Social	Living standards	Monthly payment per employee to housing price per m^2 ratio	%	Website of Anjuke	
	Social services	Healthcare coverage	number of people	Website and annual reports of BDA	
		Healthcare coverage rate	%		
		Pension coverage	number of people		
		Pension coverage rate	%		
		Compulsory education enrolment	number	Educational Bureau of BDA	Educational Bureau of TEDA
		Compulsory education enrolment rate	%		

* tsce is tonne of standard coal equivalent.

2.4 Data analysis

2.4.1 Institutional analysis

To answer the first objective of the study (Section 1.5), institutional analysis is applied to elicit the institutional landscape and the drivers of EIP development (Chapter Three). For the purpose of this study a broad definition of institutions is adopted that includes policies (Hindriks and Guala, 2014) and organisations (Hodgson, 2006). The analysis focuses on three key interrelated institutional aspects namely (a) the policies and stakeholder interactions at the national and regional level governing EIP development (Section 3.2), (b) the procedures at the EIP level governing operation and management (Section 3.3), and (c) the funding that can be leveraged to develop and implement EIPs (cross-level issue) (Section 3.4).

This entails the identification and critical reading of the key laws, regulations, measures, guidelines, and other relevant official documents of the Chinese government related to EIPs. This is complemented with information from other relevant policy domains such as industrial development and environmental conservation. The documents are collected through the portals of relevant government agencies such as the State Council and the Ministry of Ecology and Environment. This information is consolidated in tables and schematic diagrams that summarise the main policies, institutional processes and relations between stakeholders (Chapter Three).

2.4.2 Data imputation and calculation

Industrial parks are functional districts within municipalities, they are not required to disclose socioeconomic metrics as detailed as administrative districts. Hence data for some indicators is not available, particularly for earlier years. In order to fill in some data gaps we imputed the missing data for some indicators.

For data missing at random (MAR) (i.e. data dependent on or correlated to some other variables) correlation statistics is used for the extrapolation (OECD, 2008). Data before or after the year the start of the upgrade to EIP status is used to impute for data missing before or after that year respectively following the processes below. Firstly, variables that are theoretically correlated to the missing data are selected; and secondly, the strength of correlation, and explanatory power of those variables is tested. If the strength of correlation for a certain variable is too weak (e.g. $p>0.05$) then it is deleted (OECD, 2008). For tests with strong correlation but low explanatory power (i.e. small R^2) and there is no other reasonable variable to increase the explanatory power, other methods, namely Amelia (Honaker and King, 2010) and centred moving average model (Ivanovski et al., 2018), are used to impute for the missing data. Finally, if both the strength of correlation and explanatory power are satisfying, then the generated function would be used to impute the missing data.

For data not missing at random (NMAR) (i.e. data less likely or unlikely to be related to other variables, or simply not disclosed for various reasons) the Amelia method is used for imputation (Honaker and King, 2010). Amelia generates multiple imputes of "missing data in a single cross-section from a time series, or from a time-series-cross-sectional data set"[7]. It also allows "for trends in time series across observations within a cross-sectional unit, as well as priors for experts" to input their understandings about the missing values (Honaker and King, 2010)[7]. For Amelia, the tolerance is set to 0.001 with ridge 1. Due to the nature of the indicators, each data point should be greater than zero, and are likely to have upper limits, therefore, we also set bounds for more realistic simulation (Table 7).

However, for some datasets such as healthcare insurance and pension coverage for the BDA, no satisfying correlation could be found. In this case centred moving average model is used to estimate the missing data in between years, considering that the general pattern of the data set follows a gradual trend. Centred moving average model assumes the trend of the time series continues while the values are dependent only on the random error terms with mean zero and variance σ^2 (Ivanovski et al., 2018).

A few indicators of TEDA have no enough data before intervention points for regression analysis. Centred moving average model is not possible as there is no data before missing data; and the imputation results from Amelia are less reliable for the same reason (Honaker et al., 2012). Considering the high R^2 values (all greater than 0.96) for regressions using all available data including data after intervention points, the predicted regression model is likely to be fitting for data before intervention too. Therefore, all available data are used for regression and prediction. However, the interpretation of the Interrupted Time Series analysis for those a few indicators (Section 5.4 and 5.5) should be taken with caution as this analysis tried to examine whether the trend before intervention continues after intervention. See Table 7 for a summary of the indicators with missing data and methods used for imputation missing data.

[7] Also refer to James Honaker, Gary King & Matthew Blackwell's brief introduction to Amelia at https://gking.harvard.edu/amelia

Table 7. indicators with missing data, and methods used to impute missing data

EIP	Variable	Method	Years of data missing	Correlated variable / Specification of imputation	R square
BDA	Employee number	Linear regression	Before 2009	Economic output based on price of 2000	0.978
	Freshwater use	Linear regression	Before 2009	Economic output based on price of 2000	0.97
			After 2009		0.98
	Waste heat use	Linear regression	Before 2009	Freshwater use	0.96
			After 2009	Energy use, electricity use	0.97
	Pension coverage	Centred moving average		Two periods	
	Healthcare coverage	Centred moving average		Two periods	
TEDA	Economic output	Amelia		Tolerance: 0.001 Ridge: 1	
	Energy use	Linear regression	Before 2004	Industrial area *	0.99
	Freshwater use	Linear regression	Before 2004	Economic output based on price of 2000	0.98
	Waste heat use	Linear regression	Before 2004	Energy use, energy use for industry, energy use from natural gas *	0.99
	Reclaimed water sales	Linear regression	Before 2004	Freshwater use, wastewater treatment capacity *	0.96
	Monthly payment per employee to housing price per m^2 ratio	Linear regression	Before 2008	Number of local residents, number of employees *	0.996
	Healthcare coverage	Linear regression	Before 2008	Number of employees, pension coverage rate, economic output based on price of 2000, days of air quality better than level II, average age *	0.99
			After 2008	Employee number	0.99
	Pension coverage	Linear regression	After 2008	Employee number	0.99
	Compulsory education enrolment	Centred moving average		Two periods	

* means for that imputation all available data used for regression as no enough data is available before 2004.

As there are no documents with the amount of GHG emissions disclosed except a published paper for the emissions of BDA from 2005 to 2010 (Liu et al., 2014b), this indicator is calculated according to the following method.

The calculation of GHG emissions for the two EIPs follows the procedures of Liu et al. (2014b) while referring to the recommendations by Intergovernmental Panel on Climate Change (IPCC). Both EIPs have literally no agriculture productions in place, emissions from agriculture are excluded. Both EIPs utilise farmlands, barren lands or lands claimed from the sea for construction while parks being built, and trees planted along roads. The difference of carbon stock between farmlands and urban parks/trees might not be significant. Furthermore, remote sensing using GIS (Geographic Information System) to calculate the carbon stock of EIPs is likely subject to 10%-30% uncertainty (according to trial analysis by the authors). Both EIPs have no forests either, therefore, the category of land use, land-use change and forestry is thus excluded too. Therefore, the scope for GHG emissions in this research is energy, industrial processes and product use (IPPU), and waste.

To make the scope of calculation consistent, energy is divided into energy from electricity, energy from heat or natural gas (depending on the released data of EIPs), and other energies. The conversion factor for electricity to carbon emissions is taken from the baseline emission factors for regional grids of China released by the MEE yearly.

BDA and TEDA do not disclose emissions related to IPPU. For both EIPs, solar panels and panels for display are the main products that consume and emit GHGs as a result. Companies in BDA disclose the sales of panels in monetary or size terms. TEDA discloses the number of items produced. These values provide the basis for GHGs emissions calculation.

The average municipal solid waste per person is assumed to be the same as the level of Daxing District for BDA, and Tianjin city for TEDA. Conversion factors used for calculation are summarised in Table 8. Assumptions used to calculate the size of panels produced at TEDA are summarised in Table 9.

Table 8. conversion factors used for GHG emissions calculation

Category	Source data	Conversion	Reference
Energy	Standard coal use	To CO_2 emissions	Liu et al., 2018; Xing et al., 2017
	Electricity use	To CO_2 emissions	baseline emission factors for regional grids of China (MEE)
	Electricity use	To standard coal use	Key China Energy Statistics (LBNL, 2012)
	Heat use	To CO_2 emissions	Liu et al., 2018; Xing et al., 2017
	Heat use	To standard coal use	Key China Energy Statistics (LBNL, 2012)
	Natural gas consumption	To CO_2 emissions	Shan et al., 2018
	Natural gas consumption	To standard coal use	Key China Energy Statistics (LBNL, 2012)
IPPU	Per m2 panel production (BDA)	To Fluorinated GHGs (F-GHGs)	EICC, 2016, company reports
	Per m^2 semiconductor, thin-film-transistor flat panel display (TEDA)	To Fluorinated GHGs (F-GHGs)	IPCC, 2006
	Global Warming Power of GHGs other than CO_2	To CO_2 emissions	Second Assessment Report (IPCC, 2007)
Waste	Natural gas consumption	To electricity production	Ni, 2007; China5e, 2017 (for waste generation calculation)
	Volatile organic compounds, hazard waste incineration, sewage waste compost, municipal solid waste landfill	To CO_2, CH_4, and N_2O	Liu et al., 2014b

Table 9. assumptions for the size of panels and integrated circuits produced at TEDA

Size of products (in inch) / Year	LCD	TV	Mobile phone screen	Laptop	Computer screen	Car GPS	Integrated circuit for semiconductor
2001	14.97	No productions	1.10	13.05	14.97	No productions	1.25*1.25 cm^2 (SIA, 2003)
2002	15.03		1.30	13.15	15.03		
2003	15.09		1.50	13.24	15.09		
2004	15.35		1.70	13.29	15.80		
2005	16.50	25.70	1.90	13.34	16.50		
2006	17.20	27.20	2.10	13.39	17.20		
2007	18.62	28.70	2.30	13.44	17.90		
2008	18.60	30.20	2.50	13.49	18.60		
2009	19.30	31.70	2.80	13.54	19.30		
2010	19.90	33.20	3.10	13.60	19.90		
2011	20.30	34.50	3.60	12.80	20.30	4.5	
2012	20.70	35.90	4.10	12.10	20.70	4.5	
2013	20.90	38.60	4.60	12.20	20.90	4.6	
2014	21.40	40.40	5.00	12.20	21.40	No disclosure	
2015	21.90	40.60	5.20	12.20	21.90		
2016	22.20	42.70	5.30	12.20	22.20		
Height width ratio	4:3	4:3	2:1	16:9	4:3	5:3	1:1

The scope for social indicators related to healthcare, pension and compulsory education is slightly different from the system boundary mentioned above. The difference is explained below.

The data scope of social indicators is (migrant and local) employees who contribute to the social services via their employers in the EIP, and local residents who contribute directly to the social services system. Local residents working in companies outside of the EIPs are not considered in the scope. The denominator of social service indicators is the number of employees. The difference of the scopes for numerator and denominator lies between the local residents who contribute directly to the social services system. The number of local residents of both EIPs is considerably small. For BDA, it ranged around 4% of the number of employees. For TEDA, the ratio increased gradually from 6% to 16% between 2000 and 2016. However, considering that local residents in the urban area are likely to have joined social services via their employers, local residents contributing directly to the social services system would be even fewer.

For compulsory education enrolment rate, the base population should include those who have local household status and those who register as temporary residents locally. Many companies in the EIPs provide dormitory for employees locally so they are included in the scope. We assume those local residents who are not employed in the EIP are counter-balanced by the employees who do not live and register locally. Due to the fact that the EIPs do not disclose more detailed information regarding the base population for these social services, we take the number of employees as the denominator. The data scope of the numerators and the denominators used for social indicators are summarised in Figure 11.

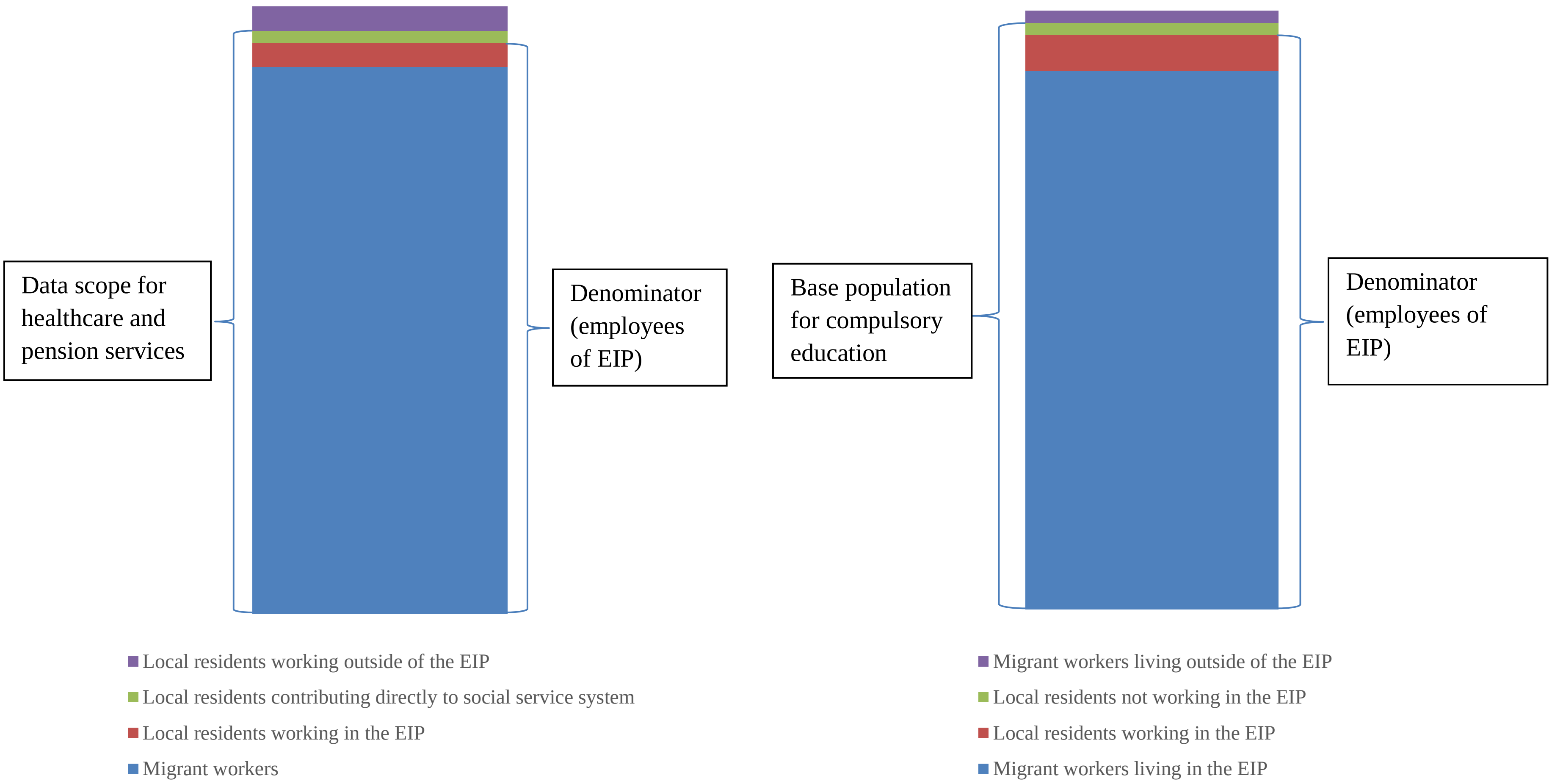


Figure 11. data scope of the numerators and denominators for social service indicators. Left: healthcare and pension services; right: compulsory education.

Note: sizes of categories are not a reflection of actual population.

2.4.3 Multi-Criteria Decision Analysis

To answer the second objective of the study (Section 1.5), which is to assess the change of sustainability performance of EIPs we analyse the holistic sustainability using Multi-criteria decision analysis (MCDA) with the indicator framework finalised earlier (Section 2.3.2). Such approaches have been used in studies to understand the performance of different energy options (Hyde et al., 2003), environmental and social impacts assessment (Ortiz et al., 2018), among others. There are a few tools available to conduct MCDA. Among them, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) has been proven to be useful, and also used in sustainability assessment (Hyde et al., 2003; Ortiz et al., 2018). Other merits for this method are: 1) it allows decision-makers to decide thresholds of indifference and strict preference; 2) its analytical operations allow researchers to control easily what criteria to be considered, and 3) its graphics functions help visualize and present the options clearly.

PROMETHEE produces actions to be ranked in various forms. One visually comprehensible form is ranking actions in preferred order with Phi value as the vertical axis (Brans and Vincke, 1985). Criteria are shown in bars with the upper end indicating their Phi+ values and lower end Phi- value. Phi value equates Phi+ minus Phi-, and higher Phi value denotes higher preference.

The indicator framework in Section 2.3.2 is slightly adjusted, which results in the indicator list containing seven economic indicators, 16 environmental indicators and seven social indicators. The indicators were clustered into three clusters, economic, environmental and social, while environmental pillar was further grouped into positive environmental (where the greater value indicates better performance) and negative environmental (where the greater value indicates worse performance). The indicators used for MCDA in this study are summarised in Table 10.

There are several ways to set the weightings for criteria in a multi-criteria decision analysis, all with respective advantages and disadvantaged (OECD, 2008). As this research takes a holistic approach to understanding and evaluating sustainability (refer to Research Approach section), and the impacts and indicators identified reflect different aspects of EIP development and operations, even if the values of indicators are statistically correlated with each other (regression analysis), and could be simplified to components that contribute to the causality (e.g., Principal Components Analysis), the nature and importance of the selected indicators nevertheless is intended to be independent from each other. Therefore, for MCDA, equal weighting for each sustainability pillar is adopted, and equal weighting for each indicator within a sustainability pillar. To show the change of performance of different sustainability pillars, analysis with each sustainability pillar is conducted so that the presence and overshadowing of other sustainability pillars are removed. In addition, a sensitivity test is conducted to show the variation of performances of the EIPs when different weights are applied. The results vividly show how different weightings would affect the performance of EIPs.

Table 10. indicators selected for MCDA and their initial weights

Pillar	**Indicator**	**Unit**	**Abbreviation**	**Weight ***		**Non-scale**	**Weight ***	
Economic	Economic output	100m RMB	Ec_1	4.76%	33.33%			33.33%
	Ratio of economic output to economic output of city	%	Ec_2	4.76%		√	11.11 %	
	Employee number	number	Ec_3	4.76%				
	Economic output per employee	10,000 RMB/p	Ec_4	4.76%		√	11.11 %	
	Economic output per unit area	100m RMB/km^2	Ec_5	4.76%		√	11.11 %	
	Nominal monthly payment per employee	RMB/m	Ec_6	4.76%				
	Monthly payment per employee (inflation adjusted)	RMB/m	Ec_7	4.76%				
Positive Environmental	Waste heat use	tsce/y	En_P_1	1.96%	11.76%			11.11%
	Residual heat reuse ratio	%	En_P_2	1.96%		√	3.70%	
	Reclaimed water sales	t/y	En_P_3	1.96%				
	Reclaimed water sales ratio	%	En_P_4	1.96%		√	3.70%	
	Air quality better than Level II	days	En_P_5	1.96%		√	3.70%	
	Wastewater treatment capacity	t/y	En_P_6	1.96%				
Negative Environmental	Energy use	tsce/y	En_N_1	1.96%	21.57%			22.22%
	Freshwater use	t/y	En_N_2	1.96%				
	Land use	km^2	En_N_3	1.96%				
	Energy use per unit economic output	kg (SCE) /10,000 RMB	En_N_4	1.96%		√	3.70%	
	Energy use per unit area	tsce/km^2	En_N_5	1.96%		√	3.70%	
	Freshwater use per unit economic output	t/10,000 RMB	En_N_6	1.96%		√	3.70%	

	GHG emissions	t CO_2	En_N_7	1.96%				
	GHG emissions per unit economic output	t CO_2/10,000 RMB	En_N_8	1.96%		√		
	Wastewater discharge	t/y	En_N_9	1.96%				
	Wastewater discharge per unit economic output	t/10,000 RMB	En_N_10	1.96%		√	3.70%	
	Wastewater discharge per unit area	t/km^2	En_N_11	1.96%		√	3.70%	
	Monthly payment per employee to housing price per m^2 ratio	%	So_1	4.76%		√	8.34%	
	Healthcare coverage	Number of people	So_2	4.76%				
	Healthcare coverage rate	%	So_3	4.76%		√	8.34%	
Social	Pension coverage	Number of people	So_4	4.76%	33.33%			33.33%
	Pension coverage rate	%	So_5	4.76%		√	8.34%	
	Compulsory education enrolment	Number of people	So_6	4.76%				
	Compulsory education enrolment rate	%	So_7	4.76%		√	8.34%	

Note: * due to rounding, the sum does not add to 100%.

Visual PROMETHEE (1.4 Academic Edition, 2013) is used for the MCDA of this study. Each EIP of a specific year is treated as an action in PROMETHEE, while indicators are criteria. All the years with available data for the selected indicators were used for ranking. Because some indicators are related to the scale (or size) of the EIPs, such as economic output, number of employees, resource use etc., which would bias the results as EIPs continued to expand, we performed two tests, Test AL refers to the test using all indicators, and Test NS with only non-scale indicators to understand the change of efficiency of the EIPs. The details of the analysis are listed in Table 11.

The ratio of economic output (of EIP) to economic output of city is defined as a non-scale indicator for the following reason. Although the administrative boundaries of municipalities in China remain relatively stable, the major momentum for economic growth comes from built areas in the city. As demonstrated in Figure 12, the built area of both Beijing and Tianjin increased gradually, and the pace of growth is comparable to that of the EIPs. Therefore, this indicator reflects how significant the economy of the EIP is in relation to a dynamically changing economy of the city (Zhang et al., 2009).

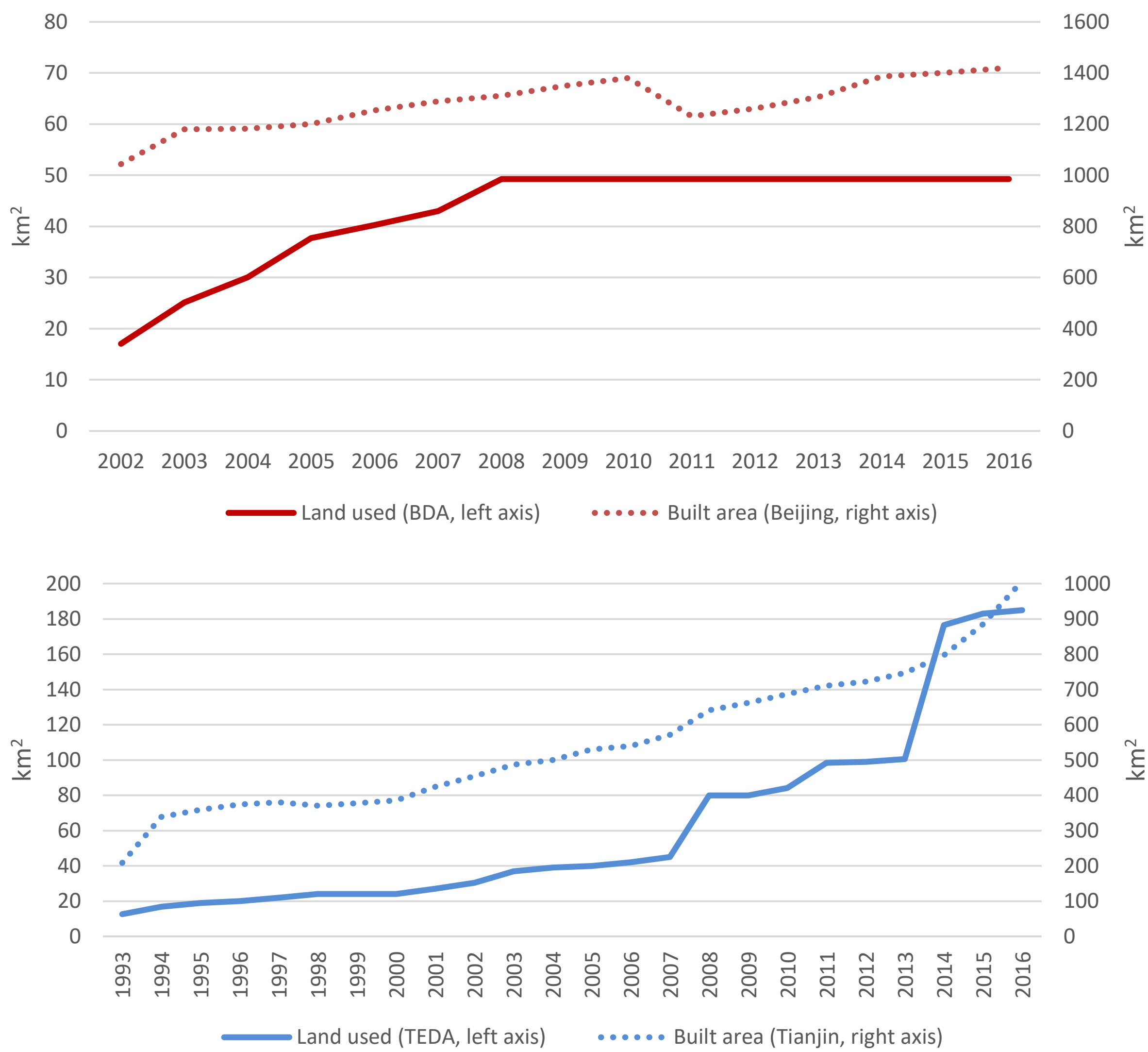


Figure 12. size of built area of BDA, TEDA, Beijing and Tianjin

Table 11. details of the actions, tests, and indicators chosen for MCDA

Action		Test (indicators used)	
EIP	Years	Test AL	Test NS
TEDA	2003, 2004, 2005, 2006, 2008, 2009, 2010, 2012, 2013	31 indicators aggregated	16 non-scale indicators aggregated
BDA	2006, 2007, 2010, 2011, 2016		

PROMETHEE requires users to specify how to distinguish between different options of actions (preference function and thresholds). The decisions are explained below.

PROMETHEE needs to input whether the smallest difference among the actions of a particular indicators is negligible or not. To decide this, we refer to relevant regulations and guidelines (MEP, 2015) to decide whether a certain amount of change (the smallest difference in PROMETHEE) should be considered negligible. For instance, the smallest difference for energy use per unit area for TEDA of the years compared is 723.43 tsce/km^2, which is about 1.47% change for the two years with this difference (2003 and 2005). However, viewing from the national standards for EIPs, the improvement of energy use per unit area should be at least 0.94% in two-year's span. Therefore, although this difference is small, it is not to be negligible. For criteria without clear regulation stipulations, we decide 5% of change on the smallest value of a criterion to be the threshold to show whether there is a significant difference between two values. Table 12 lists the details of expected threshold for year on year change of indicators.

Table 12. expected threshold for year on year (yoy) change based on technical guidelines

Indicators	Expected threshold for yoy change
Economic output	15%
Economic output per unit area	6%
Freshwater use	8.25%
Energy use	9%
Land use	8.50%
Energy use per unit economic output	-5.22%
Energy per unit area	0.47%
Freshwater use per unit economic output	-5.87%
GHG emissions	11.55%
GHG emissions per unit economic output	-3%
Wastewater discharge	4.50%
Wastewater discharge per unit economic output	-9.13%
Wastewater discharge per unit area	-3.68%
Others	5%

PROMETHEE also requires users to determine if the same difference is of same importance to two pairs of values. The preference function of thresholds was adjusted according to the nature of the indicators, depending on whether the same change of value is more likely to be:

a) significant for criteria with smaller values (percentage function would be preferred). For instance, to upgrade residual heat use by a certain amount is more difficult and significant for smaller capacities. Or

b) significant for criteria with greater values (absolute function would be preferred). For instance, it is more difficult to increase the days of air quality better than level II when the air quality has generally been good. Another example is that we expect monthly wage and housing price to increase at the same time, however, the ratio of monthly wage to housing price to increase as well (indicating that employees are enjoying higher life quality). Therefore, for larger ratios, we expect it to be more significant as monthly wages need to increase much more than in previous years. Or

c) indifferent (absolute function would be preferred). For instance, to increase wastewater treatment capacity depends on needs and extra investment rather than in relation to the existing capacity. Another case where the same change is indifferent is that the same change is both significant for small and great values when there might be a cap for this criterion.

2.4.4 Causal Impact analysis

To answer the third objective of the study (Section 1.5), which is to understand the effects of EIP upgrading on sustainability performance, we employ two time series analytical methods, the first one is Causal Impact analysis (Brodersen et al., 2015), which has been used in very diverse applications to identify longitudinal patterns (Rinaldi, 2017), and the second one Interrupted Time Series analysis, which has been used to test whether an intervention or interruption creates significant effects on the studied object using time series data (Wong et al., 2015). The rest of this section describes the methodology of CI analysis, and Section 2.4.5 describes the details of ITS analysis.

CI analysis is based on Bayesian structural time-series models, which assumes the error terms to have normal distribution. CI analysis makes use of covariates to fit a model to the observations before the intervention (EIP upgrade in this case). The selected covariates should have good predictive power for the observations and should ideally not have experienced treatment or spill-over effects (Brodersen et al., 2015). This covariate is used to generate a regression relation with the observed data of the EIP before the intervention period. The analysis requires at least three pairs of values before the treatment point to generate reliable model specifications, as it assumes that the relation between the observations and covariates in the model continues to be the same after the treatment point as if no treatment is present (Brodersen et al., 2015). The predicted data is then compared with actual data to see whether there is significant difference, with the difference ascribed to the intervention (Brodersen et al., 2015).

Two important methodological decisions when implementing the CI analysis method are (a) the determination of the intervention period, (b) the selection of appropriate covariates.

For (a), it is important to note that the upgrade to EIP status is a gradual and not instantaneous process (Hong and Gasparatos, 2020). There are two very crucial points in this namely: 1) the year the EIP is approved for upgrade; 2) the year the EIP is verified. The first point signifies the beginning of change in production practices and the adoption of appropriate technological solutions to achieve EIP status. Hence there is an expectation of a gradual change in the performance of some (or all) indicators from that point onwards, reflecting the different changes in the industrial park. The second point signifies the end of the upgrading process, and thus the reconfiguration of production processes to meet the cleaner production expectations of an EIP (Hong and Gasparatos, 2020).

For (b), we use two sets of covariates populated with, 1) data from another industrial park in the same municipalities; 2) aggregate data from the industrial sectors and urban areas of the same municipalities. The first type of covariate is justified by the fact that even though industrial parks in the same municipality are likely to be subject to same policies and measures (e.g. roll out of cleaner production actions), EIP upgrade is more intentional and extensive, and the practices of an EIP have not been widely applied to or required of conventional industrial parks. In this study we use Zhongguancun Science Park (ZSP) in Beijing for the covariates of BDA, and Binhai New District (BND) in Tianjin for the covariate of TEDA (refer to Box 1 for more details of these two industrial areas). Due to the fact that BDA mostly overlap with ZSP, and TEDA is essentially a part of BND, we deducted the values of EIPs from the overall parks to obtain covariate values. The second type of covariate is justified by the fact that Chinese EIPs (and conventional industrial parks for that matter) do not solely contain industrial activities, but also households and other commercial facilities (Zhao et al., 2014a). In essence, with the exception of not having (or having a negligible agricultural sector), industrial parks usually function as an urban district within their respective municipalities. For this study, we used the aggregate data of the industrial sector and urban areas of Beijing and Tianjin municipalities for BDA and TEDA respectively. The only exception was residual heat, for which national data was used due to data availability.

Box 1: industrial parks used for covariate development

Zhongguancun Science Park (ZSP) in Beijing was selected as one of the covariates for BDA. ZSP was set up in 1988 as a trial industrial zone for new technology development. It is the first high-tech park in China and holds the title of National Independent Innovation Demonstration Zone. It has an initial planned area of about 100 km^2, which reached 488 km^2 in 2012. A major part of BDA was integrated into ZSP in 2000. As of 2016, ZSP has formed “industrial cluster featuring electronic information, biomedicine, energy and environmental protection, new materials, advanced manufacturing, aerospace, R&D and service” (China Daily, 2017). ZSP’s industrial output was 993,770m RMB, employing over 2,482,000 people. ZSP does not undergo park-wide EIP upgrade, making it a reasonable covariate for Causal Impact analysis of BDA.

Binhai New District (BND) was selected as one of the covariates for TEDA. BND started in 1994 on the basis of TEDA and Tianjin Port Free Trade Zone with a constructed area of 110.85 km^2. In 2009, it expanded to include the rest of Tanggu District, Hangu District, and Dagang District, reaching 2270 km^2 in size. It is also a National Independent Innovation Demonstration Zone. By the end of 2016, its constructed area was 367.38 km^2, with an economic output for secondary and tertiary industry of 990,747m RMB and over 761,000 employees. Similarly, BND does not undertake region-wide EIP transformation.

Following the above considerations, we conduct four different causality tests in each EIP to reflect the different combinations of intervention points and covariates. Test 1A and 2A denote the tests using data from other industrial parks for the covariates, with the year of EIP approval for upgrade (Test 1A) and the year of EIP verification (Test 2A) as intervention points. Test 1B and 2B denote the tests using aggregate municipality data for the covariates, with the year of EIP approval for upgrade (Test 1B) and the year of EIP verification (Test 2B) as intervention points. Table 13 contains the test information for BDA and TEDA.

Table 13. tests for Causal Impact analysis

		Test 1A	Test 2A	Test 1B	Test 2B
Covariate		Another industrial park as covariate		Industrial/urban data as covariate	
Intervention point	BDA	2009	2011	2009	2011
	TEDA	2004	2008	2004	2008

For this analysis the package of "pycausalimpact" (v0.012, 2019) in Python is used following the analytical procedure outline in Figure 13. The outcomes of these analyses are values that indicate the pointwise absolute and relative effects of the intervention, and its p value (Brodersen et al., 2015). The analysis also gives out beta value, which conveys how strong the covariate is correlated with the observed data, and positively or negatively. Whether a certain value of beta means strong or weak correlation depends on the variables and the fields of study (Akoglu, 2018). In this study, we set 0.3 as the threshold. Whenever a covariate is not a good predictor for the indicator (absolute beta <0.3), then time is tested as the covariate. However, if time as the covariate still produces absolute beta value lower than 0.3, then the results of the original covariates would be accepted.

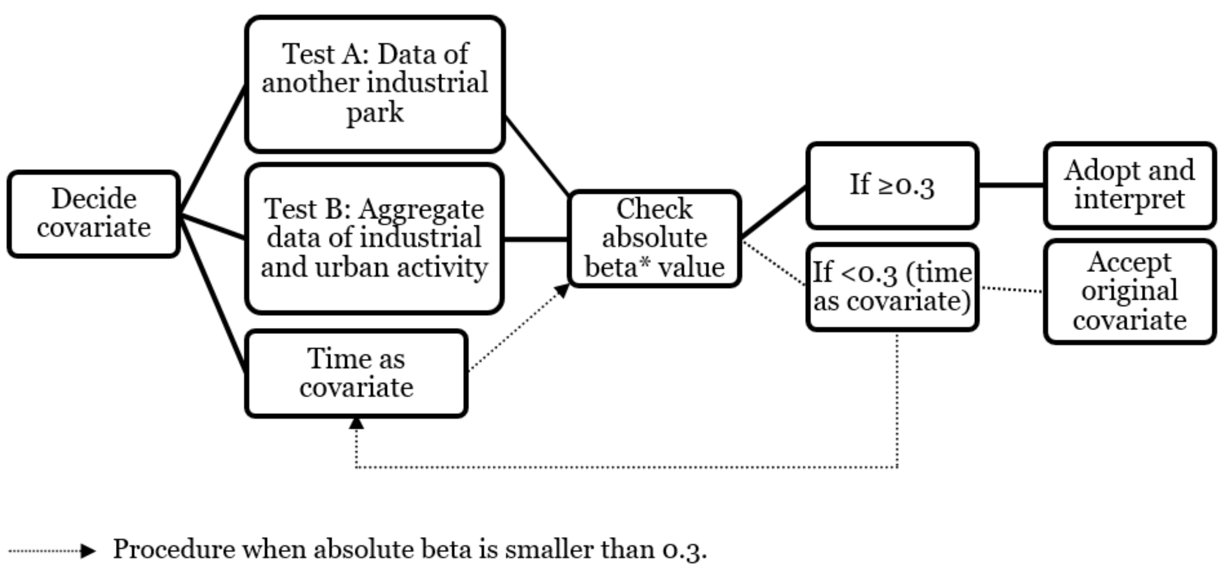


Figure 13: procedures of Causal Impact analysis used in this study

2.4.5 Interrupted Time Series analysis

The second method used for causality analysis to understand if EIP upgrade improves the performance of a certain indicator is Interrupted Time Series analysis. ITS analysis has been used to test whether an interruption or intervention causes significant change on the studied object using time series data (Wong et al., 2015). For ITS analysis, all indicators identified in Section 2.3.2 are analysed.

To implement ITS, it is important to define 1) a model that fit the observations before the intervention so the counterfactual value would be reliable, and 2) how the intervention impacts on the trend, whether it is abruptive or gradual (Bernal et al., 2018).

To decide a model for the observations, we used the procedures outlines in Figure 14. STATA (SE 14.2, 2018) is utilised for this purpose. Firstly, we would test data autocorrelation. If data were autocorrelated, we would then use auto-regression (AR) and moving average (MA) to test for 1st difference (① in Figure 14). If 1st difference showed autocorrelation, we would decide AR and MA values based on testing results, which would then be used for ARIMA regression. If 1st difference were not autocorrelated, we would use Poisson regression. After regression, we would then check for residual autocorrelation. If resitual were not correlated, this ARIMA model would be adopted. If residual were still correlated, we would use Prais-Winsten for regression and then check for residual correlation. If residual were not correlated, this Prais-Winsten model would be adopted. If residual were still correlated, we would adjust AR and MA values for regression, and repeat the process of checking for residual correlation. If residuals keep on showing autocorrelation after all possible and feasible AR and MA values have been tried, we would abandon this line of test, and assume that the data are not autocorrelated in the first place.

In the case where data do not exhibit autocorrelation, we would first use Poisson regression to test for residual autocorrelation (② in Figure 14). Unless residuals do not show autocorrelation, this model would be abandoned. If this model were abnadoned, we would then use general linear regression to check for residual autocorrelation (③ in Figure 14). Unless residuals of this model do not show autocorrelation, this model would be abandoned. The results show that general linear regression fit our data the best (Lopez et al., 2017).

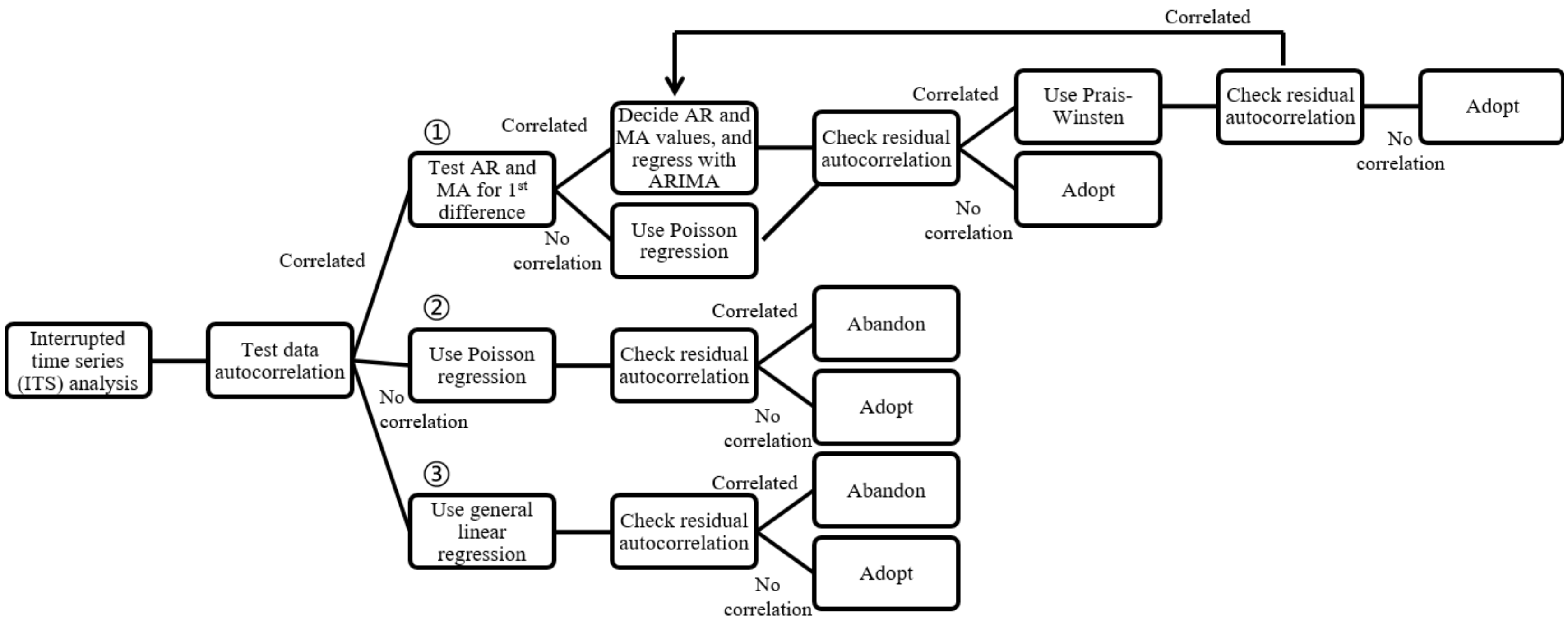


Figure 14: procedures to decide a regression model for observed data. ①, ② and ③ denote the order of model fitting.

To understand the impacts of intervention (in this study EIP upgrade), we opted for three tests, with Test ST meaning the perceived effective year of EIP upgrade intervention is at the start of the upgrade, Test GR meaning the impact of EIP upgrade is gradual and equally distributed along the years, and Test VE considering the effect to be at the verification year of the upgrade. The details of the tests are summarised in Table 14. Time, and impact power of EIP upgrade are used as variables. When time variable is not a good variablel (P>0.05), we would regress with impact power only to capture the effect of EIP upgrade. If impact power was not a good variable (P>0.05), it means that EIP upgrade does not have significant impact on the indicator.

Table 14. tests based on perceived effective year or period of intervention

EIP	**Test ST**			**Test GR**			**Test VE**
Effective year for BDA	2009	2009		2010	2011		2011
Impact power	100%	33%		67%	100%		100%
Effective year for TEDA	2004	2004	2005	2006	2007	2008	2008
Impact power	100%	17%	33%	67%	83%	100%	100%

Note: Impact power denotes how much the impact of intervention (EIP upgrade) exerts on indicator value.

2.4.6 Establishing patterns between tests

Considering the different specifications across tests, and inconsistence in data availability, which result in discrepancies in the results for different tests. For instance, the same indicators with the same method might have different results for different tests.

In order to identify and explain the factors contributing to the patterns of the results, the number of tests agreeing or disagreeing with each other for a certain indicator is compared to understand the underlying influencing factors. Specifically, more tests showing a certain pattern for a certain indicator is likely to indicate that this indicator does improvement regardless of methods and tests used, and the factors behind are likely to be contributing to the patterns. However, as there is uncertainty involved, a narrative approach is adopted to explain the factors yielding to the results (Section 5.6.2).

2.5 Research limitation

The main research limitations of this study relate to low data availability for some indicators, both in the case study EIPs, as well as the entities function as the covariates. It was not possible to perform all causality tests with the CI analysis, especially when using other industrial parks as the covariates. Even though we believe that it is a theoretically better option to use another industrial park in the same region as the covariates, data availability limitations similar to the case study EIPs did not make it possible to establish covariates for many indicators, even when using extensive imputation (Section 2.4.2). This affects the explanatory power of the study in different ways and should be kept in mind when discussing and conveying the results of the research.

Secondly, it was not possible to use in this study some other sustainability indicators that are relevant in EIP contexts such as emissions of specific pollutants, environmental quality, or social aspects of EIP operation, for example, medical costs spent by employees to evaluate the change of working environment of EIPs (Hong and Gasparatos, 2020; Lee, 2019; Piatkowski et al., 2019). Furthermore, due to the change in reporting scopes and inconsistencies of the EIP administrations, it was not possible to create a more complete or representative measure of output (e.g. a basket of product output) as a means of developing additional intensity indicators to those expressed in per unit economic output, land area or employee.

Chapter Three

Drivers and Key Institutional Aspects

3.1 Background

The stakeholders, drivers, regulations and other key institutional aspects have not been systematically analysed and summarised before (Section 1.4), while they are essential for understanding the take-off of the EIP programme, its operations and management, and the implications for the conduction of this study, particularly in deciding what indicators are relevant to the evaluation of the sustainability changes brought by this programme, and what the policy implications could be drawn. With this mind, we conducted an institutional analysis to detangle the relations of stakeholders, regulations and EIPs (Section 2.4.1). The results are presented in the rest of this chapter.

3.2 National policies for EIP development

A series of laws and regulations define the overall institutional framework for the development, operation and regulation of EIPs. Of these, the "*Environmental Protection Law*" (amended in 2015) is the fundamental ministerial regulation pertaining to the environment. Other important laws governing the practicalities of EIPs include the "*Clean Production Promotion Law*" (2003), the "*Energy Conservation Law*" (2008), and the "*Circular Economy Promotion Law*" (2009), among others. Additionally, some strategic documents issued by the State Council reinforce, update, or push for the efforts of certain actions such as the "*Opinions on Accelerating the Promotion of Ecological Cultural Construction*" (2015) (Table 15).

Within this overarching institutional framework there is a constellation of administrative measures issued by relevant ministries and commissions that directly regulate EIPs. The measure most directly linked to EIP development is the "*Administrative Measures on National Demonstrative Eco-Industrial Parks*" jointly issued by EPA, MOST, and MOFCOM. This regulation was issued in 2007 and amended in 2015, and serves as a guideline for the application, establishment, verification, nomination and supervision of demonstrative EIPs in China (Table 15).

Many different governmental departments, administrations, bureaus, and research/academic institutes provide appropriate guidance for the implementation of the aforementioned regulations and processes. Figure 15 visualises the connections between the different governmental bodies and other stakeholders related to the operation of EIPs. Figure 16 provides a schematic representation of the processes followed during the application, verification and nomination of national demonstrative EIPs. It is worth mentioning that EIP policies and initiatives have strong interactions with other programs related to environmental protection and sustainable development in the context of industrialisation and urbanisation but fall outside the purview of this analysis.

It can be argued that environmental concerns and economic priorities have been the two major underlying drivers of EIP development in China when looking critically at the policies that have shaped its development (and the mobilised funding to support their development). These two underlying drivers are highly interlinked in that resource conservation within EIPs contributes to economic gains, and at the same time reduces environmental pressures (Chapter 1).

EIPs are essentially parts of a long series of top-down environmental regulations and investments influenced by national environmental catastrophes and widespread pollution incidents that have had negative ramifications for public health (Liu and Diamond, 2005)[8]. Such events have inherently shaped some of the underlying national environmental regulations related to EIPs (Li and Lin, 2016) (Table 15). At the same time the national government has engaged more closely with international and regional environmental issues through the UN Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) (FAO, 2010, UN, 2020) and other regional agreements with Northeast Asian countries (MOE, 2018).

In order to meet such environmental commitments without compromising economic growth, the latter of which has historically taken higher priority over the environment (Geng et al., 2006), there has been a need to reform economic structures (Shi et al., 2012a), and energy use patterns, as well as to improve regulations, technology, funding mechanisms, and management capacity, among others (Shi et al., 2012b). Thus, EIPs have been essentially perceived as one of the approaches for transitioning to a "green economy" that links both environmental and economic imperatives (Zeng and Shi, 2018).

8 It is worth noting that environmental concerns are increasingly articulated directly by the Chinese public. In a notable such event, citizens and scientists raised concerns against the development of a chemical plant in Xiamen by the local government. Even though this plant could potentially substantially boost the local economy, it could have had significant negative environmental impacts (Gu, 2016).

Table 15: major laws and regulations related to EIP development and operation in China

Issuing Government Body	Name of Law or Regulation	History	Milestones related to EIPs
State Council	Environmental Protection Law	1979: Pilot version 1989: Amendments and formal version 2014: New amendments	- Fundamental national law regarding environmental protection, public health and sustainability - Sets appropriate instruments/bodies, and legal procedures to achieve the above objectives
	Law on the Prevention and Control of Environmental Pollution by Solid Wastes	1995: Issued 2004: Amended, effective in 2005	- Promotes clean production and circular economy approaches - Mandates the reporting and registration of industrial solid waste
	Energy Conservation Law	1997: Issued 2007: Amended, effective in 2008	- Requires energy savings in the industrial sector - Encourages the use of residual heat and pressure
	Clean Production Promotion Law	2002: Issued, effective in 2003	- Offers a clear definition of clean production in the industrial sector and lays out relevant financial incentives
	Environmental Impact Assessment Law*	2003: Issued 2016: Amended	- Introduces significant potential penalties for failing to meet environmental requirements - Simplifies and increases the effectiveness of verification
EPA	Provisions on the Application, Denomination and Management of National Demonstrative Eco-Industrial Parks (Trial); Guideline for Eco-Industrial Park	2003: Issued 2007: ** amended, effective in 2008	- Provides appropriate governing bodies, procedures and planning standards

	Planning (Trial)**; The Application, Denomination and Management Provisions on Demonstrative Circular Economy Zones (Trial); Guideline for Circular Economy Zone Planning (Trial)		
State Council	Opinions on Accelerating the Development of Circular Economy	2005: Issued	- Recognises the historical environmental problems caused by industrialisation, promotes 3R principles and circular economy - Sets out major tasks, research and standards development needs, legal system establishment, and appropriate bodies for the implementation
EPA	Standard for Sector-Specific Eco-Industrial Parks (trial); Standard for Sector-Integrated Eco-Industrial Parks (trial)***; Standard for Venous Industry Base Eco-Industrial Parks (trial)	2006: Issued 2009: *** replaced by a new standard 2012: *** modified 2015: The three standards were combined into Standard for National Demonstration Eco-Industrial Parks, effective in 2016	- Provides technical standards - Relaxes the requirements of EIP development and simplifies the process by integrating three sets of standards into a single standard
EPA, MOFCOM & MOST	Notice on Deploying the Development of National Demonstrative Eco-Industrial Parks	2007: Issued	- Launches the pilot for EIP development in line with resource-saving and eco-friendly needs
MEP, MOST & MOFCOM	Administrative Measures on National Demonstrative Eco-Industrial Parks (Trial)	2007: Trial version issued 2015: Amended	- Articulates the role of the leading office comprised of MEP, MOST and MOFCOM
State Council	Circular Economy Promotion Law	2008: Issued, effective in 2009	- Promotes circular economy to a national law - Encourages the integrated utility of resources

			within industrial parks
CLONDEC	Notice on Strengthening the Development of Low-Carbon Economy in National Demonstration Eco-Industrial Parks	2009: Issued	- Shifts the focuses of EIP development to low-carbon economy
MEP, MOFCOM & MOST	Instruction on Betterment of National Demonstration Eco-Industrial Parks' Construction Work (Request for Comments)	2011: Issued; the comments were integrated to make Instructions on Strengthening the Development of National Demonstration Eco-Industrial Parks (Issued in late 2011).	- Reinforces the importance of EIP development - Sets out the major tasks, and legal system establishment needs
State Council	Circular Economy Development Strategy and Near-Term Action Plan	2013: Issued (targeting end of 2015)	- Concludes the achievement of "11th 5-year plan" - Details the tasks for major industrial sectors of the economy - Lays out a plan for whole society involvement, and implementation measures
State Council	Opinions on Promoting the Innovative Development of the Reforming and Upgrading of National Economic and Technological Development Zones	2014: Issued	- Emphasises the importance of industrial parks, and their needs to be upgraded
State Council	Opinions on Accelerating the Promotion of Ecological Civilisation Construction	2015: Issued	- Recognises the lagging behind of ecological civilisation construction, and China's role in global combat against climate change

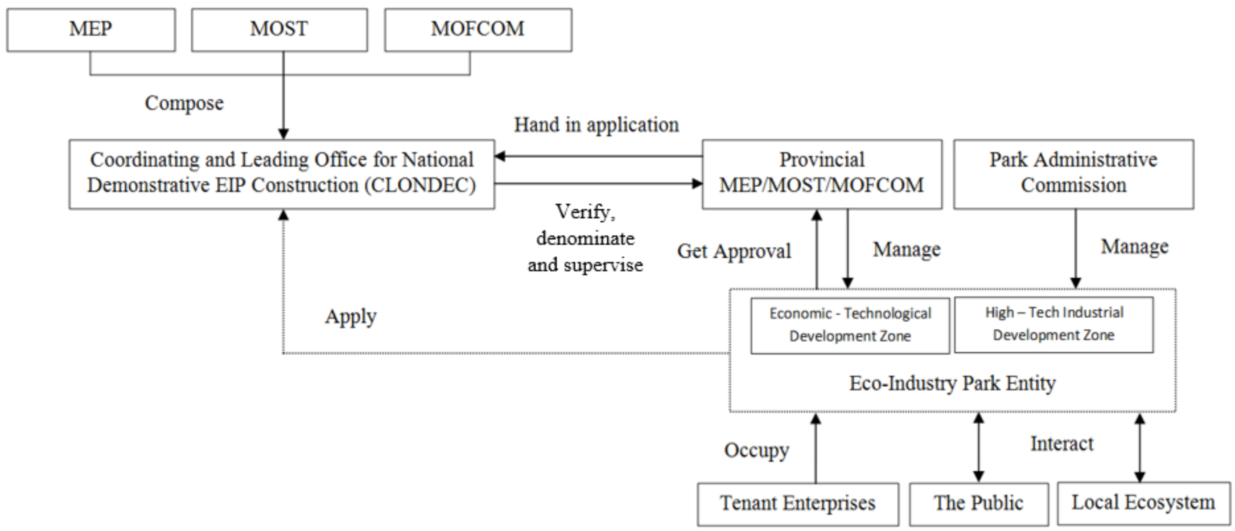


Figure 15: stakeholder connections during the development of national demonstrative EIPs

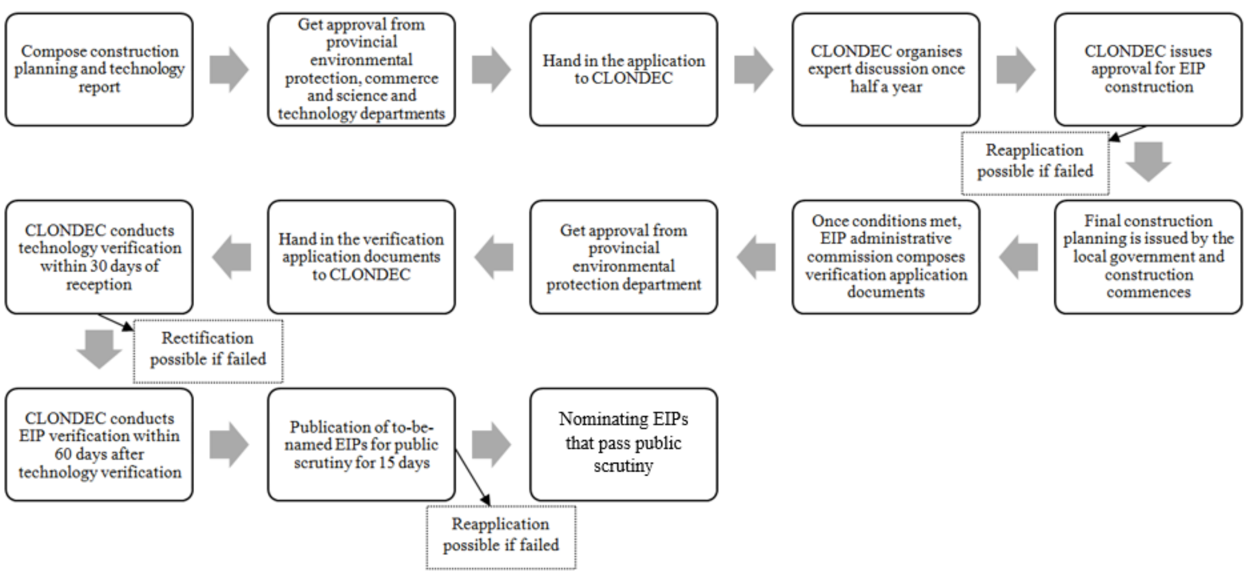


Figure 16: procedures for the application, verification and nomination of national demonstrative EIPs

Economic expectations at various levels (e.g. national, regional, enterprise) have also driven EIP development (Yu et al., 2015c). As discussed above, at the national and regional level, EIPs are perceived as avenues to catalyse green economic transitions through enhancing resource use efficiency and waste reuse/recycling, and minimising transportation (Lin et al., 2004) (Section 1). Such economic benefits are big incentives for many enterprises to engage in industrial symbiosis (Yu et al., 2015c). Even though national authorities do not provide subsidies or favourable taxation for EIPs (Thieriot and Sawyer, 2015), the Guide for the Establishment of Eco-Industrial Parks Planning (2007) encourages governments at various levels to draft policies that support the various aspects of EIP development and operation. Tax breaks and subsidies are more often applied to individual enterprises meeting some criteria (Yu et al., 2015c), but such incentives might put a burden on local government. Yet local governments are also incentivised to use EIPs in their areas to attract investments, especially those concerned with environmental performance (Geng et al., 2009).

3.3 EIP operation and management

The administration commission of EIPs is the governing body that is most directly involved in EIP development. There are two main types of governing models for EIPs: (a) the integrated administration commission model, and (b) the autonomous administration commission and development company model (Dechema, 2007). In the former, the local municipal government, in addition to providing basic infrastructure services, delegates the administration commission and fulfils some governmental functions. This strong role of the local municipal government might have important ramifications for management effectiveness and market orientation (Zhang and Huang, 2017). The latter model involves an investment and development company that is responsible for financing infrastructure, utility services, and waste disposal (Dechema, 2007). Even though the investment and development company is profit-driven, it is often a state-owned enterprise that has aligned interests with the national/local government (Chen and Meyer, 2011). It is worth noting that different administrative models might not yield distinctive results and that the EIP administration might disagree with the central government’s political targets (Chen and Meyer, 2011).

The governing bodies might delegate their authorities to self-regulating entities in relevant industries including, but not confined to, the China Association of Environmental Protection Industry, Industrial Conservation and Clean Production Association (Wu, 2002). Several governmental documents encourage industrial associations to provide technical, managerial, consulting, and other related services to EIPs (MEP et al., 2011; State Council, 2013). Such industrial associations tend to facilitate technology and information sharing through conferences, introducing experts that can provide consulting services to other stakeholders (Song et al., 2018), and through the influence of their committee members (who are often strongly linked to the government) (Zhou, 2010).

In addition to laying out the guidelines for EIP planning, EPA, MOFCOM, and MOST have also co-issued a set of standards for EIP development and operation (Table 15). These standards were issued originally in 2006, and then amended in 2015 to improve aspects related to industrial symbiosis and environmental protection (Huang et al., 2019). The two EIP standards have slightly different indicators and foci, but the latest one includes a broader set of categories including goals for (a) economic development, (b) symbiosis processes, (c) resource conservation, (d) environmental protection, and (e) information disclosure (Section 3.1). These standards essentially lay the foundation and imperatives for EIP operation and management, and substantially affect the sustainability of EIP development and operation. It is interesting to note that apart from technological and environmental criteria, there are also requirements for organisational aspects and innovations, such as information disclosure in terms of (a) environmental information disclosure, (b) development of an eco-industrial information platform, and (c) publicisation of events related to EIP activities.

Apart from these EIP-specific standards, there are also broader standards related to environmentally sound industrial production such as the ones issued by NDRC and MOF (2017), and MIIT (2016). These standards have different foci, but all have the intention to catalyse the transformation of the material and energy flows of economic activities from linear to circular, and from individual to symbiotic patterns (Table 16).

Table 16: standard systems related to the upgrade of industrial parks in China

Standards	Issuing body	Year of issue	Category	Description
Standard for National Demonstration Eco-Industrial Parks	MEE	2015 (updated)	- Economic development - Industrial symbiosis - Resource saving* - Environmental protection* - Information disclosure	Industrial symbiosis among entities in the industrial park
Notice on the End-of-term Evaluation and Capital Settlement of the National Demonstration Industrial Parks of Circular Economy Upgrade and Urban Mining Demonstration Pilots	NDRC and MOF	2017	- Resource productivity* - Resource consumption - Comprehensive utilisation of resources* - Pollutant emissions* - Other indicators - Specific indicators - Subsidised projects - Self-implemented projects	Circular use of resources from agriculture and industry within industrial park
Requirement for the Evaluation of Green Industrial Parks, under the Notice on the Establishment of a Green Manufacturing System	MIIT	2016	- Energy utilisation - Resource utilisation* - Infrastructure - Industry - Ecology and environment* - Management	Green factory, green products, green industrial parks, green supply chains

Note: * denotes the main foci of each standard system. Source: Adapted and updated (Piatkowski et al., 2019)

3.4 Funding mechanisms

Mobilising sufficient and sustained funding is an important aspect for the development and operation of EIPs in China (Zhu et al., 2015). Given the strong link between EIPs and environmental abatement, there is a large pool of potential funding that is available for EIP development in China. Between 2001 and 2016 the total investment for environment pollution abatement had grown at an average of 15.5% per year

(Figure 17). These investments are classified into three broad categories, namely (a) urban environmental infrastructure, (b) environmental treatment facilities that need to have synchronised design-construction-operation with the main project investment (in 2013 this category was re-named “investment with environmental protection verification”), and (c) mitigation of industrial pollution sources (especially outdated facilities) (Figure 18).

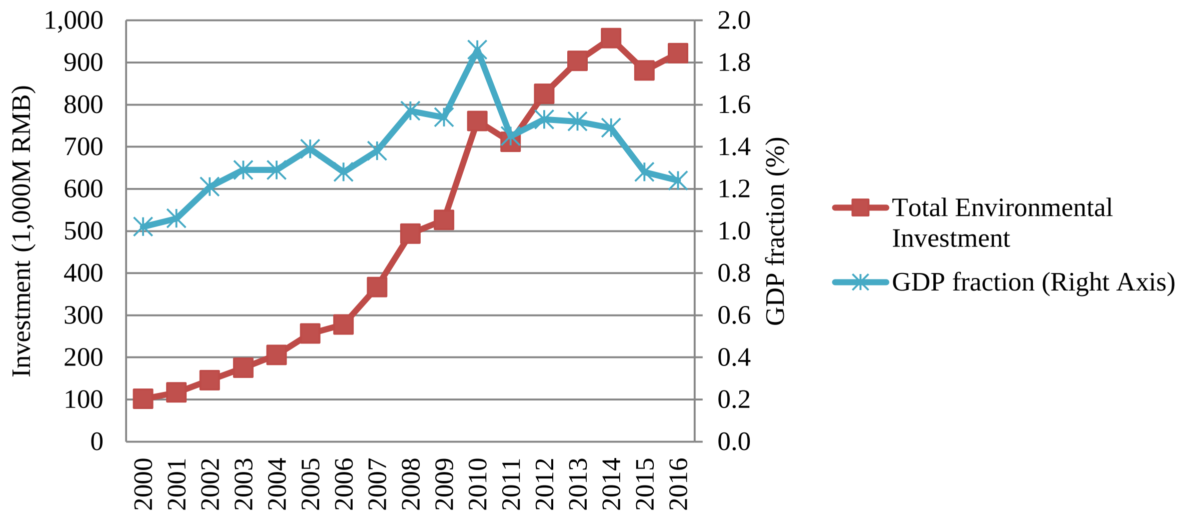


Figure 17: amount of environmental investment (left y-axis) and its GDP fraction (right y-axis)

Source: developed with data collected from the National Bureau of Statistics of China

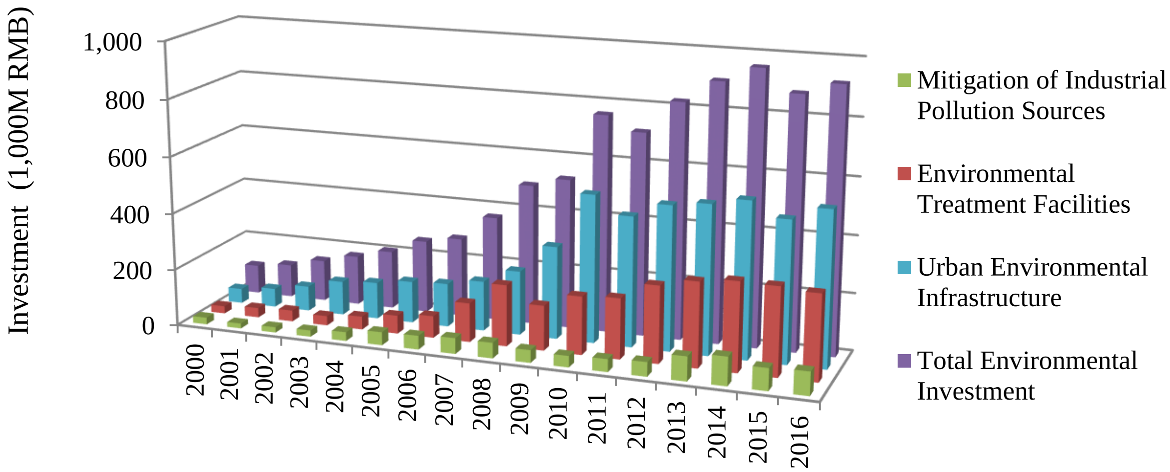


Figure 18: breakdown of environmental investments by category

Source: developed with data collected from the National Bureau of Statistics of China

The growth in EIP investment has likely followed similar trajectories. For example, Figure 19 outlines aggregated investment trends for two Chinese EIPs, Beijing Economic Development Area (BDA) and Tianjin Economic Development Area (TEDA). Even though EIP promotion is often perceived to lack specific financial support from the national government (Thieriot and Sawyer, 2015), some key governmental documents encourage financial support for EIPs in the form of subsidies and tax reduction (MEP et al., 2011, 2015). Some EIPs are joint investments between the Chinese government and foreign governments such as the China-Germany for the Qingdao Sino-German Eco-park and China-Singapore for the Suzhou Industrial park. Supranational organisations such as the United Nations Environmental Programme (UNEP) and the Asian Development Bank (ADB) have also provided financial support for relevant projects in China (Geng et al., 2006). As EIP development is also a normal business operation, capital has been invested through infrastructure construction, FDIs (foreign direct investments, Asian Development Bank, 2019), and private domestic investment, among others (Piatkowski et al., 2019). Table 17 summarises some other funding schemes applicable for EIP development.

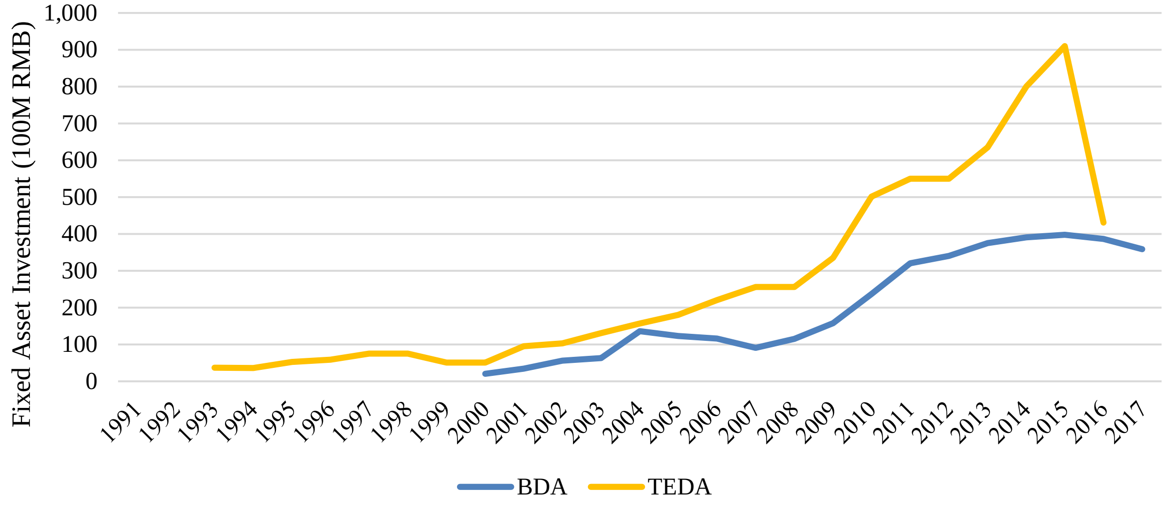


Figure 19: investment in fixed assets for two EIPs

Source: developed with data collected from the annual reports of TEDA and BDA

Table 17: funding channels for EIP development

Governing body	Funding source	Scheme	Target field	Project category	Funding timescale
NDRC and MOF *	MOF, or self-funding	Industrial park recycling transformation	Resource productivity, land productivity, waste recycling, reducing energy and water consumption intensity, etc.	Industrial chain extension, water conservation and recycling, energy saving and cascade utilisation, pollution prevention, information platform construction, infrastructure construction	Approval, mid-term, final stage, 3-5 years
MOST **	MOST	863, 973, Torch and Spark	Related to science and technology development	Research project, enterprise, or education programme	Mid-term evaluation, 5 years (2+3)
Municipal government	Municipal government	Technology Development Fund, Technology VC Fund	Technology innovation, industries unique to the corresponding municipality	R&D, applied research, R&D infrastructure, S&T management, and advocacy, basic research, social science, international cooperation, and others for local technologies	Varies, normally mid- to long-term

Source: (* Wen et al., 2018; ** Tan, 2010)

3.5 Discussion on critical institutional aspect

Despite the extensive promotion and support of EIPs from the national, provincial, and local governments, their development and implementation still face many challenges. Sections 3.5.1-3.5.4 critically discuss these major challenges including the (a) gaps of (and lack of adherence to) EIP guidelines and standards (Section 3.5.1), (b) disjoint between EIP planning and implementation (Section 3.5.2), (c) misconception and manipulation of key EIP concepts (Section 3.5.3), and (d) knowledge gaps and non-comprehensive assessment frameworks (Section 3.5.4).

3.5.1 Gaps and lack of adherence to guidelines and standards

Guidelines and standards are key aspects of EIP development and implementation and span different technical and institutional domains (Section 3.2 and 3.3). Many scholars have pointed to some of the positive outcomes of the adoption and strict implementation of guidelines and standards on EIP performance. For example, the implementation of strict environmental regulations coupled with increased infrastructure investment has helped some EIPs to improve eco-efficiency (Fan et al., 2017b). The needs for large-scale technological innovation (Wang et al., 2019), mobilisation of economic/financial capital

(Dong et al., 2016), and information-sharing (Song et al., 2018), require coordinated actions among multiple stakeholders. In this sense EIP development and upgrading has improved the coordination capacity of different stakeholders (Wang et al., 2017), creating wider benefits (Yu et al., 2014b).

Some scholars have criticised certain gaps and failures in the implementation of EIP guidelines and standards. For example, there is a lack of balanced indicators in current standards between economic and environmental improvement, as well as a lack of certain social indicators related to occupational health and gender issues, among others (Piatkowski et al., 2019). It has been pointed out that the first set of national standards was overly restricted to eco-efficiency without considering broader sustainability aspects (Geng et al., 2008). Criticisms for the updated standards have focused on the need to further incorporate indicators on symbiosis, social impacts, and reduction efforts (Huang et al., 2019).

One contentious aspect has been public engagement mechanisms. Many scholars have pointed out that enhancing public and industrial awareness on EIP practices might increase the support for such initiatives (Geng and Côté, 2003). Yet many EIPs have formulated park policies without consulting the public (Geng et al., 2009). Even though the interaction of EIPs with surrounding communities is rather dynamic (Section 1.3), initially there was no requirement to maintain public engagement following EIP verification. The need to engage continuously with the public has been encapsulated now in the amended EIP standards of 2015, especially in terms of environmental information disclosure and EIP-themed activities at least twice every year (Section 3.3), though it is not clear if this happens for most EIPs (MEE, 2018a).

3.5.2 Disjoint between planning and implementation

Some scholars have identified a disjoint between EIP planning and implementation (Zhang et al., 2010). This has so far manifested in different means such as in the improper development of facilities, loss of EIP status after verification, and lack of follow up actions as discussed below. For example, in some EIPs certain facilities were built just for passing the verification stage rather than geared towards actual use, while in other cases the inaccurate understanding of important “industrial ecology” and “symbiosis” concepts led to the excessive construction of facilities (Zhang et al., 2010). Another example of this disjoint has been the loss of EIP status for some parks due to inappropriate operation. For instance, the Qingdao Xintiandi Venous EIP lost EIP status in 2016 (only after two years of operation) due to breaching the regulations related to handling of hazardous wastes (MEP, 2016). Despite the aggressive expansion of EIPs in some provinces in the early phases of the national EIP programme in 2001 (Section

1.3)[9], there have hardly been any follow-up implementation actions related to the verification of the approved parks and in the monitoring of already verified EIPs (UNIDO, 2016). In some cases, the disclosure of operation is neglected (MEE, 2019), despite being required by strict guidelines encapsulated in the EIP standards (Section 3.2).

Such disjointed actions can be possibly tracked to the fact that most EIPs have been upgraded from conventional industrial parks that did not originally follow industrial ecological design and construction principles (Mathews and Tan, 2011). Thus, it is not easy to optimise symbiotic chains when upgrading existing infrastructure, factories and other facilities (Shi and Zhou, 2007).

3.5.3 Misconception and manipulation of key concepts

The designation of circular economy as a key national development strategy (Sections 3.2), "incentivised" local governments to construct EIPs as a means of improving their political track record (Chien, 2006). Scholars have argued that some local governments poorly understood some eco-industrial concepts (Geng et al., 2009). For example, the Jiaozuo West Industrial Cluster allegedly included circular economy features and was designated as an ecological-industrial zone, but there are no evident reusing or recycling of by-products/wastes by industrial clusters (Jiaozuo Daily, 2012). In this case, it seems that the concept of eco-industry was understood as linking downstream enterprises more closely to upstream enterprises (i.e. raw material providers) to form elongated circular industrial chains. This failed to add any value apart from generating some savings related to the transportation of raw materials (Jiaozuo Daily, 2012). One possible reason for such misconceptions might have been the ambiguous translation of "eco-industrial" into Chinese, which could be interpreted to mean either industrial systems that mimic ecosystems, or that are generally eco-friendly (Wang et al., 2009).

In other cases, despite the initial large investments into EIP construction and development, some EIPs are unable to attract companies later (CBJ, 2013). Some possible reasons could be (a) the fierce competition for investments in China (Thieriot and Sawyer, 2015), (b) industrial symbiosis requires robust planning (e.g. matching upstream and downstream entities), which could easily be affected by time lags between planning and actual construction (Qu et al., 2015a), and (c) the adoption of new technologies to allow

9 For example, Jiangsu province pursued the aggressive development of provincial EIPs, with 30 verified provincial EIPs and a further 55 approved for construction (by June 2014). Similarly, Jiangxi Province started the development of provincial EIPs in 2008, and by August 2010, had approved 50 EIPs for construction.

participation in symbiosis is often challenging for some entities despite having waste information systems in place (Wen et al., 2018). To avoid losing some of the investment, some EIPs have resorted to practices that go beyond the initial plans and strict standards (Section 3.3). For example, some have manipulated rules encouraging good industrial practices if such rules do not produce the desired outcomes (e.g. some upgraded EIPs have not followed standard practices when attracting more investment or subsidies from the government) (CMMA, 2019). In an extreme case of deviating from initial plans, a provincial EIP used most of the planned industrial land to build real estate (CBJ, 2016).

3.5.4 Gaps in knowledge and assessment frameworks

EIPs have multiple environmental and socioeconomic impacts (Section 1.3) (Shi et al., 2012c). There are significant knowledge gaps about many impacts, both thematically and methodologically. Methodologically, many studies exploring environmental impacts tend to use simulations and proxy measures, thus reducing the ability to understand the actual extent of some effects (Section 1.3) (Figure 4). Thematically, there are very few studies exploring the impacts of EIPs on biodiversity/ecosystem services (Section 1.3) and the society at large (Section 1.3) (Qu et al., 2015b) (Figure 4).

It is not clear why this happens, but it is possibly due to a combination of reasons. First, there seems to be a lack of data for some impacts, especially when longer data series are needed to allow for the actual comparison of impacts before and after verification. Second, there is sometimes an unwillingness of the EIPs to release certain disaggregated datasets, despite the current requirements for data sharing and disclosure, especially those related to indicators in the governmental standards (Section 3.3). Third, EIPs are usually integrated in areas that host various other industrial and residential activities, making it difficult to measure the exact allocation of environmental impacts from EIPs. Finally, many impacts, especially social impacts, are not well-reflected in the current EIP standards, reducing thus the willingness of EIPs to monitor such outcomes (Section 1.3, 1.4).

Apart from the actual knowledge gaps, the viewpoints adopted in EIP assessments tend to be somewhat narrow. Firstly, the existing assessment frameworks and most studies focus on the performance of the EIPs within their physical boundaries, implicitly disregarding the impacts outside EIPs. For example, Chen and Ma (2008) developed a framework to assess the performance of EIPs in Suzhou and Tianjin, but the evaluation was constrained within the EIP boundaries. Similarly, most relevant studies emphasise recycling and industrial symbiosis within the parks, failing to incorporate aspects related to the restoration and regeneration of the precinct ecosystems (and their services) (Shi et al., 2017). EIPs interact actively with entities outside the park and its surrounding environment. And whether the interaction encourages sustainable exchange is often neglected in research (Shi et al., 2010). To an extreme extent, the construction of eco-industrial parks could be counter-ecological (Cai et al., 2007), but there is still no agreed sustainability assessment framework, particularly for aspects outside EIP boundaries and social impacts.

Secondly, many studies tend to adopt an approach that aims to evaluate and justify investment decisions on infrastructure, facilities and technology, e.g. evaluation of the benefits of water treatment (Huang et al., 2009), biomass use (Zhang et al., 2016) and cleaner production (Li et al., 2011). Such studies mostly focus on the beneficial aspects of the investments, especially the financial aspects of the projects (Zhang and Xiao, 2007), rather than the possible environmental and social externalities. Finally, the theoretical research on environment investment auditing lags greatly in China (Gao, 2013), hardly making significant progress since the late 1990s (Wang, 2011), and still lacks an integrated research system (Liu et al., 2014a).

3.6 Summary

The negative environmental impacts associated with the rapid industrialisation serve as the starting point of the EIP initiative. These concerns influenced the Chinese government to implement a rather intricate set of regulations and standards to incentivise the adoption of industrial symbiosis processes in industrial parks and regulate their performance. EIP developmental and operational processes link multiple stakeholders at different levels, which clearly indicates the multi-dimensionality of the EIP initiative, and its centrality to both economic and environmental goals in China.

Through the critical synthesis of the institutional analysis and the literature review it is possible to identify five major challenges associated with EIP development and operation in China, including: (a) the current gaps in (and lack of adherence to) EIP guidelines and standards, (b) the disjoint between EIP planning and implementation, (c) the misconception and manipulation of key EIP concepts, and (d) the gaps in EIP knowledge and assessment frameworks.

Chapter Four

Multi-Criteria Decision Analysis

4.1 Background

Having understood the drivers, stakeholders, regulations, and standards related to the development of EIP in China, we are able to devise aspects and indicators relevant to the assessment of the sustainability performance of selected case study sites. This chapter aims to answer the second objective, which is to outline the sustainability performance of the EIPs for a series of sustainability aspects and indicators over time (Section 1.5). Due to the multi-faceted nature of sustainability assessment, MCDA is utilised to yield straightforward and clear results. The descriptive statistics for every indicator of the two EIPs would be presented before the MCDA results are given.

4.2 Descriptive statistics for indicators

4.2.1 Economic indicators

Except economic output per employee, most of the economic indicators of BDA show gradual upward trend gradually. Ratio of economic output to economic output of city increased from less than 1% in 2000 to about 5% in 2007 and remained roughly stable since then before dropping slightly in 2012 and afterward. Economic output per employee fluctuated with a small peak in 2001, reaching 188,660 RMB per employee, and a higher peak of 265,103 RMB per employee in 2006. This value showed a downward trend since and remained around 200,000 RMB per employee since 2014.

Economic indicators of TEDA generally show upward trend except ratio of economic output to economic output of city, where it showed drop in 1993 and 1994, and has been fluctuating between 15.87% and 17.87% since 2001. Employee number also increased greatly and reached a plateau since 2012. Economic output per unit area had two dips in 2008 and 2014 where the area of TEDA expanded drastically, while during other periods its trend had been generally increasing.

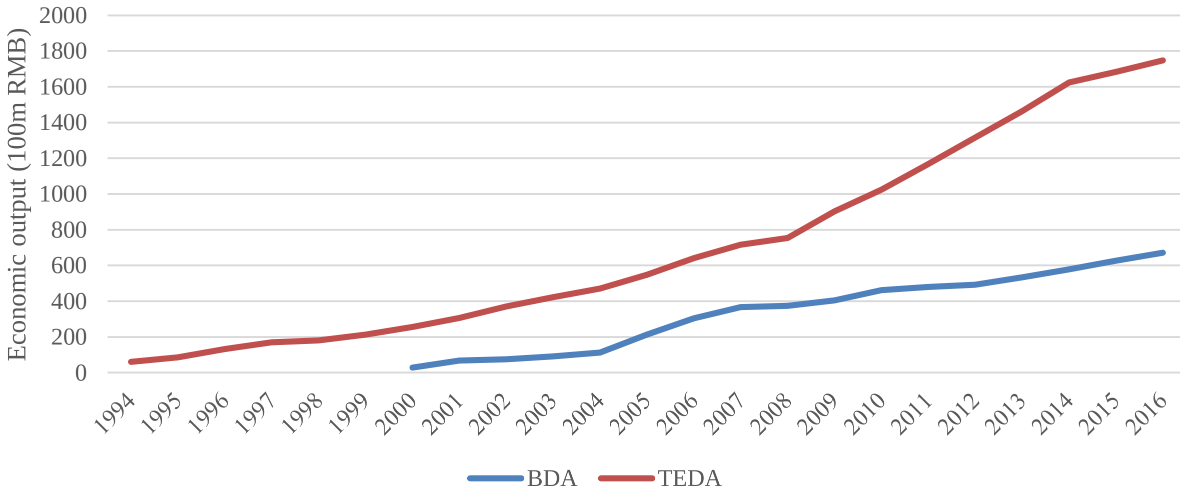


Figure 20.1 Economic output (base year 2000)

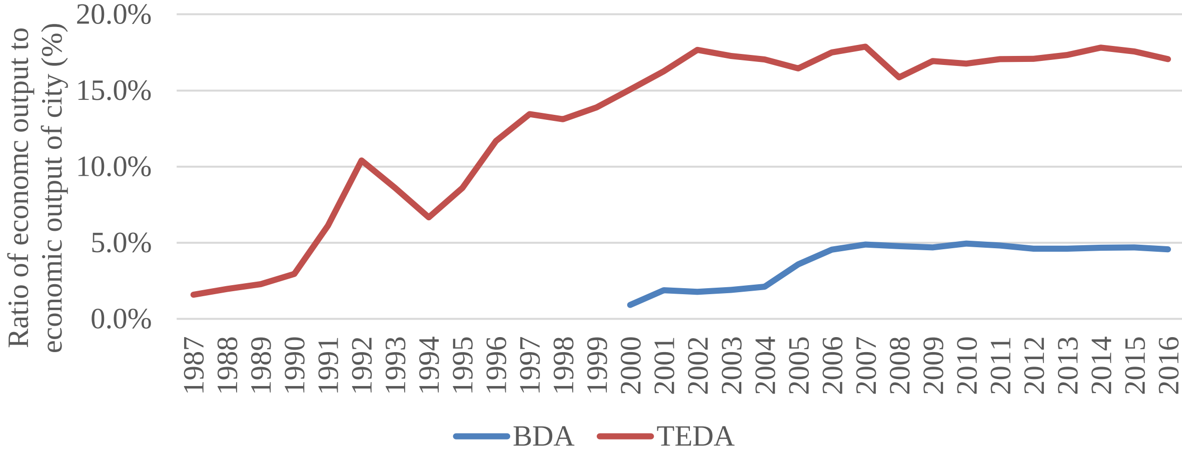


Figure 20.2 Ratio of economic output to economic output of city

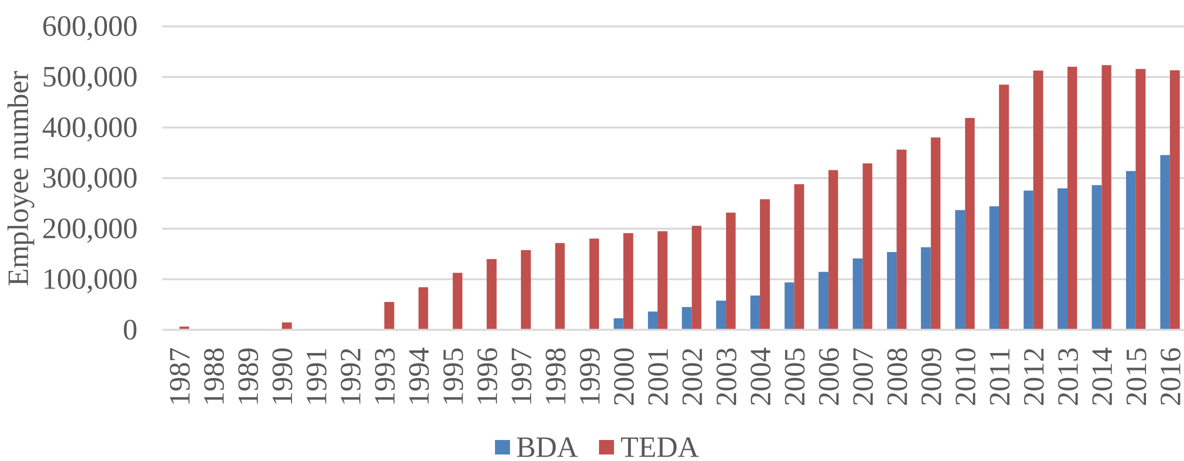


Figure 20.3 Employee number

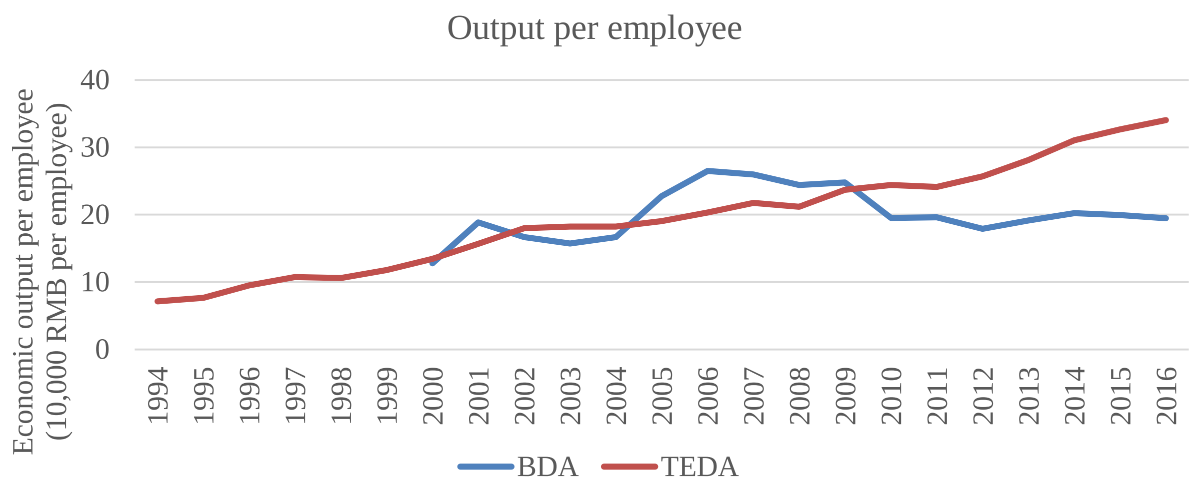


Figure 20.4 Economic output per employee

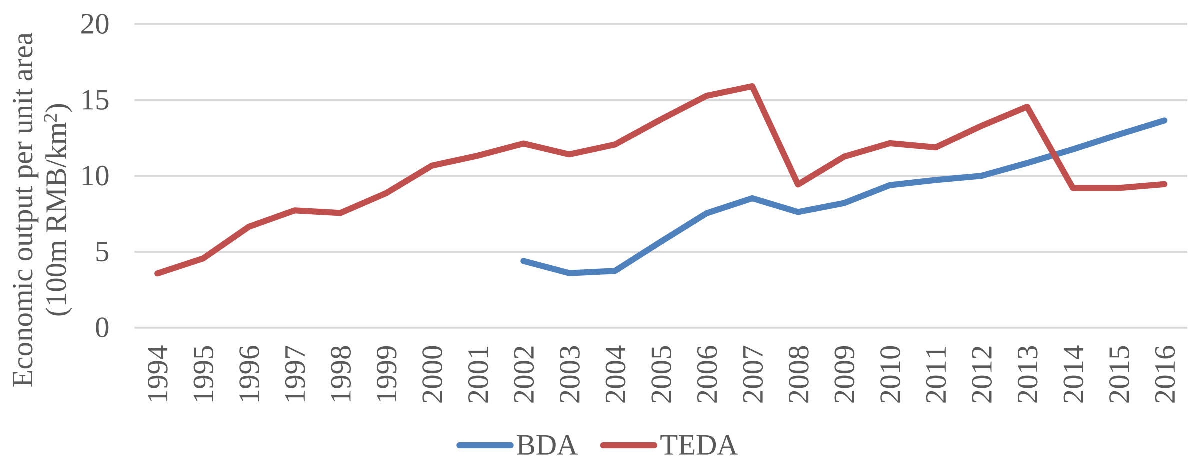


Figure 20.5 Economic output per unit area

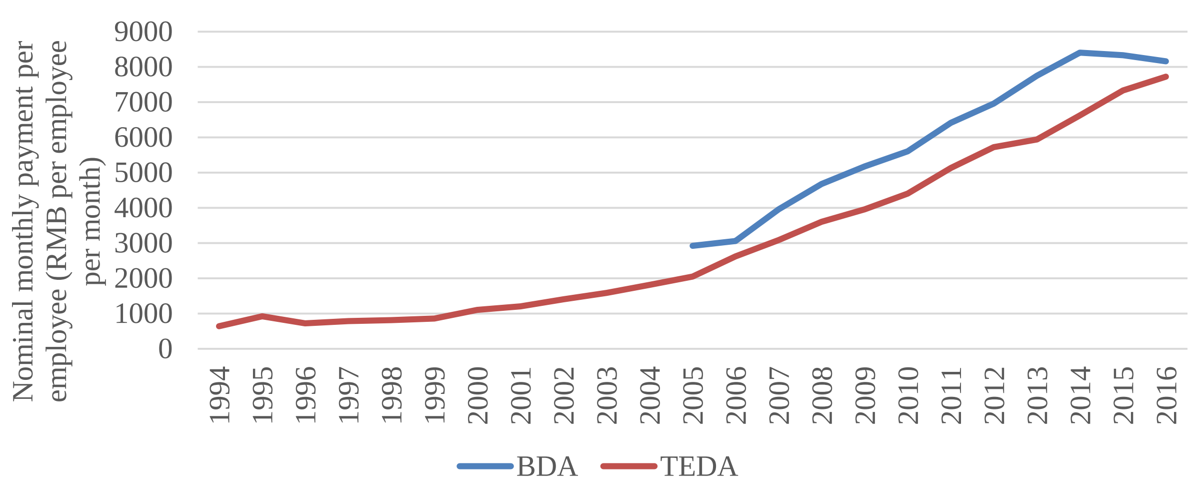


Figure 20.6 Nominal monthly payment per employee

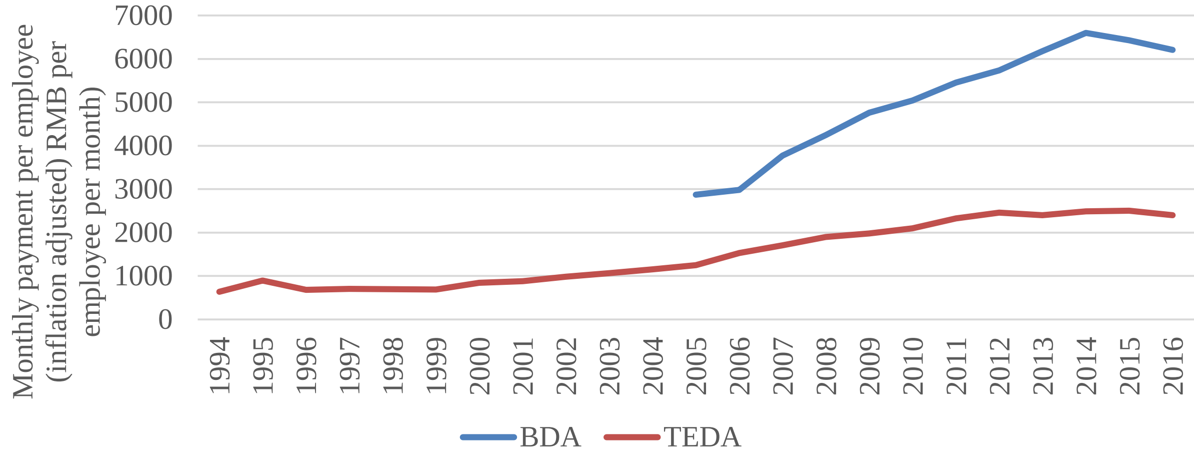


Figure 20.7 Monthly payment per employee (inflation adjusted) (inflation rate based on 2004 for BDA, 1994 for TEDA)

4.2.2 Environmental indicators

BDA has been utilising more and more resources for its operations. Energy use increased threefold from 540,445 tsce in 2005 to 1,750,000 tsce in 2016. Freshwater consumption also rose from 472000 tonne in 2000 to 46,904,000 tonne in 2016. BDA's land expanded from 17.07 square km in 2002 to 49.24 square km in 2008 and have been remaining at this level since.

Resource use efficiency indicators show different trends. Energy use per unit economic output showed fluctuation with a trough of less than 190 kg (sce) per 10,000 RMB between 2006 and 2007, increased to about 300 kg (sce) per 10,000 RMB in 2012, and then gradually decreased since. Energy use per unit area gradually increased from around 14,300 tsce per square km between 2005 and 2006 to over 35,000 tsce per square km in 2016. Freshwater use per unit economic output fluctuated greatly with a peak of 11.65 tonnes per 10,000 RMB output in 2000, and value as low as 5.49 tonnes per 10,000 RMB in 2008. The value has been stable at around 7 tonnes per 10,000 RMB since 2012.

For resource reuse and recycling, BDA's waste heat use increased from 55,807 tsce in 2005, and reached a plateau of 89,110 tsce since 2009 as it has not built any new thermal plant since (Table S7). This results in declining residual heat reuse ratio. Reclaimed water sales increased between 2008 and 2013 from 7,801,875 tonnes to 23,594,800 tonnes, but dropped back to 14,071,200 tonnes in 2016. Meanwhile, reclaimed water sales ratio fluctuated with 2010 being the highest (87.03%).

BDA's GHG emissions increased more than 2.5 times from 2,383,595 t(CO_2e) in 2005 to 8,563,652 t(CO_2e) in 2016. Its GHG emissions per unit economic output fluctuated slightly with a dip to 0.866

$t(CO_2e)$ per 10,000 RMB in 2006, which then gradually increased to 1.411 $t(CO_2e)$ per 10,000 RMB in 2013, and again has been declining since.

BDA's wastewater discharge only increased gradually between 2001 and 2010, but then jumped from 16,425,000 tonnes in 2010 to 31,025,000 tonnes in 2011, which continued to increase to 40,780,000 tonnes in 2014 before showing decline in 2015 and 2016. Wastewater discharge per unit economic output showed declining trend from 7.28 tonnes per 10,000 RMB to 3.55 tonnes per 10,000 RMB between 2004 and 2010, which also jumped to 6.48 tonnes per 10,000 RMB in 2011, and then showed similar trend as wastewater discharge. Wastewater discharge per unit area has similar trend with wastewater discharge, which showed slow upward trend between 2004 and 2010, a jump to 630,077 tonnes per km^2 in 2011, peaked at 828,188 tonnes per km^2 in 2014, and then declined in 2015 and 2016. On the other hand, wastewater treatment capacity showed stepwise increase as new wastewater treatment plants were commissioned for use.

Air quality better than Level II at BDA showed fluctuation too, with the values between 2013 and 2016 obviously lower than previous years. Ratio of green area also fluctuated with years in the middle having lower values.

TEDA has been utilising more and more resources. Its energy use increased sevenfold from 494,069 tsce in 1993 to 3,552,968 tsce in 2013 although with falls in 2005 and 2006. Its freshwater use rose 14 times from 7,010,000 tonnes in 1993 to 101,592,004 tonnes in 2013 before declining slightly afterward. Land use of TEDA showed two jumps in 2008 (from 45 km^2 in 2007 to 80 km^2), and again in 2014 (from100.6 km^2 in 2013 to 176.47 km^2 in2014).

Energy use per unit economic output and freshwater use per unit economic output both declined gradually, while energy use per unit area fluctuated, which peaked at 55,511 tsce per km^2 in 2004, declining to 23,884 tsce per km^2 in 2008 before rising again since.

TEDA's waste heat use and reclaimed water sales generally showed improvement, despite reclaimed water sales having two dips in 2003 and 2008, its values more than doubles in 2009, and continued to rise to 3,354,000 tonnes in 2014. On the other hand, residual heat reuse ratio increased from 8.6% in 1999 to 19.3% in 2009, and then declined gradually to 14.4% in 2013. Reclaimed water sales ratio fluctuated and reached a peak at 9.1% in 2010 before declining slowly to 7.2% in 2016.

TEDA's GHG emissions increased generally from 6,819,644 $t(CO_2e)$ in 2001 to 19,689,193 $t(CO_2e)$ in 2013 with only slight dips in 2006 and 2009. GHG emissions per unit economic output generally decreased from 2.02 $t(CO_2e)$ per 10,000 RMB in 2001 to 1.1 $t(CO_2e)$ per 10,000 RMB in 2013.

Wastewater discharge at TEDA showed increasing trend but with a trough between 2006 and 2011. It peaked at 44,797,500 tonnes in 2014. Wastewater discharge per unit economic output and wastewater discharge per unit area both showed generally declining trends although both experienced a slight rise in 2004. Wastewater treatment capacity increased from 36,500,000 tonnes per year in 1999 to 56,721,000 tonnes per year in 2016, but with a drop during 2007 and 2010 potentially due to out of commission or downsize as some enterprises built their own wastewater treatment facilities (Table S4).

Air quality better then Level II at TEDA fluctuated with 2013 being the worse (166 days) among all years. Ratio of green area of TEDA showed fluctuation without clear patterns but ranged between 20.5% and 35%.

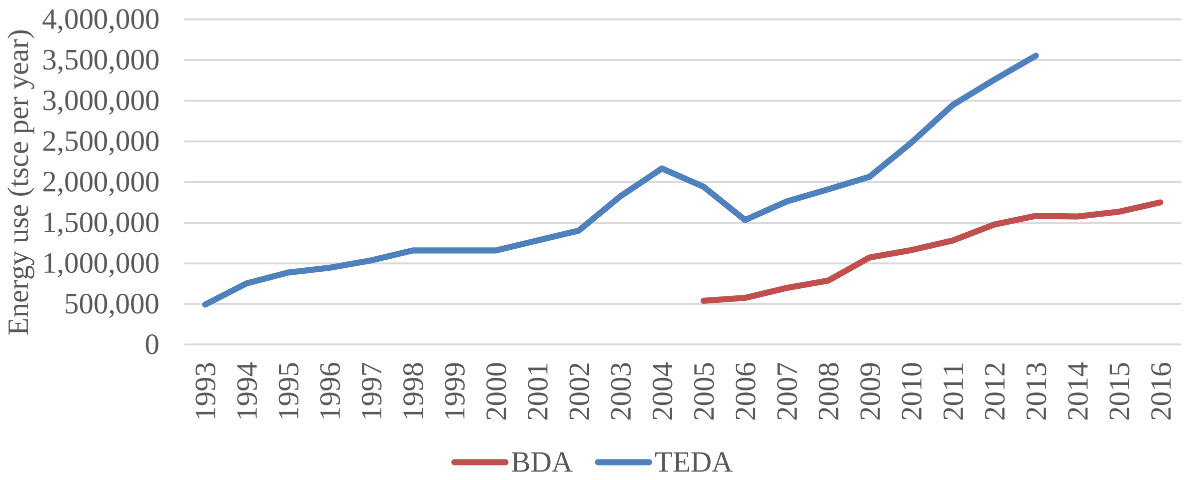


Figure 20.8 Energy use

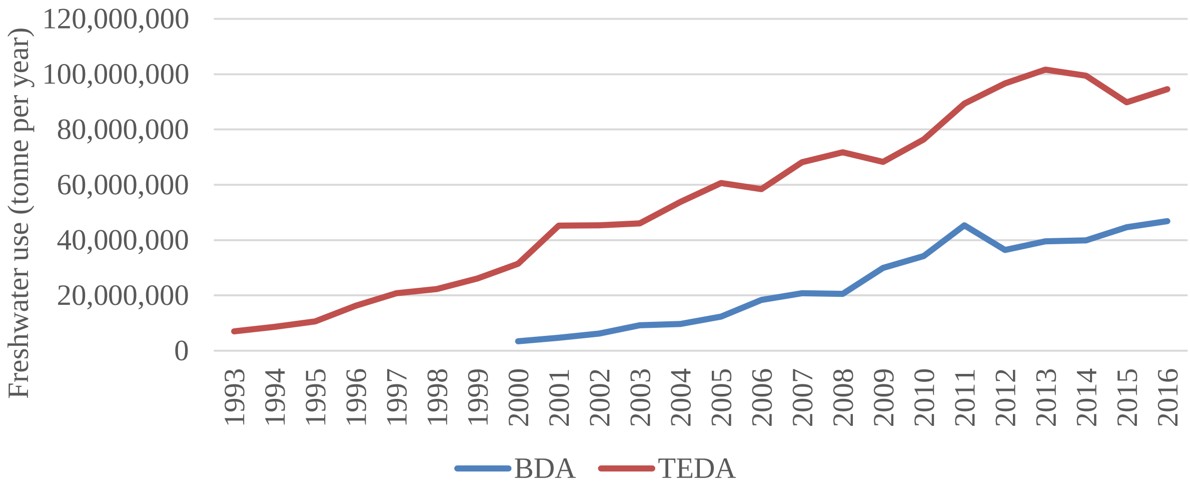


Figure 20.9 Freshwater use

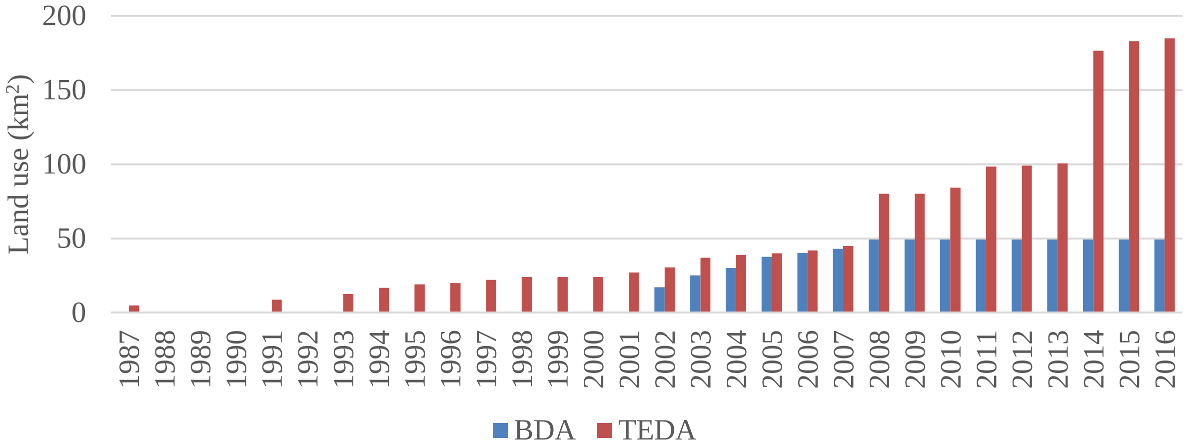


Figure 20.10 Land use

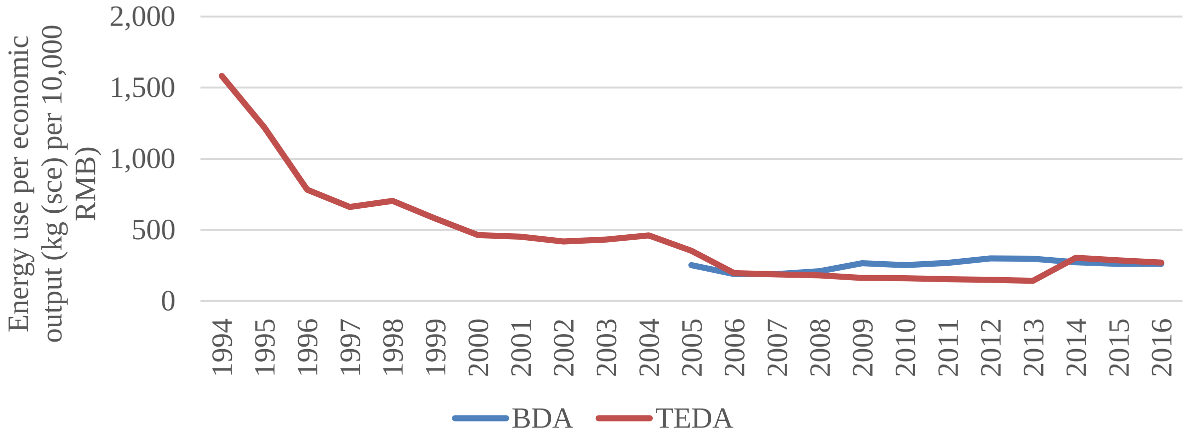


Figure 20.11 Energy use per unit economic output

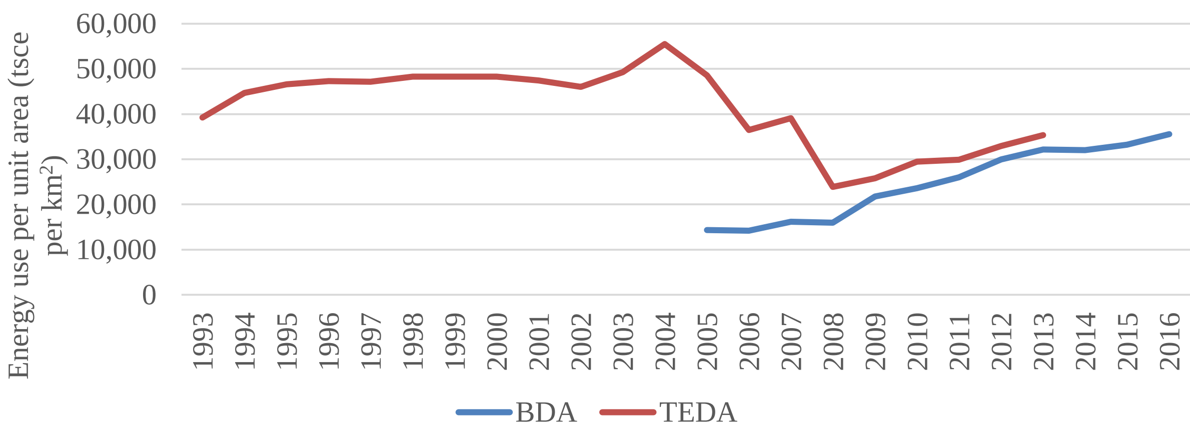


Figure 20.12 Energy use per unit area

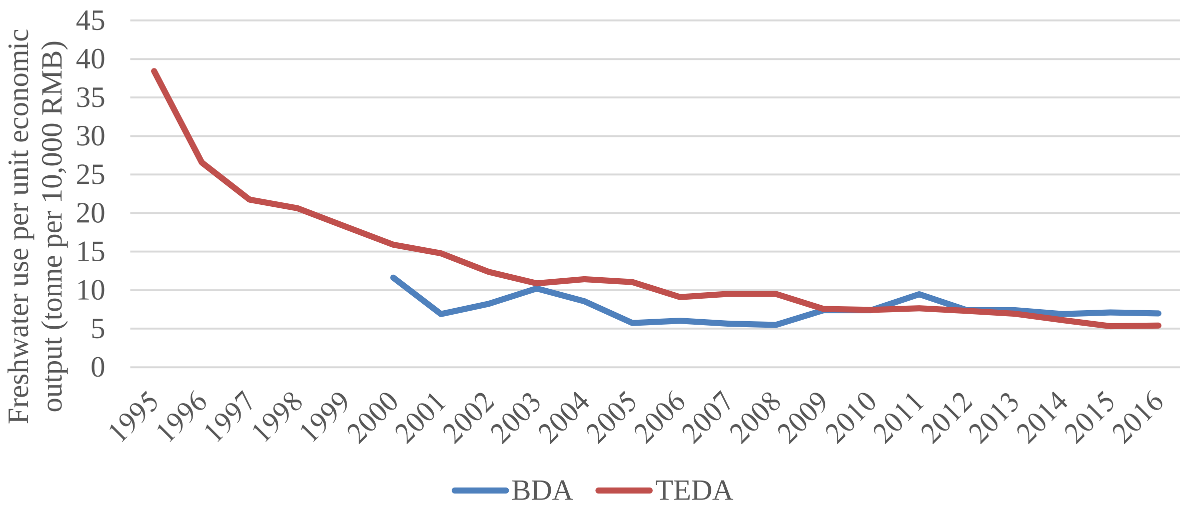


Figure 20.13 Freshwater use per unit economic output

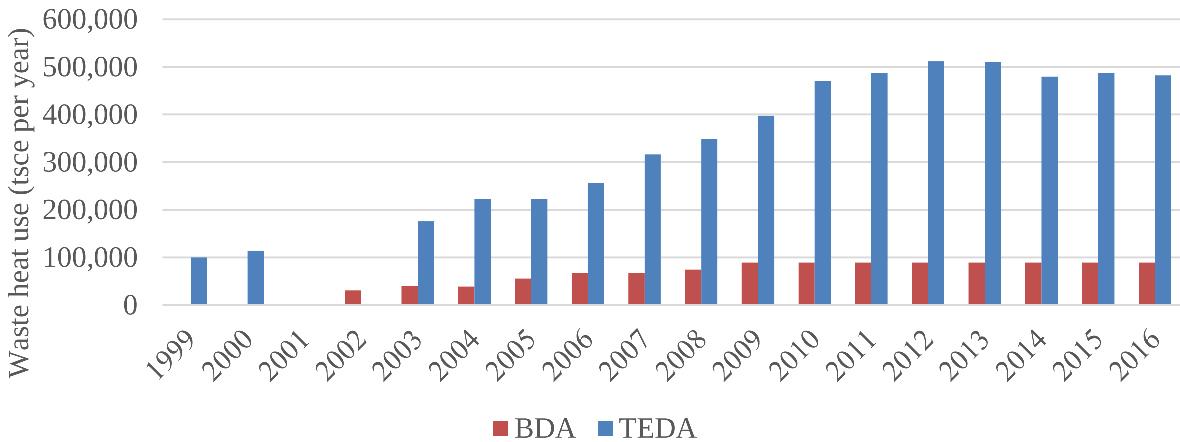


Figure 20.14 Waste heat use

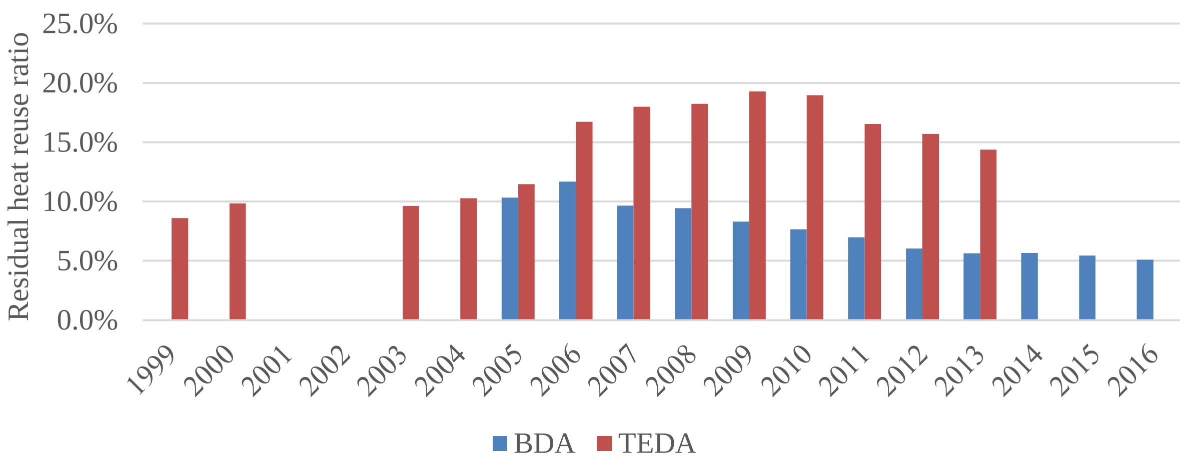


Figure 20.15 Residual heat reuse ratio

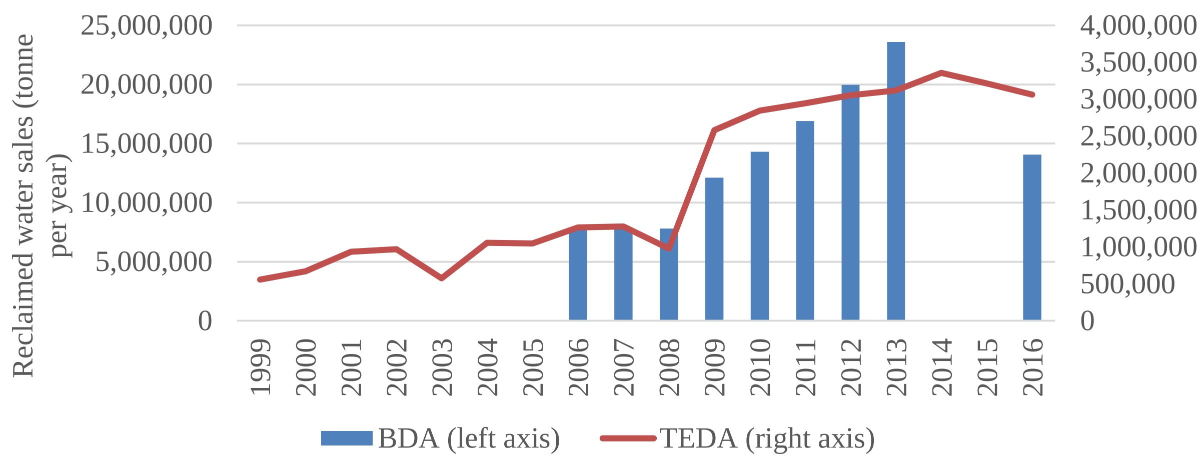


Figure 20.16 Reclaimed water sales

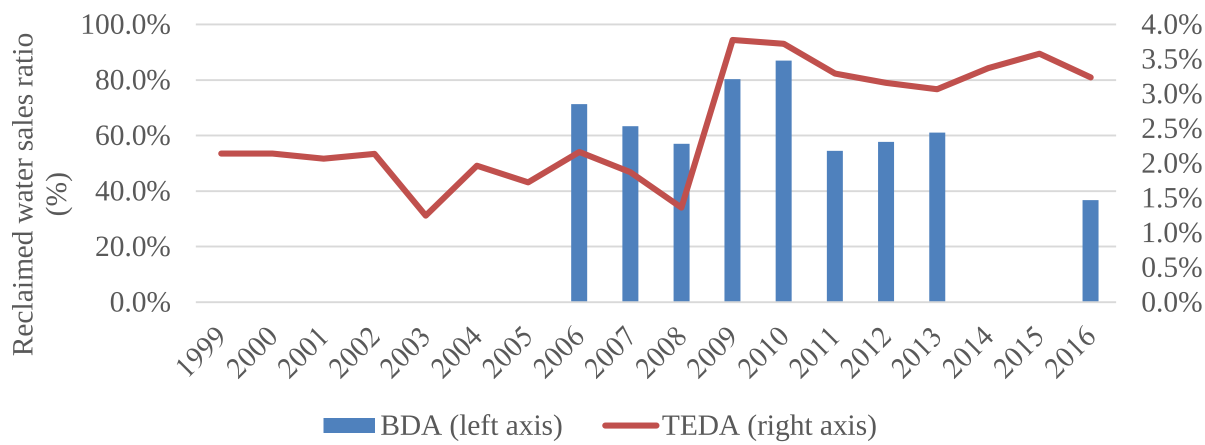


Figure 20.17 Reclaimed water sales ratio

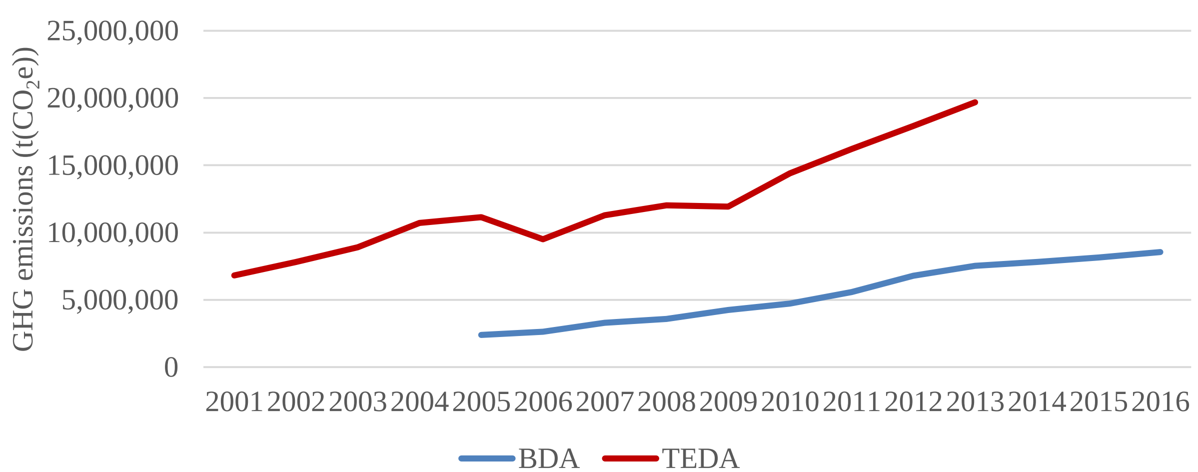


Figure 20.18 GHG emissions

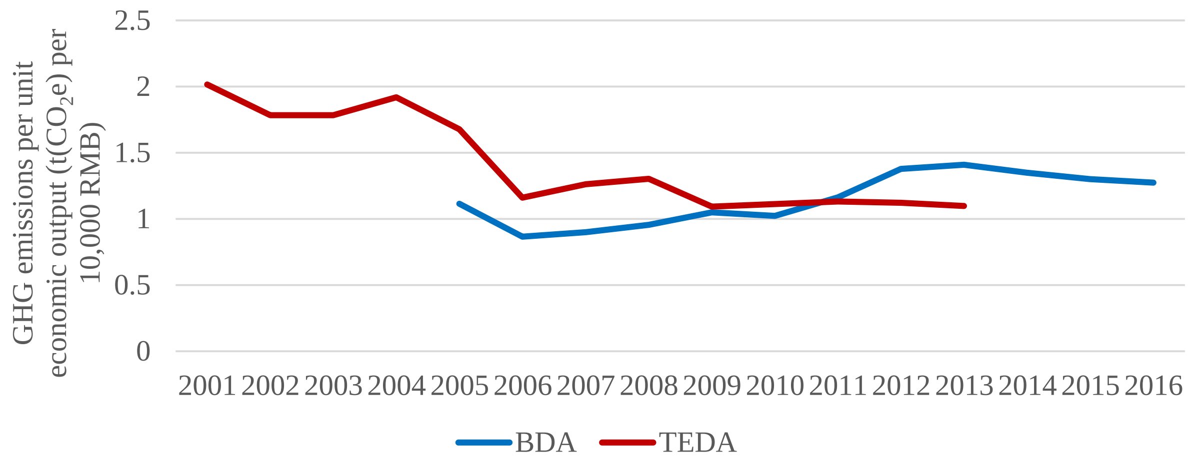


Figure 20.19 GHG emissions per unit economic output

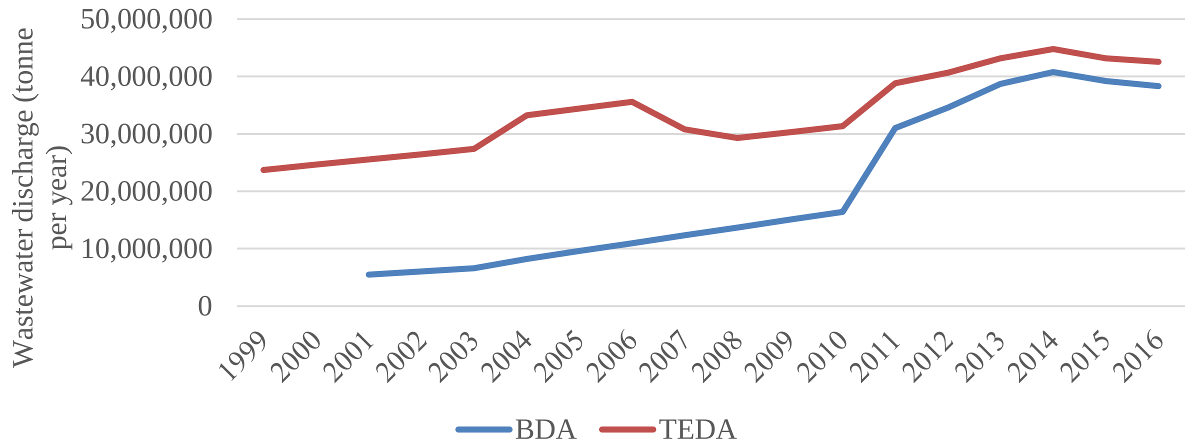


Figure 20.20 Wastewater discharge

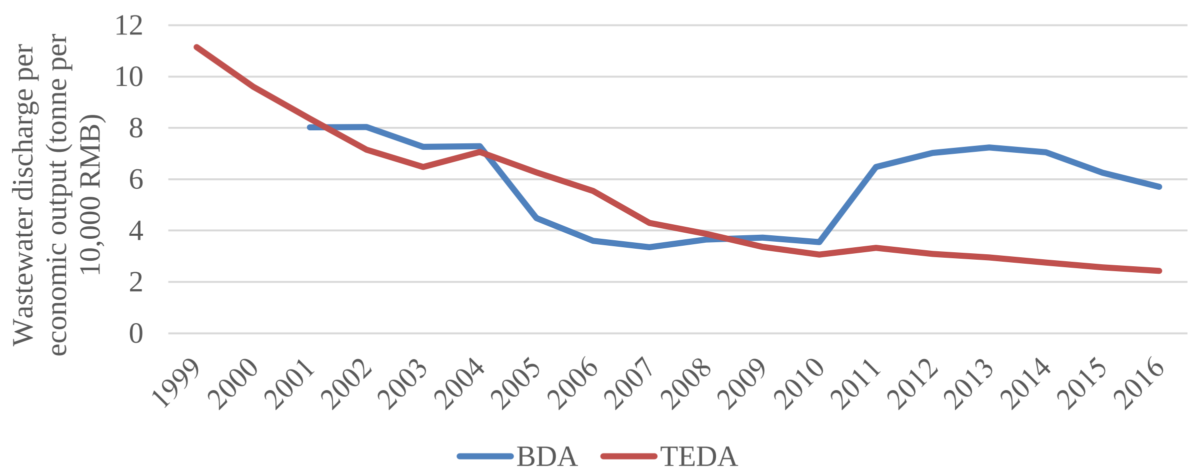


Figure 20.21 Wastewater discharge per unit economic output

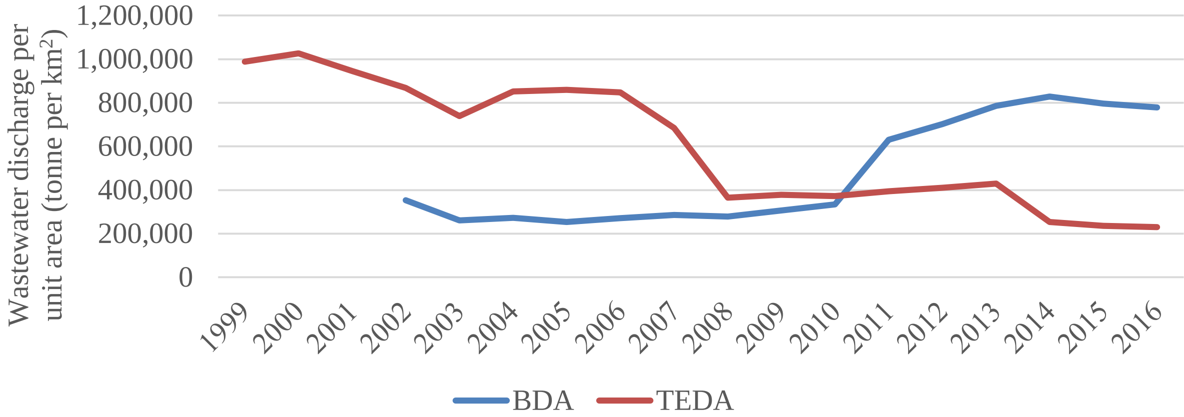


Figure 20.22 Wastewater discharge per unit area

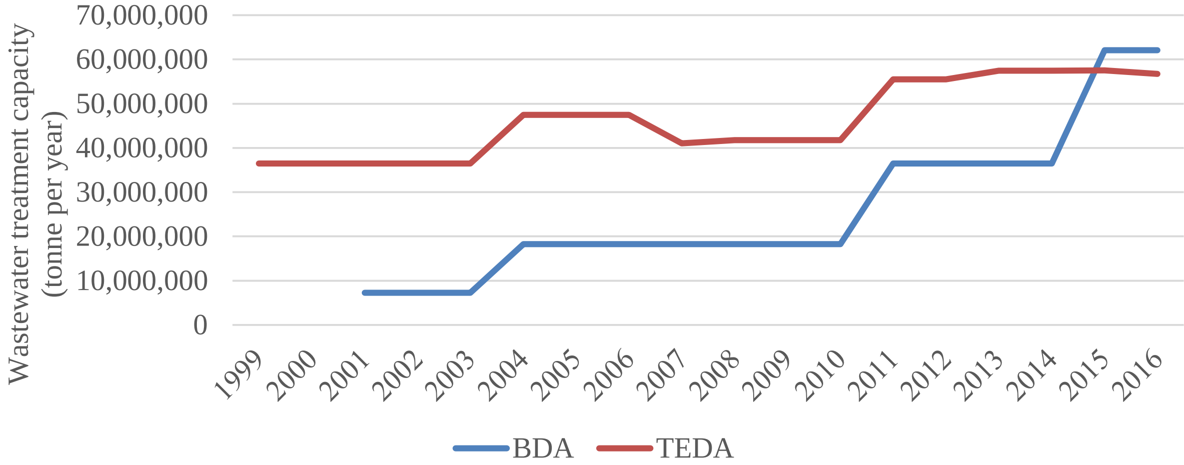


Figure 20.23 Wastewater treatment capacity

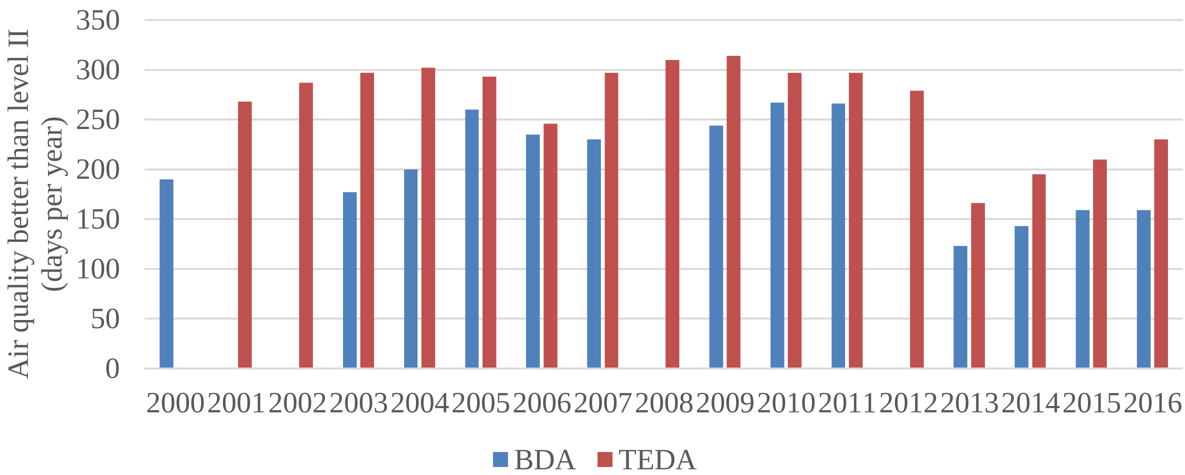


Figure 20.24 Air quality better than level II

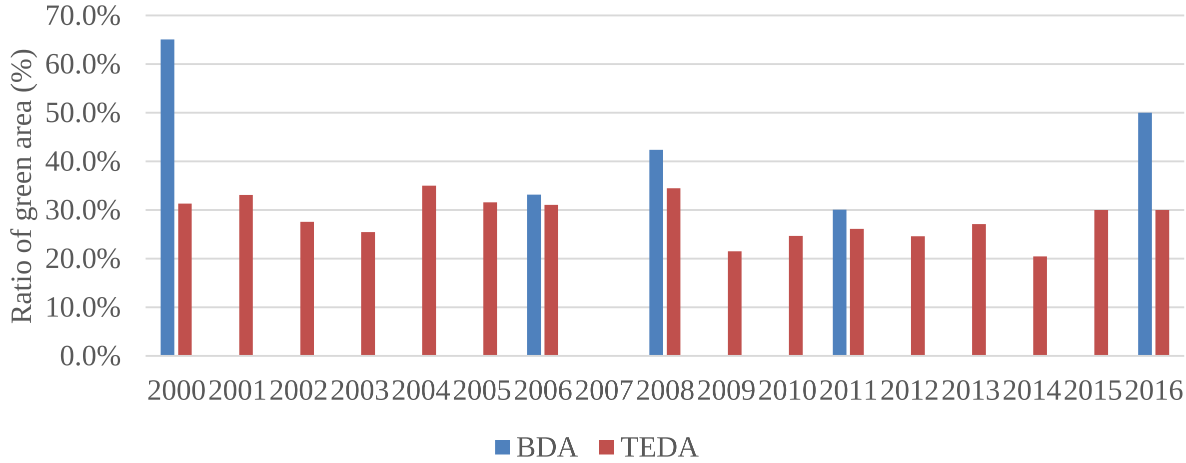


Figure 20.25 Ratio of green area

4.2.3 Social indicators

Monthly payment per employee to housing price per m^2 ratio of BDA generally declined with 2008 being the highest (60.37%), and 2016 being the lowest (23.85%). Both healthcare coverage and pension coverage of BDA increased from less than 15,000 to slightly less than 350,000 for healthcare and 385665 for pension coverage. BDA's healthcare coverage rate increased to over 100% in 2004, and has mostly remained above 100% with slight fluctuation. On the other hand, BDA's pension coverage rate increased to over 100% in 2012, continued to rise to 126.3% in 2014 before experiencing slight dips in 2015 and 2016.

Number of students in compulsory education at BDA showed steady increase from 190 in 2001 to 4834 in 2016. However, compulsory education enrolment rate only increased between 2001 and 2004, and then showed declining trend until 2011. With a few years missing data in between, the rate stands at 13.99% in 2016.

Monthly payment per employee to housing price per m^2 ratio of TEDA increased gradually from 33.6% in 2003 to 50.3% in 2016, while its value was the highest in 2015 (51.5%). Both healthcare coverage and pension coverage increased roughly threefold, but healthcare coverage ratio and pension coverage ratio reached their peaks (65.2% for healthcare coverage ratio in 2006 and 66.5% for pension coverage ratio in 2007), and then showed either declining or flat trends before picking up again in recent years. Students in compulsory education generally increased rapidly since 2002 (3500 students), and reached 12100 in 2016, with a trough in 2006 and 2007. Compulsory education enrolment rate fluctuated without obvious pattern in earlier years, but has been increasing since 2012, and reached historic high of 2.4% in 2016.

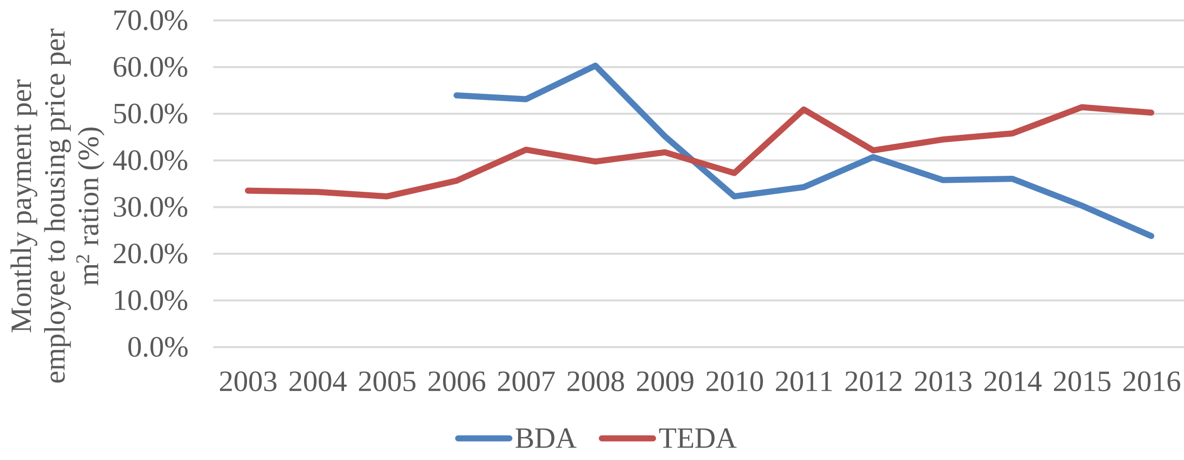


Figure 20.26 Monthly payment per employee to housing price per m^2 ratio

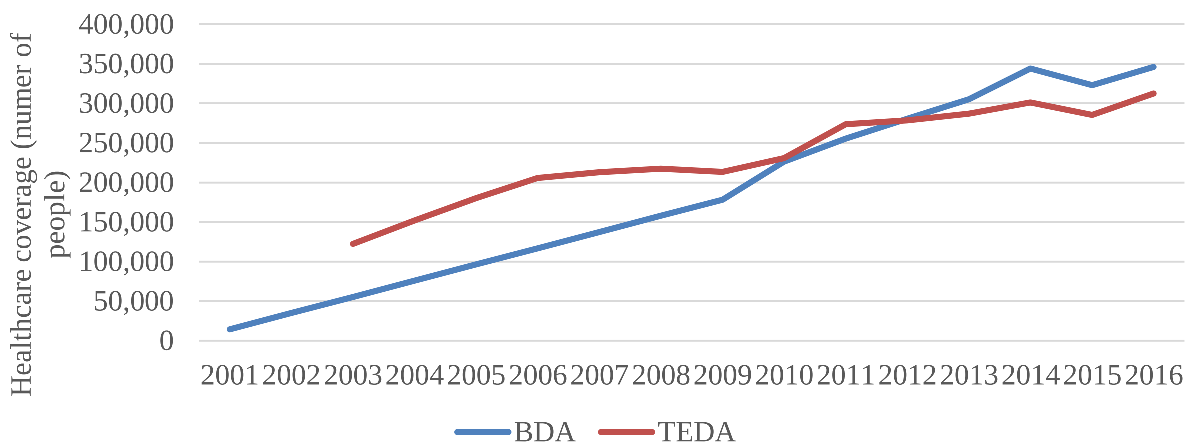


Figure 20.27 Healthcare coverage

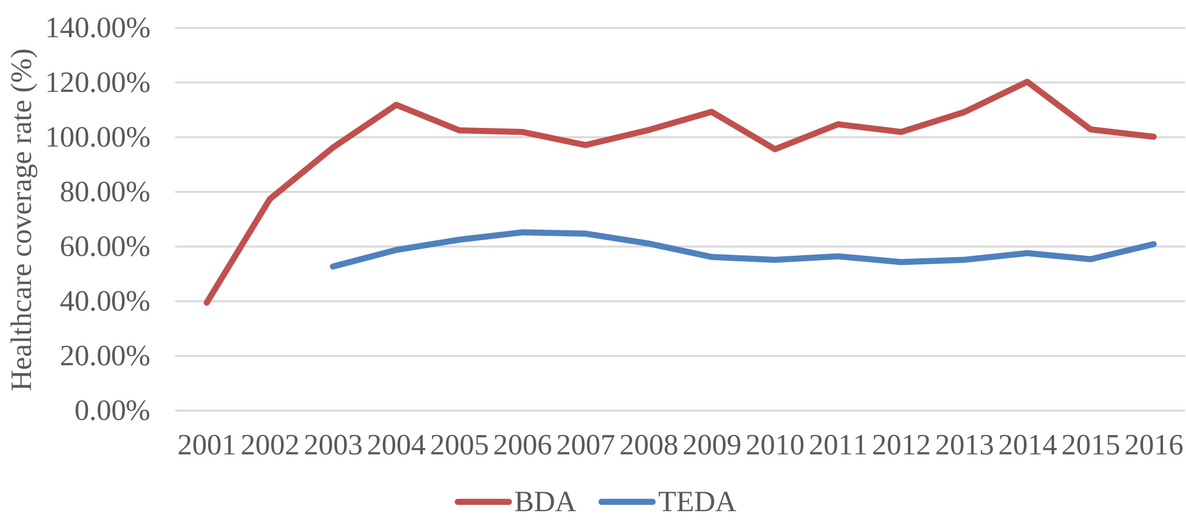


Figure 20.28 Healthcare coverage rate

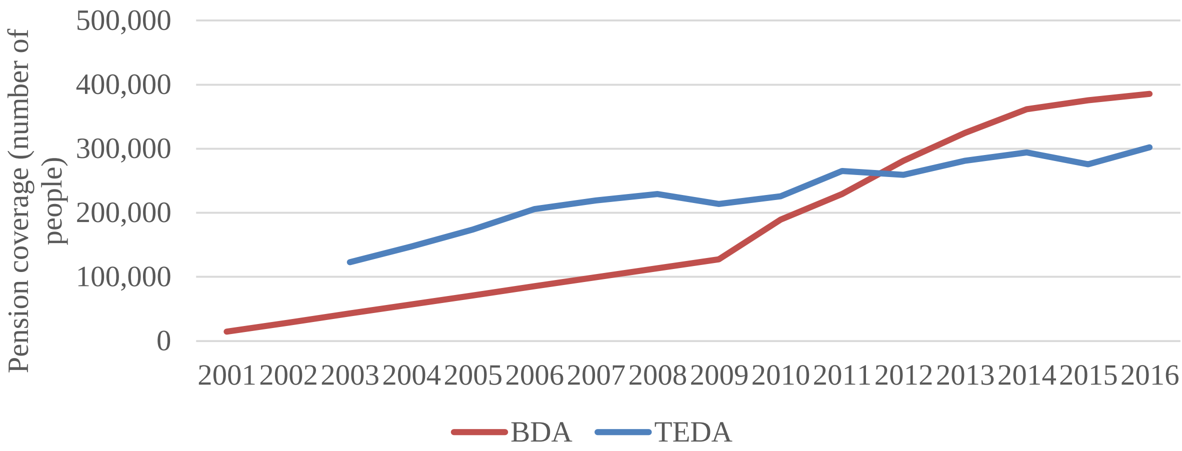


Figure 20.29 Pension coverage

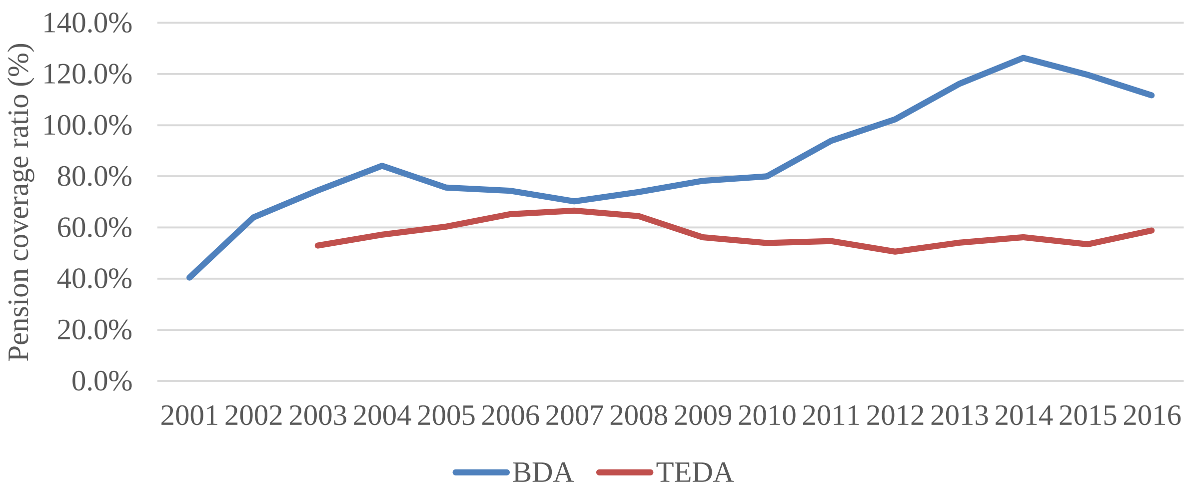


Figure 20.30 Pension coverage rate

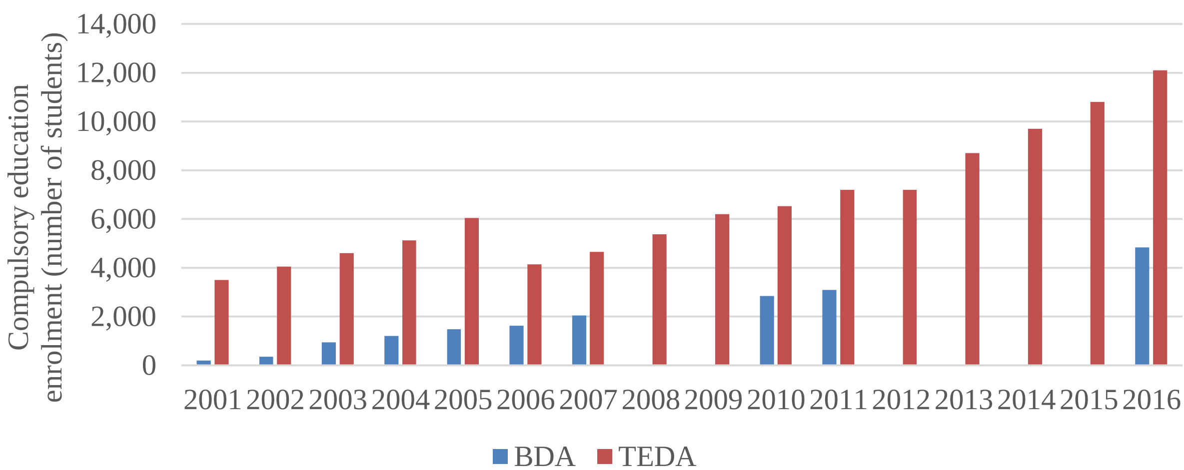


Figure 20.31 Compulsory education enrolment

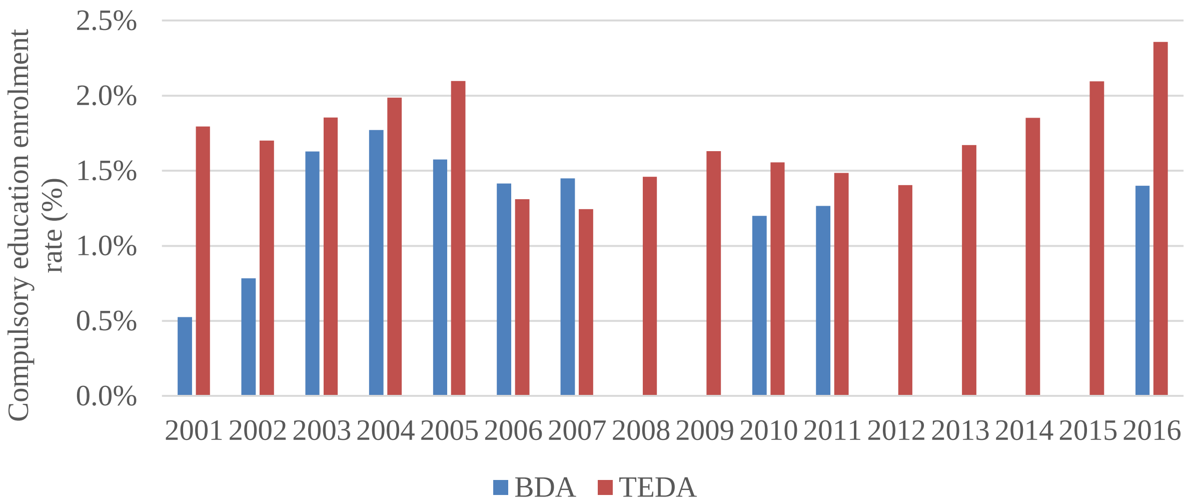


Figure 20.32 Compulsory education enrolment rate

4.3 MCDA results for BDA

4.3.1 All indicators

The results for BDA with all indicators aggregated and considered are shown in Figure 21. BDA's overall sustainability performance fluctuated throughout the years with 2016 being the best (with a Phi value of 0.1382) followed by 2007, although for 2007 and 2011, their Phi values (-0.0018 and -0.0037 respectively) are very close to each other (Table 18). BDA in 2006 performed the worst with a Phi value of -0.0956.

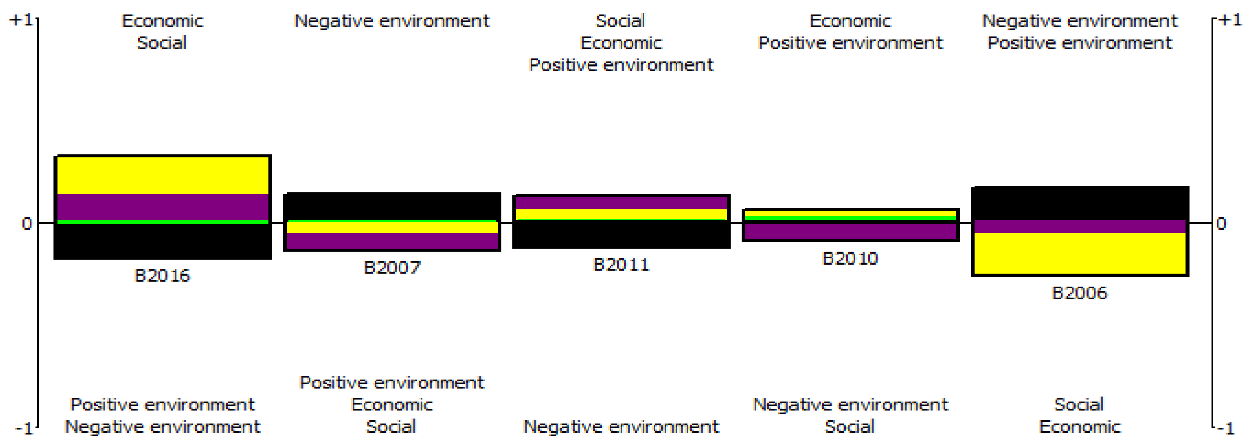
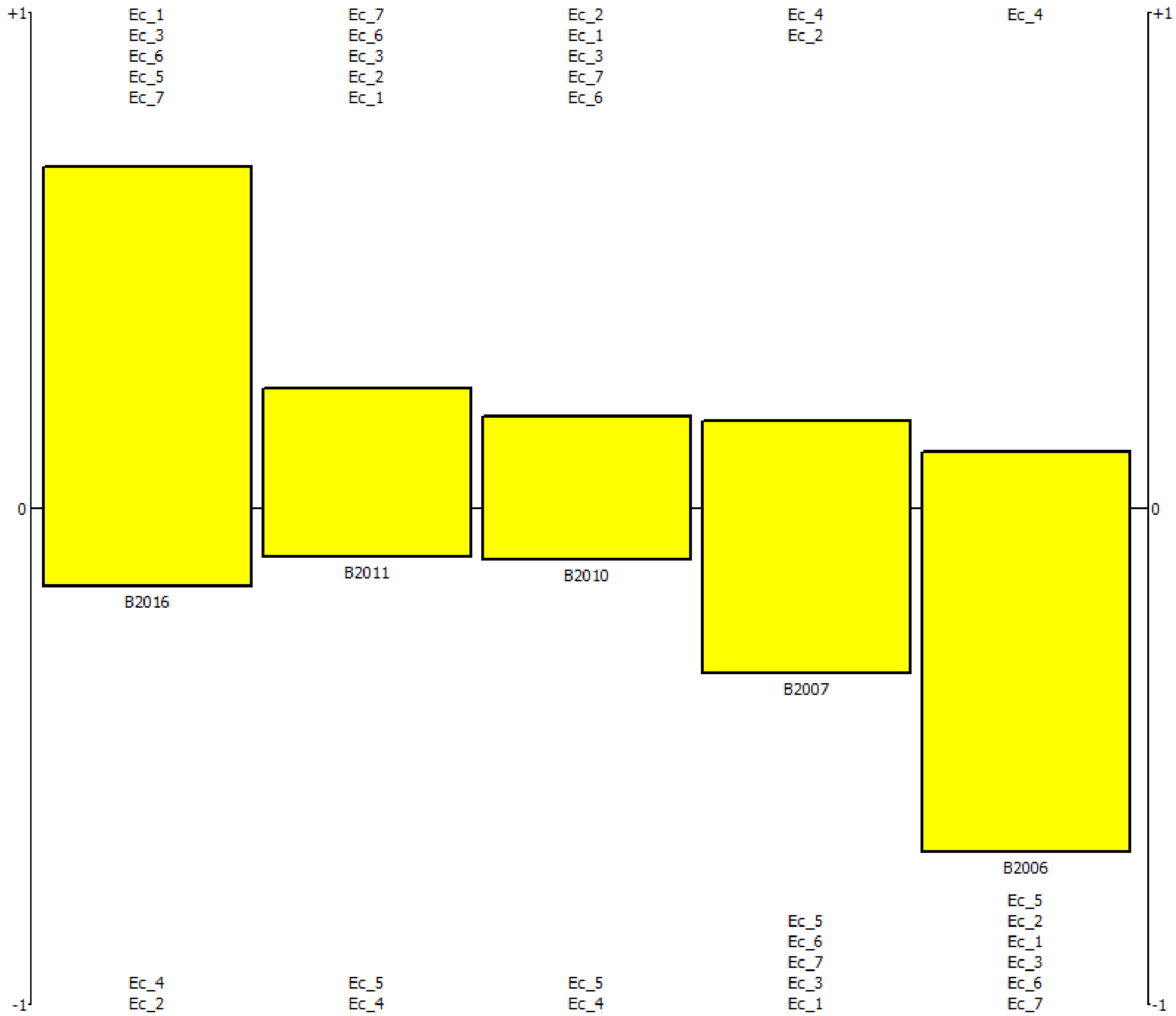


Figure 21: ranking of BDA of different years with all indicators aggregated. Economic aspect is marked in yellow, positive environmental aspect in green, negative environmental aspect in black, and social aspect in purple (the colouring of aspects is consistent in this study).

Table 18: ranking of BDA of different years considering all indicators aggregated and their respective Phi values

Rank	action	Phi	Phi+	Phi-
1	B2016	0.1382	0.4513	0.3130
2	B2007	-0.0018	0.3252	0.3270
3	B2011	-0.0037	0.3004	0.3041
4	B2010	-0.0371	0.2856	0.3228
5	B2006	-0.0956	0.2858	0.3814

We ungrouped the indicators to have deeper analysis of each indicator. The results are shown in Figure 22. Economic performance of the EIP unambiguously improved year by year, nevertheless, BDA in 2016 has two indicators, economic output per employee outperformed by 2006 and 2007, and ratio of economic out to economic output of city outranked by 2007, 2010 and 2011. As opposed to the overall trend with all indicators aggregated, environmental aspects worsened gradually, particularly with 2016 having 14 indicators outperformed by at least another year. BDA in 2016 only performs clearly better in waste heat use than 2006 and 2007, wastewater capacity than 2006, 2007 and 2010. Social aspect in 2016 performs the best, and 2010 is the worst among all years. Specifically, only monthly payment per employee to housing price per m^2 ratio in 2016 is obviously outperformed by 2006 and 2007; on the other hand, BDA in 2010 only has better compulsory education enrolment and healthcare coverage than in 2006 and 2007.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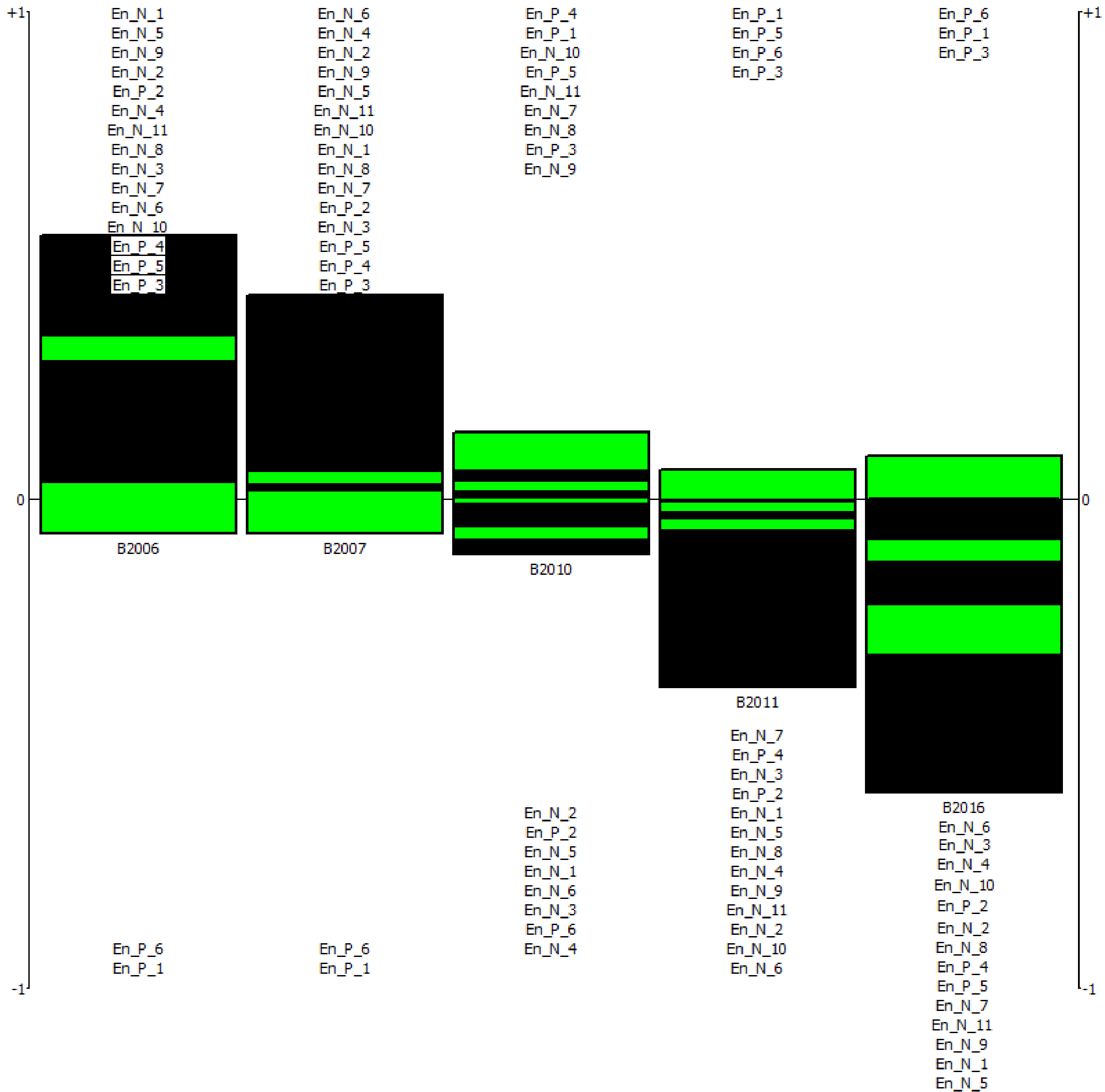
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Figure 22: rankings of Test AL with indicators of different aspects ungrouped for BDA

4.3.2 Non-scale indicators

For assessment based on aggregated non-scale indicators, the results are shown in Figure 23, and Phi value in Table 19. In contrast to the assessment with all indicators aggregated, BDA's sustainability performance declined gradually in this test. The Phi value of 2006 is very close to that of 2007 (0.2585 and 0.2792 respectively), and 2010 is close to that of 2011 (-0.1376 and -0.1598 respectively), too.

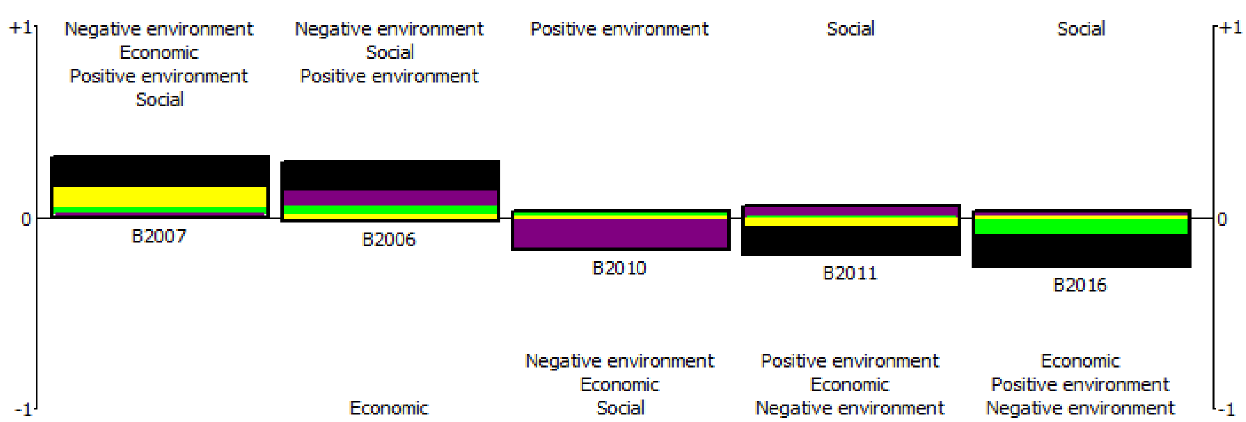
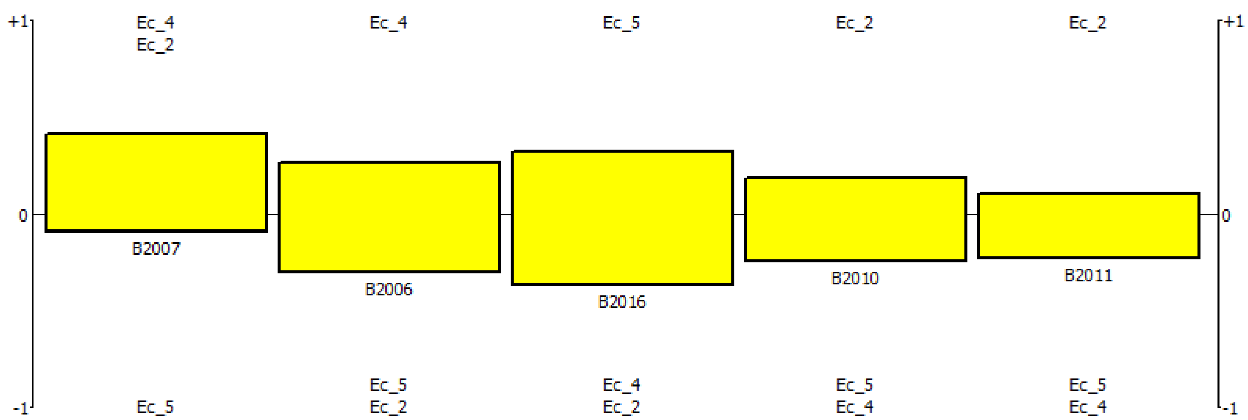


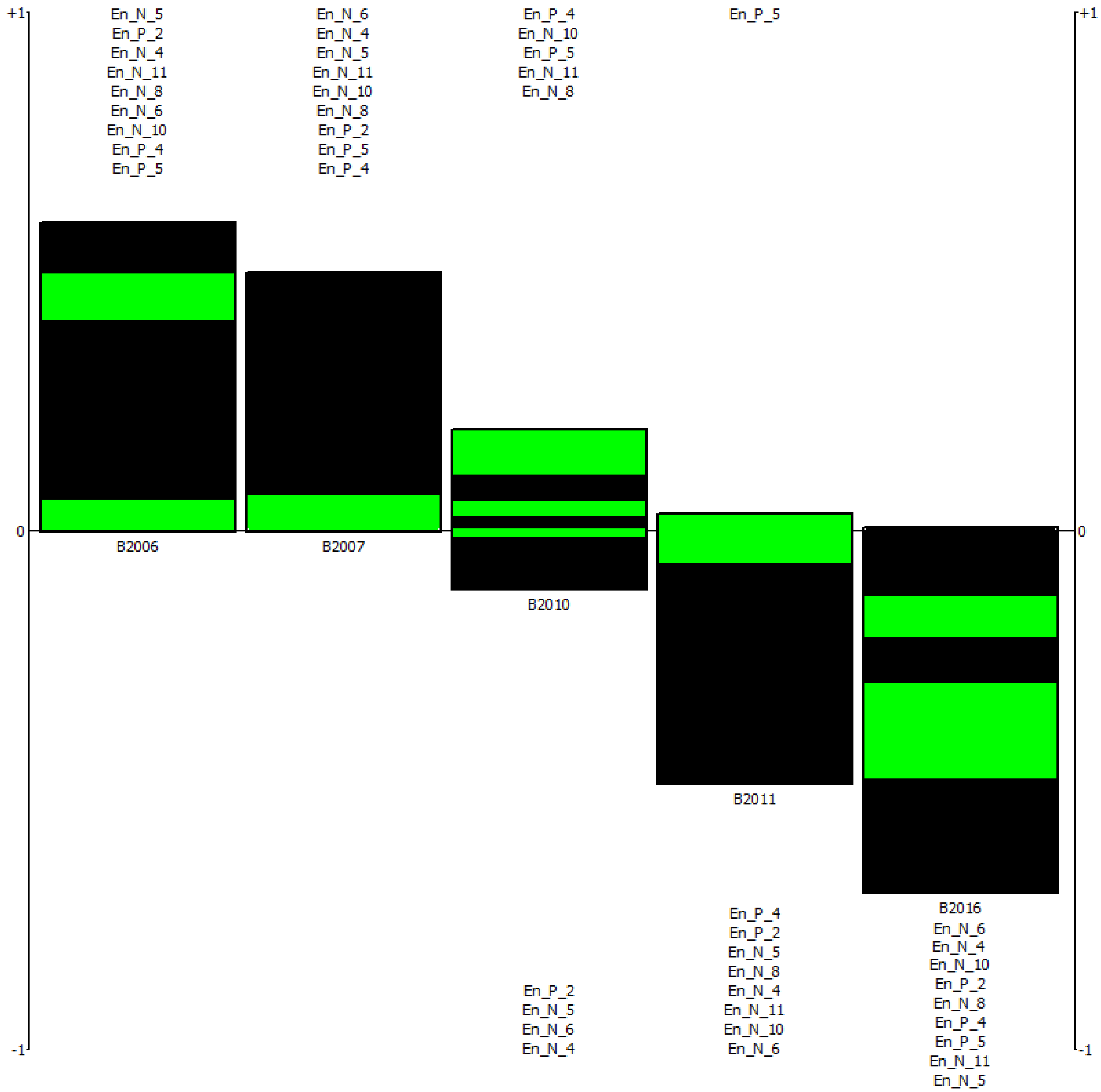
Figure 23: ranking of BDA of different years with non-scale indicators aggregated

Table 19: ranking of BDA of different years considering aggregated non-scale indicators and their respective Phi values

Rank	action	Phi	Phi+	Phi-
1	B2007	0.2792	0.4069	0.1277
2	B2006	0.2585	0.4052	0.1467
3	B2010	-0.1376	0.2017	0.3394
4	B2011	-0.1598	0.1870	0.3468
5	B2016	-0.2403	0.2226	0.4628

The results are again ungrouped to show a more detailed trend of the change of and within each aspect (Figure 24). BDA in 2007 is the best while 2011 is the worst regarding economic performance. To be specific, economic output per employee clearly outperformed 2010, 2011 and 2016, while ratio of economic output to economic output of city also outperformed 2010 and 2011. Economic output per unit area is only significantly outperformed by 2016. For environmental aspect, the EIP's performance again worsened year by year. BDA in 2016 has all non-scale indicators worse than 2006 and 2007. BDA in 2011 shows similar results, only with air quality better than Level II not significantly worse than 2006 and 2007. Social aspect fluctuated with 2006 performed the best and 2010 the worst. BDA in 2010 has clearly worse compulsory education enrolment rate than all other years except 2011, its healthcare coverage rate is worse than other years too except 2007.

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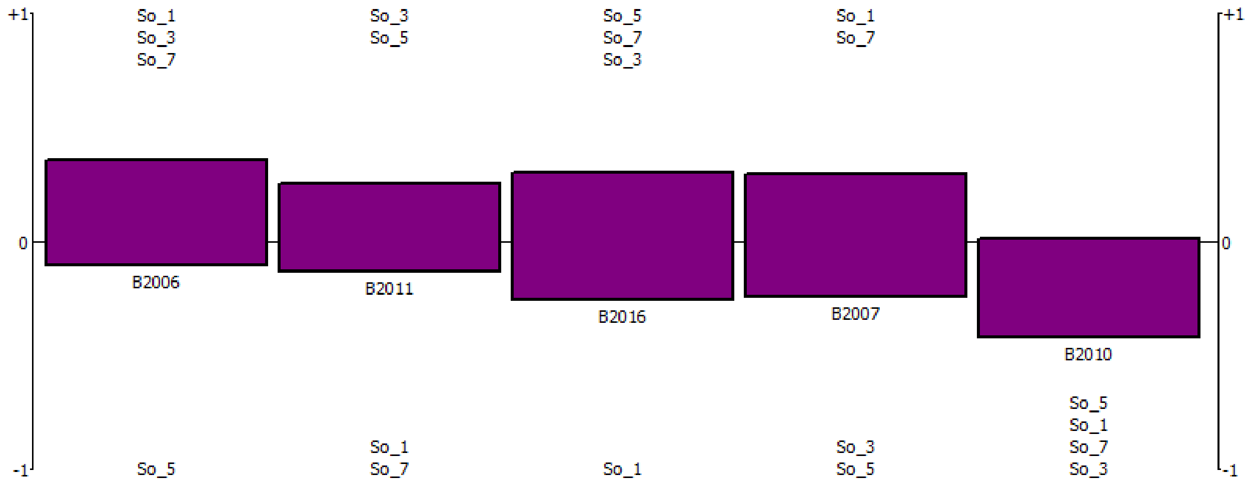
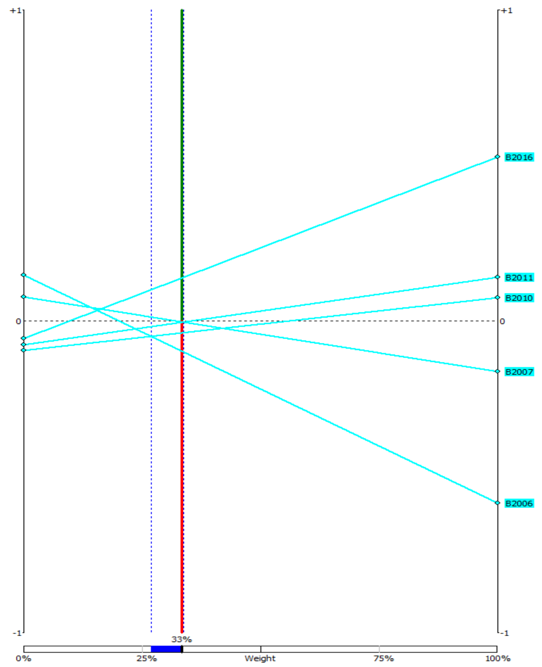


Figure 24: rankings of Test NS with indicators of different aspects ungrouped for BDA

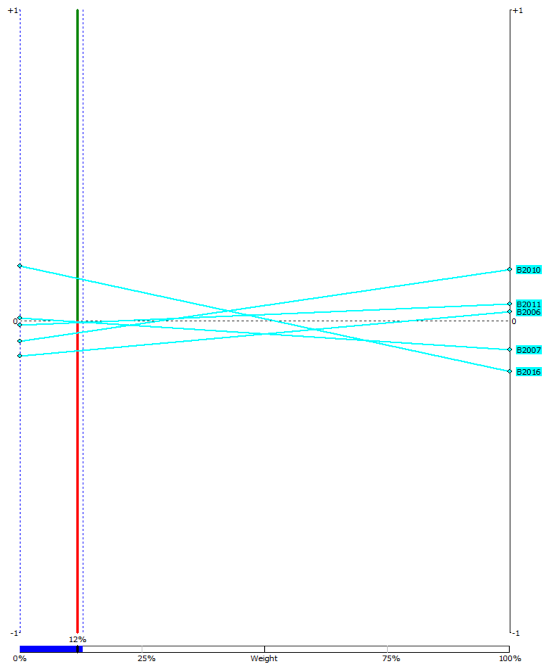
4.3.3 Sensitivity analysis

PROMETHEE also produces sensitivity analysis visually, and the results for all indicators aggregated are shown in Figure 25, while for aggregated non-scale indicators Figure 26. For both tests, we could see that except for positive environmental aspect of Test NS, one end of the stability interval for each aspect is close to current weight, which means that if the weight of a certain aspect crosses over this end, the ranking would change. Specifically, for test with all indicators, the sensitivity interval of economic aspect is 26.86% to 33.74%, with the higher end close to the current weight of 33.33%. The sensitivity interval of positive environmental aspect is 0% to 12.87%, while the current weight is 11.76%. Negative environmental aspect has a sensitivity interval of 21.44%-26.66%, and the current weight is 21.57%. The current weight of social indicators of 33.33% is again close to the higher end of the sensitivity interval of 27.03% to 33.67%. For test with all indicators aggregated, 2007 and 2011 are prone to change their ranks.

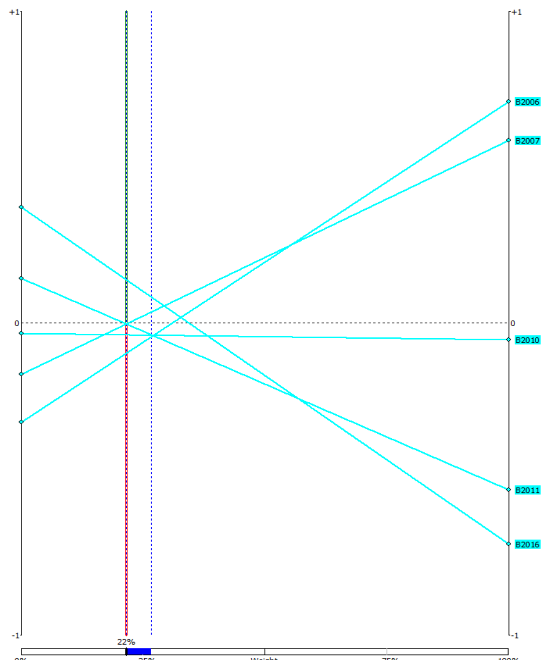
For test with aggregated non-scale indicators, 2006 and 2007 are less robust regarding their rankings for economic aspect with their crossing point stands at 29.26% and current weight is 33.33%. Negative environmental aspect has a sensitivity interval of 19.23% to 59.14%, and social aspect 0% to 36.02%, which results in 2010 and 2011 prone to change their ranks (current weights for negative environmental and social aspects are 22.22% and 33.33% respectively).



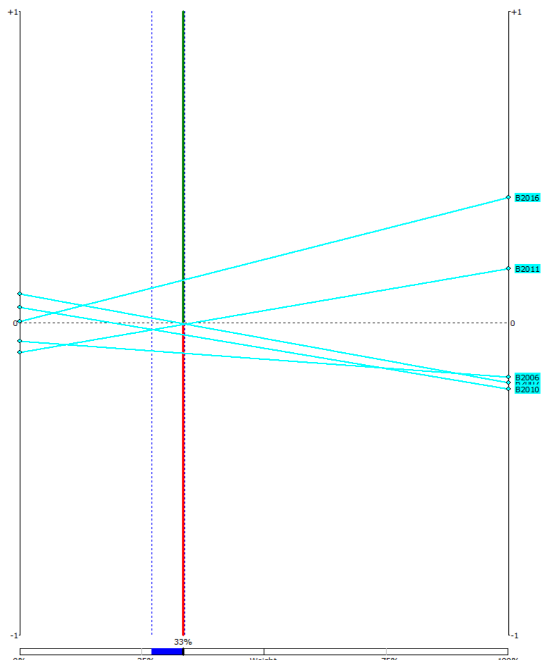
Economic: 26.86%-33.74%



Positive: 0%-12.87%

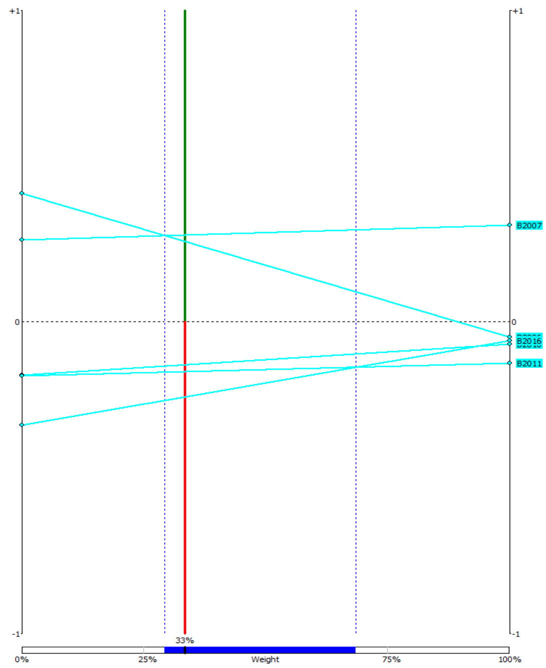


Negative: 21.44%-26.66%

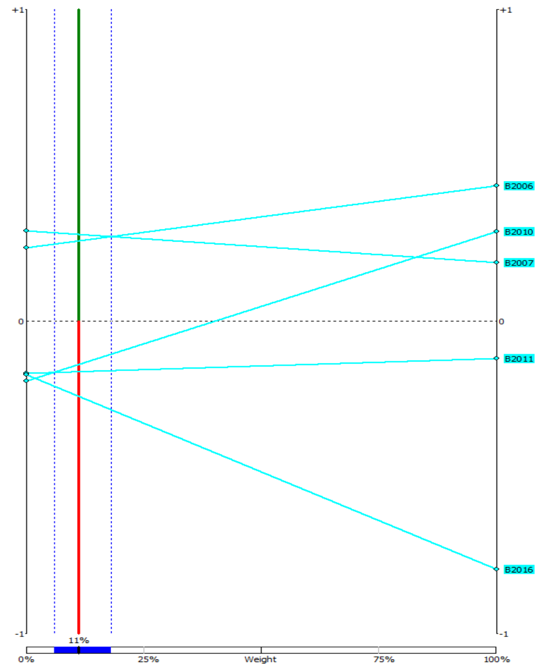


Social: 27.03%-33.67%

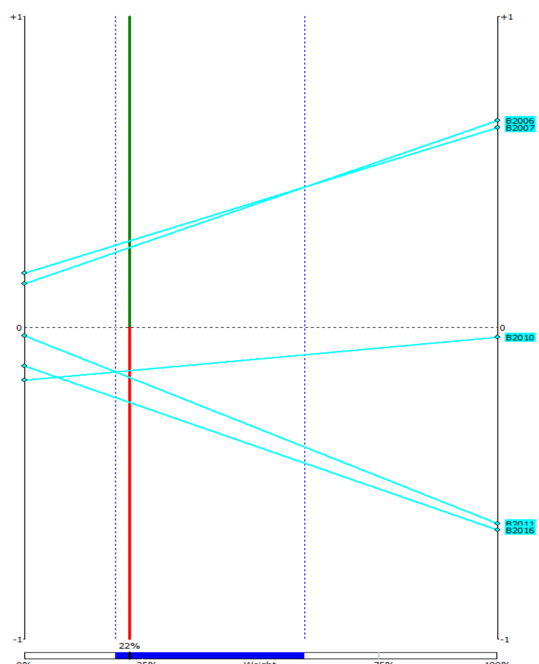
Figure 25: stability intervals for different aspects of BDA with all indicators aggregated



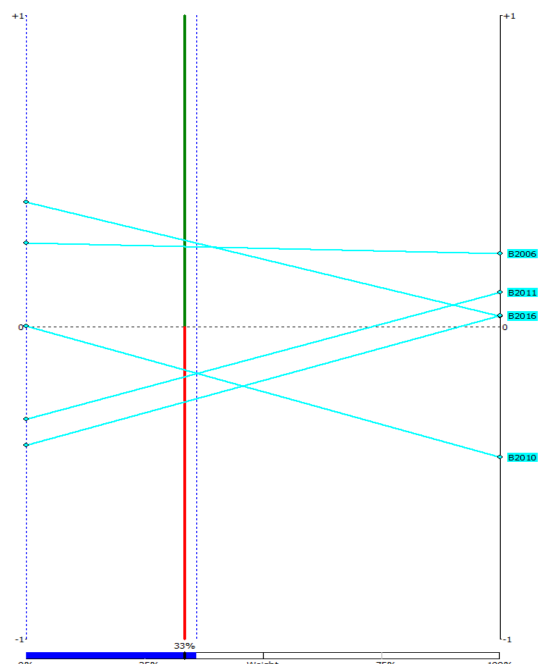
Economic: 29.26%-68.50%



Positive: 5.98%-18.02%



Negative: 19.23%-59.14%



Social: 0-36.02%

Figure 26: stability intervals for different aspects of BDA with non-scale indicators aggregated

4.4 MCDA results for TEDA

4.4.1 All indicators

The results for TEDA with all indicators aggregated and considered are shown in Figure 27. Similar to BDA, TEDA's overall sustainability performance improved gradually with 2013 having a Phi value of 0.3568 and the lowest Phi value of -0.4441 for year 2003 (see also Table 20). The Phi value of 2010 only leads 2009 by 0.0004. Aggregated negative environmental indicators of 2012 and 2013 were outperformed by years between 2006 and 2010. Although TEDA in 2009 has all aspects performing better than four to five other years, the differences are not as great as the gaps led by following years.

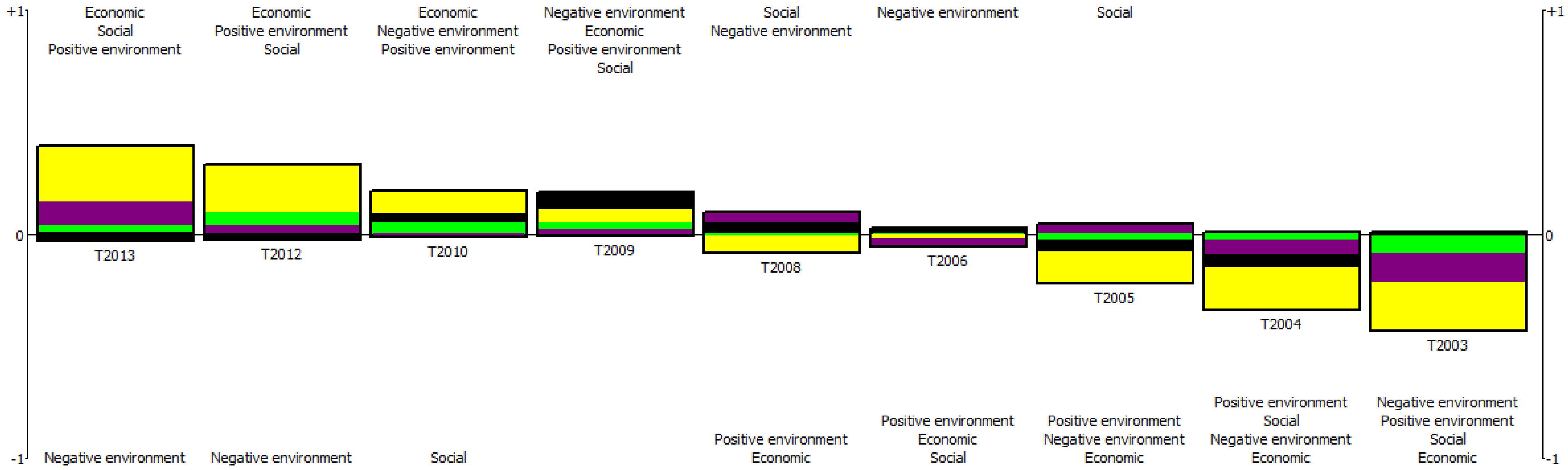
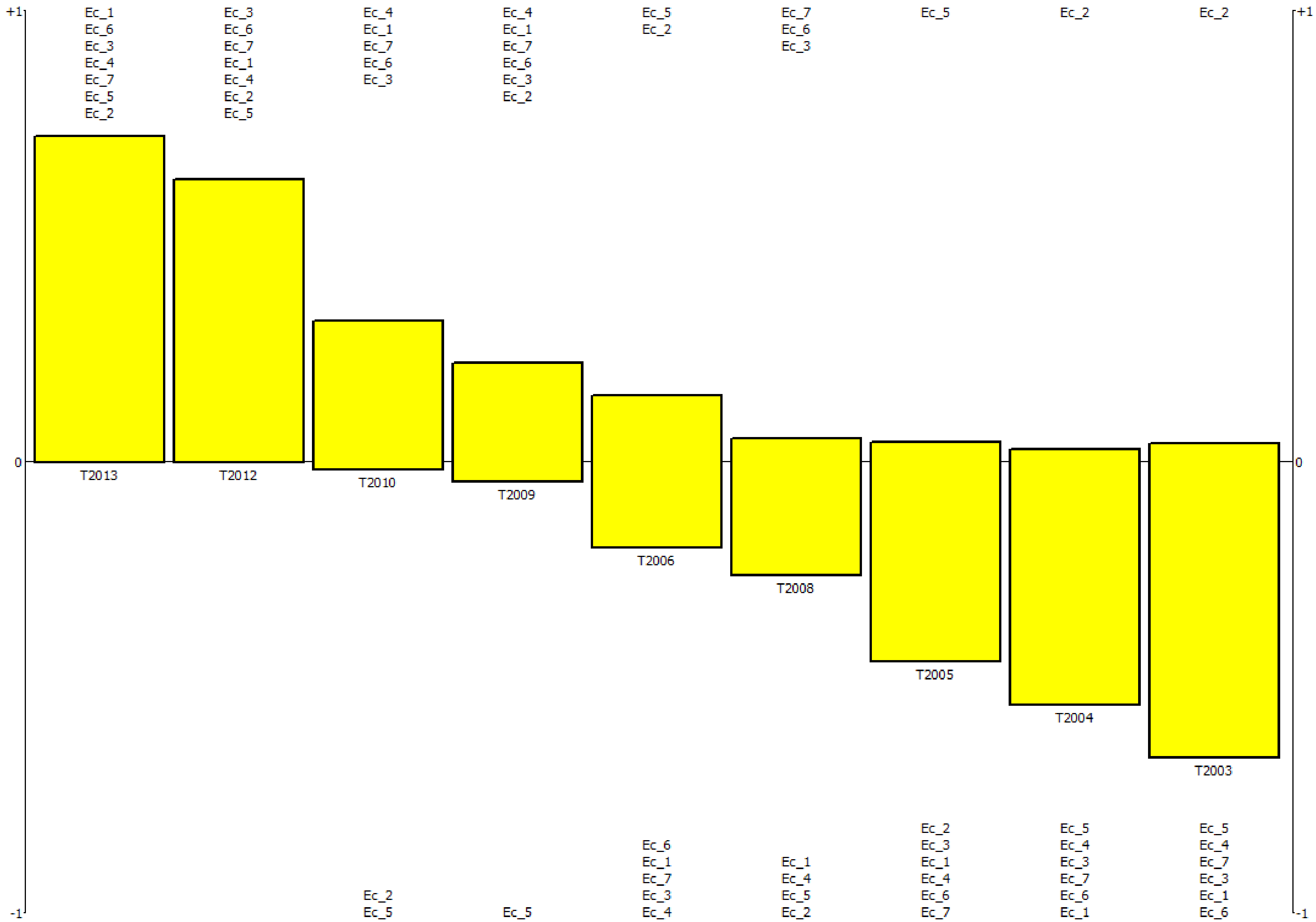


Figure 27. ranking of TEDA of different years with all indicators aggregated

Table 20: ranking of TEDA of different years considering all indicators aggregated and their respective Phi values

Rank	action	Phi	Phi+	Phi-
1	T2013	0.3568	0.5146	0.1578
2	T2012	0.2790	0.4441	0.1651
3	T2010	0.1767	0.3599	0.1831
4	T2009	0.1763	0.3569	0.1805
5	T2008	-0.0019	0.3136	0.3155
6	T2006	-0.0315	0.3092	0.3407
7	T2005	-0.1847	0.2084	0.3931
8	T2004	-0.3267	0.1305	0.4572
9	T2003	-0.4441	0.1116	0.5557

Results of ungrouped indicators of Test AL are shown in Figure 28. The economic performance of TEDA generally improved along the years. However, in 2008, the year it was verified as an EIP, is worse than 2006. TEDA in 2012 and 2013 are clearly better than 2003, 2004 and 2005 in almost every indicator except ratio of economic output to economic output of city of 2003 and 2004, and economic output per unit area of 2005. Environmental performance fluctuated with 2009 being the best and 2004 being the worst. Freshwater use and land use in 2009 are worse than that of 2003 to 2006, but not obviously worse than other years. Wastewater treatment capacity of 2009 is worse than 2004, 2005, 2012 and 2013. Social performance also showed fluctuation with 2013 being the best and 2003 the worst. Compulsory education enrolment tends to be better since 2009, compulsory education enrolment rate has nevertheless worsened since 2008.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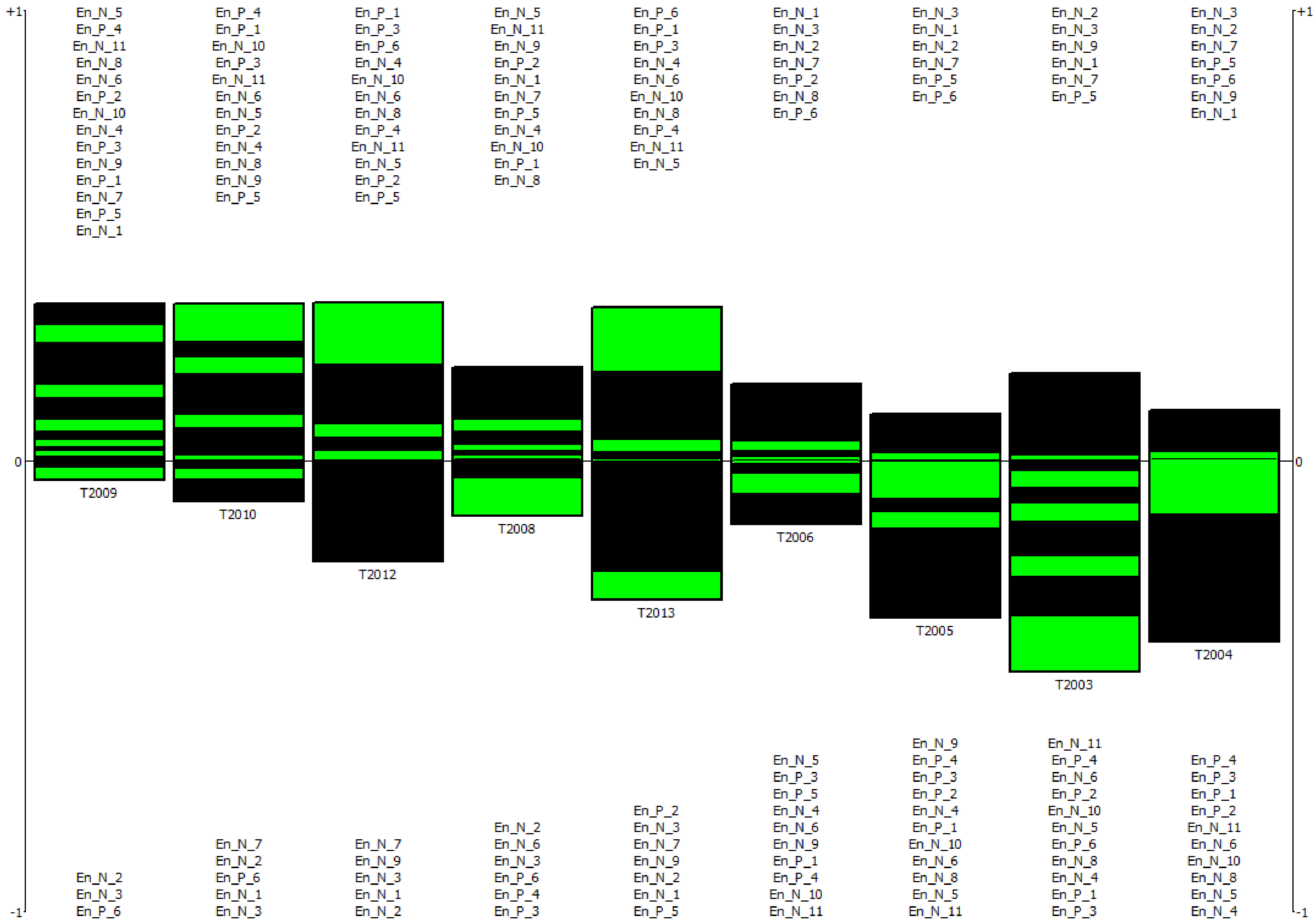
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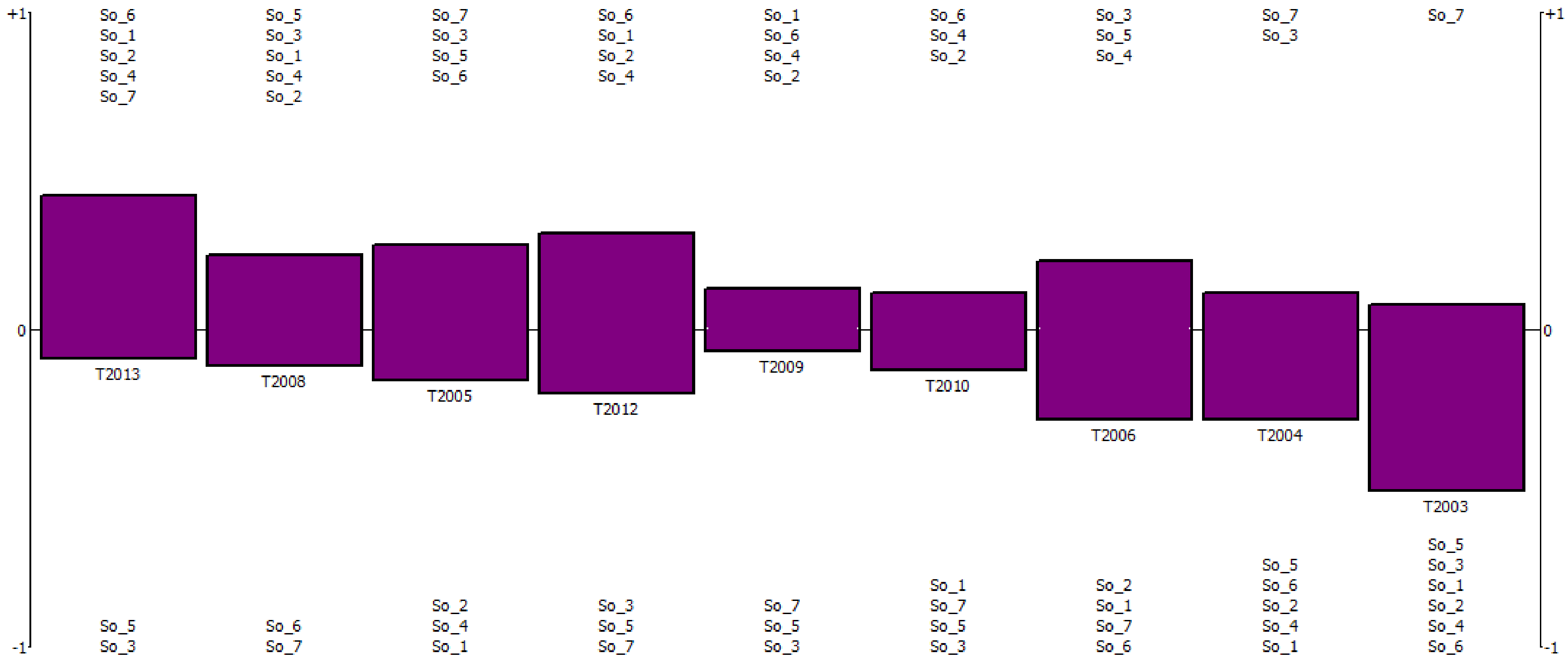


Figure 28: rankings of Test AL with indicators of different aspects ungrouped for TEDA

4.4.2 Non-scale indicators

For non-scale indicators aggregated (Test NS), the results of TEDA are shown in Figure 29 and Phi value in Table 21. Although TEDA showed betterment for Test NS in general, the year TEDA was verified as an EIP, 2008 (Phi value -0.0596), performed worse than 2006 (Phi value 0.0635), while the next year, 2009 (0.1919), was better than 2010 and 2012 (0.1276 and 0.1679 respectively). As opposed to the test will all indicators aggregated, TEDA in 2013 has better performance in negative environmental aspect compared to years from 2003 to 2006, while positive environmental indicators are close to the performance of those years.

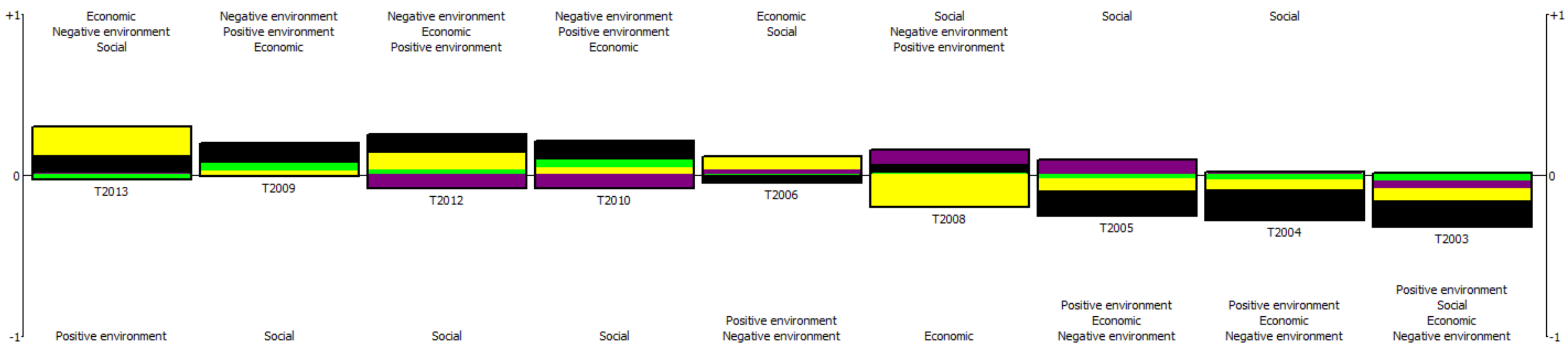
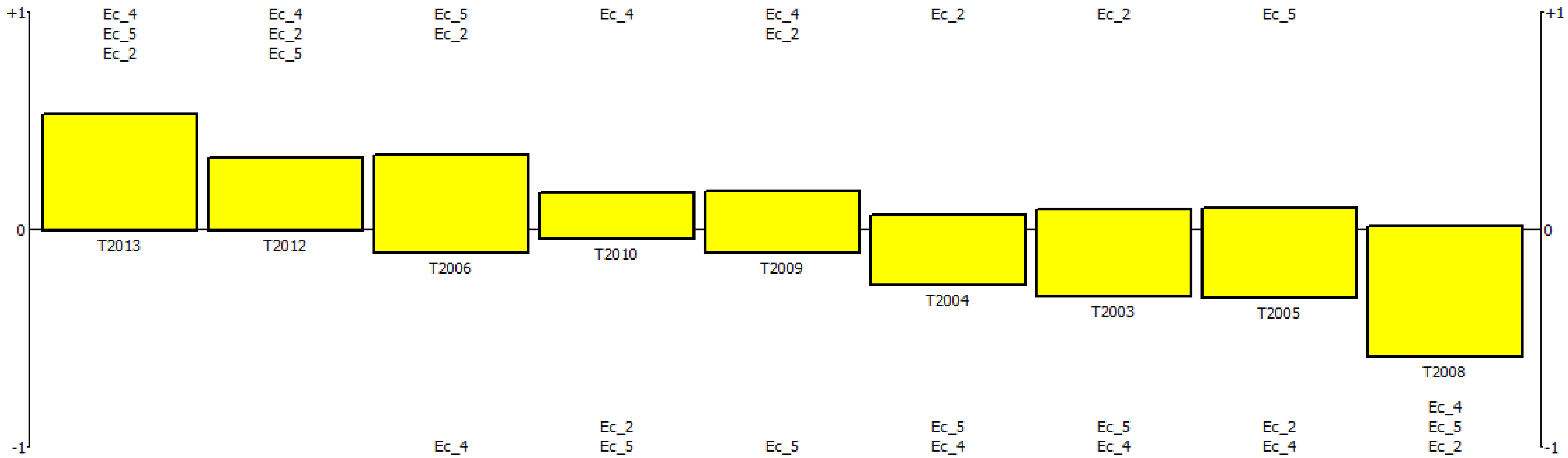


Figure 29: ranking of TEDA of different years with non-scale indicators aggregated

Table 21: ranking of TEDA of different years considering aggregated non-scale indicators and their respective Phi values

Rank	action	Phi	Phi+	Phi-
1	T2013	0.2683	0.4039	0.1356
2	T2009	0.1919	0.32	0.1281
3	T2012	0.1679	0.3139	0.146
4	T2010	0.1276	0.2812	0.1536
5	T2006	0.0635	0.3265	0.263
6	T2008	-0.0596	0.2771	0.3367
7	T2005	-0.1633	0.1927	0.356
8	T2004	-0.2658	0.1081	0.3739
9	T2003	-0.3306	0.0951	0.4257

If we looked at the different aspects in Test NS with indicators ungrouped (Figure 30), 2008 is has the worst economic performance, while 2006 is only worse than 2012 and 2013. TEDA in 2012 and 2013 have economic output per employee and economic output per unit area better than other five years, while their ratio of economic output to economic output of city is clearly better than 2005, 2008 and 2010, and close to other years. Environmentally, 2009 and 2010 has the best performance. All non-scale environmental indicators in years 2009, 2010 and 2012 are either clearly better than other years, or similar to the performance of others. Years from 2003 to 2005 perform similarly with almost all non-scale indicators outperformed or parred by other years except the indicator of air quality better than Level II. TEDA in 2005 has the best social performance while 2010 is the worst socially. Monthly payment per employee to housing price per m^2 ratio generally improved except 2010 being outperformed by 2008. All other three non-scale social indicators show fluctuation along the years.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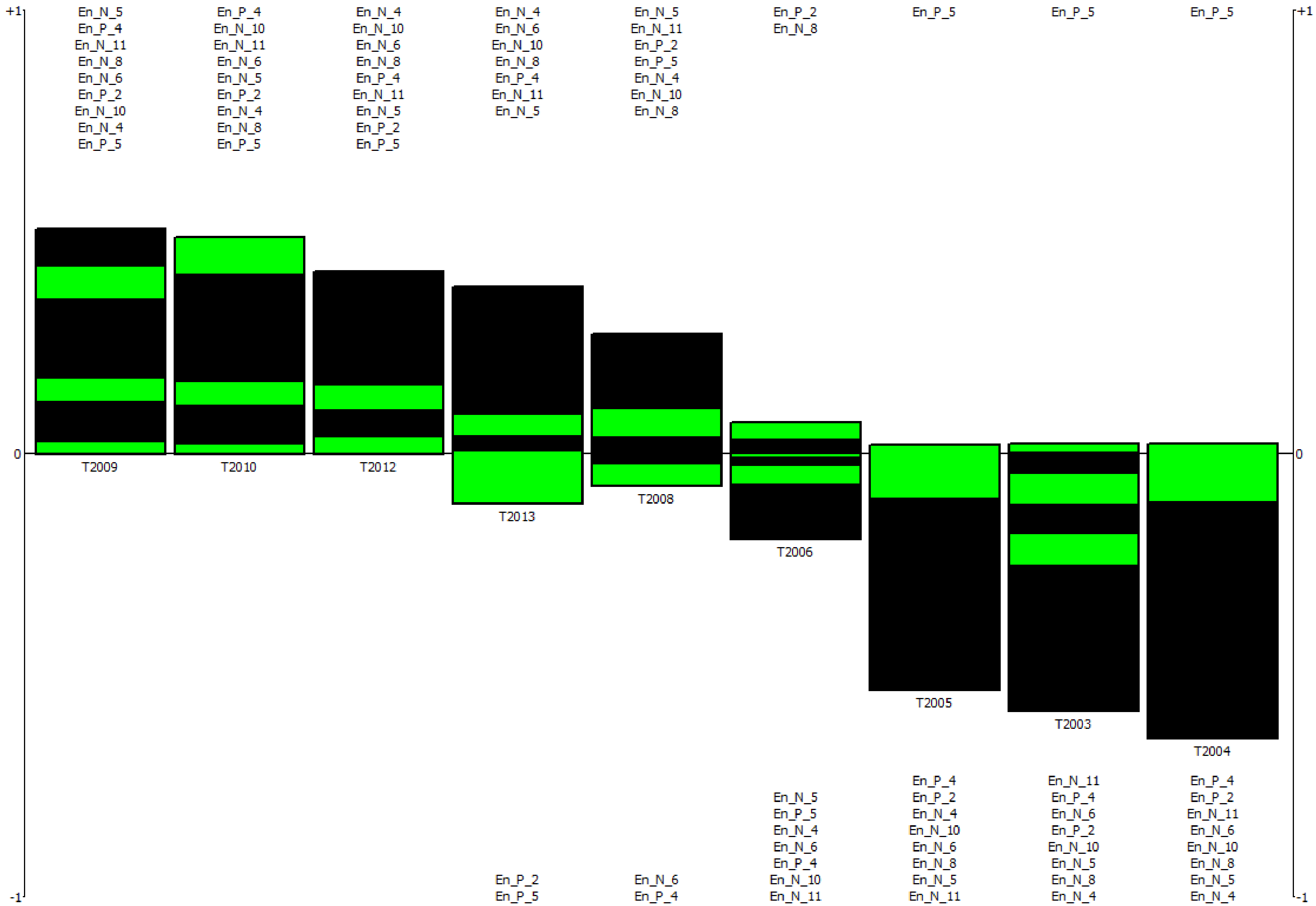
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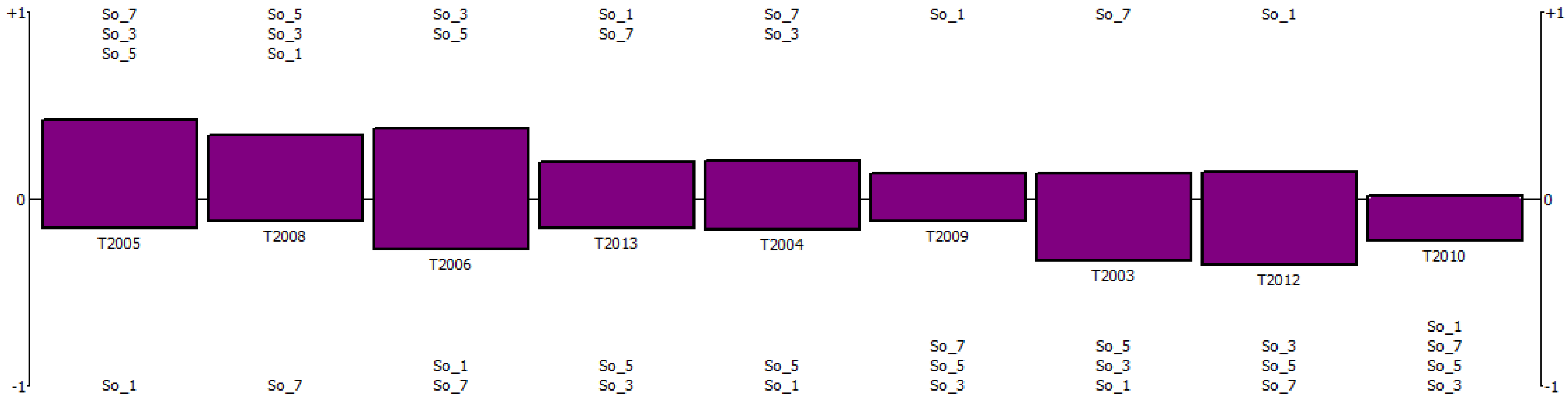
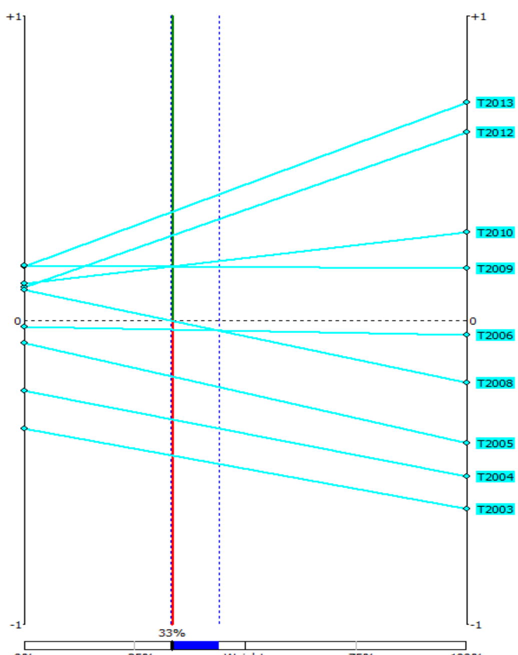


Figure 30: rankings of Test NS with indicators of different aspects ungrouped for TEDA

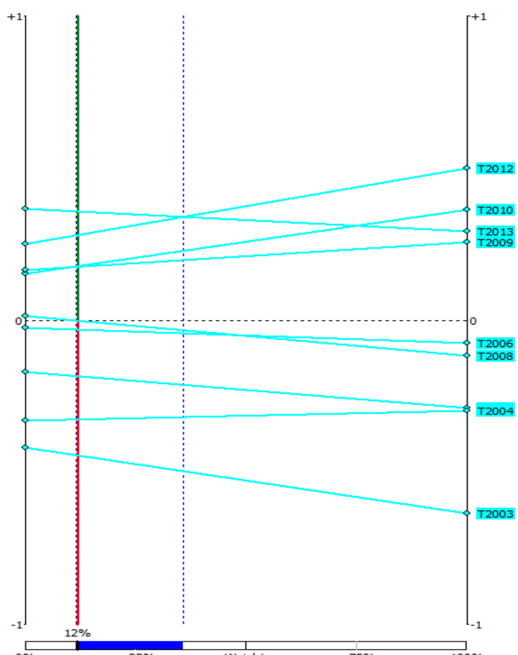
4.4.3 Sensitivity analysis

The sensitivity interval results are shown in Figure 31 for Test AL, and Figure 32 for Test NS. For Test AL, at least one end of the stability interval is close to current weight for all aspects, meaning the rankings (of 2009 and 2010) would change if the weights of these two aspects cross over one end of the interval. Specifically, the sensitivity interval of economic aspect is 33.10% to 44.03%, with the lower end close to the current weight of 33.33%. The current weight of positive environmental aspect of 11.76% is also close to the lower end of the sensitivity interval (11.41% to 35.81%). For negative environmental aspect, the current weight of 21.57% is close to the higher end of the sensitivity interval (0-21.83%). Similarly, the weight of social aspect of 33.33% is also close to the higher end of the interval (20.72%-33.71%).

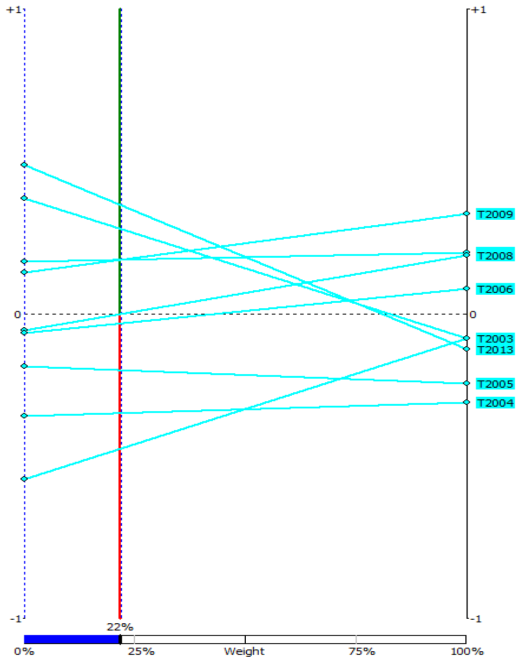
However, for test with non-scale indicators, the stability interval is relatively wide for all aspects (33.33% in relation to 21.28%-39.13% interval of economic indicators, 11.11% in relation to 0-20.74% for positive environmental aspect, 22.22% in relation to 14.16%-39.46% for negative environmental aspect, and 33.33% in relation to 25.44%-44.63% for social aspect), which means the rankings are less like to change, unless significant changes in the current weights are justified.

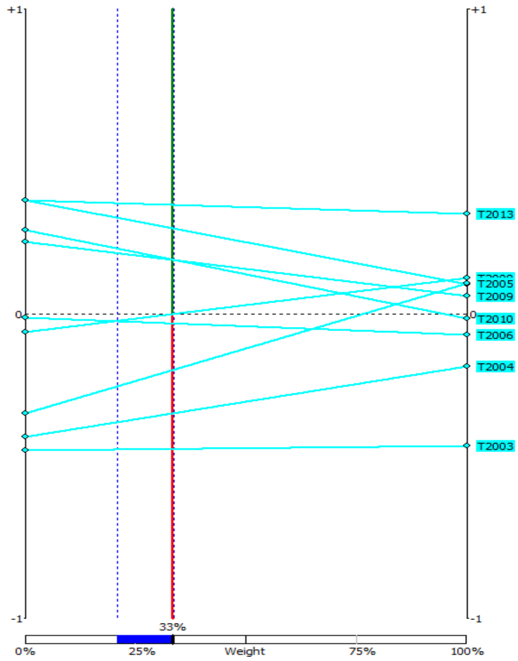


Economic: 33.10%-44.03%



Positive: 11.41%-35.81%

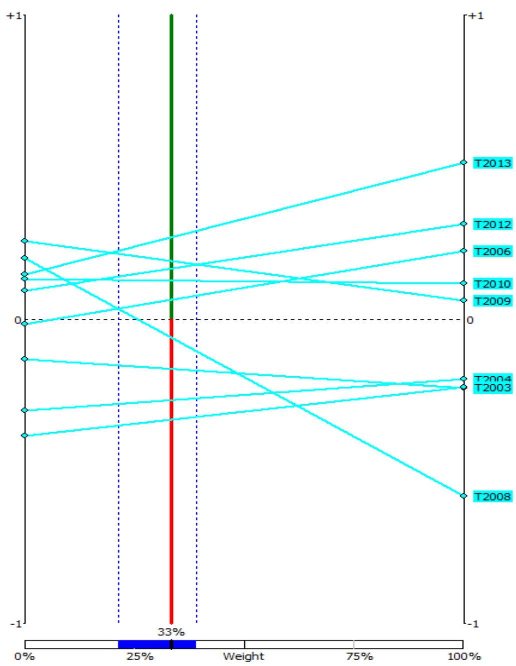


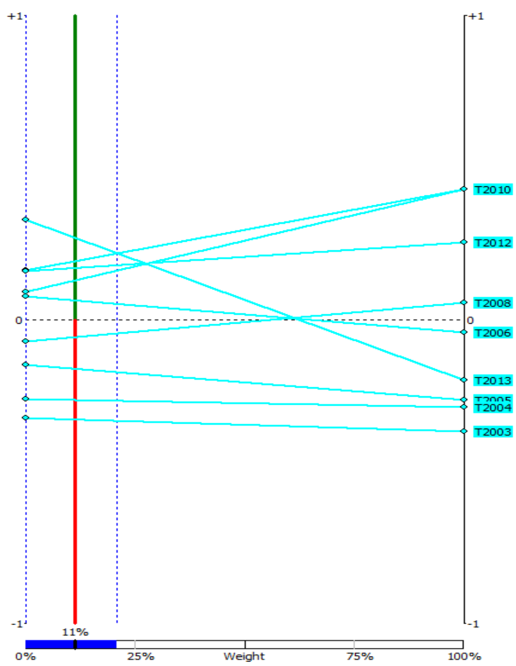


Negative: 0-21.83%

Social: 20.72%-33.71%

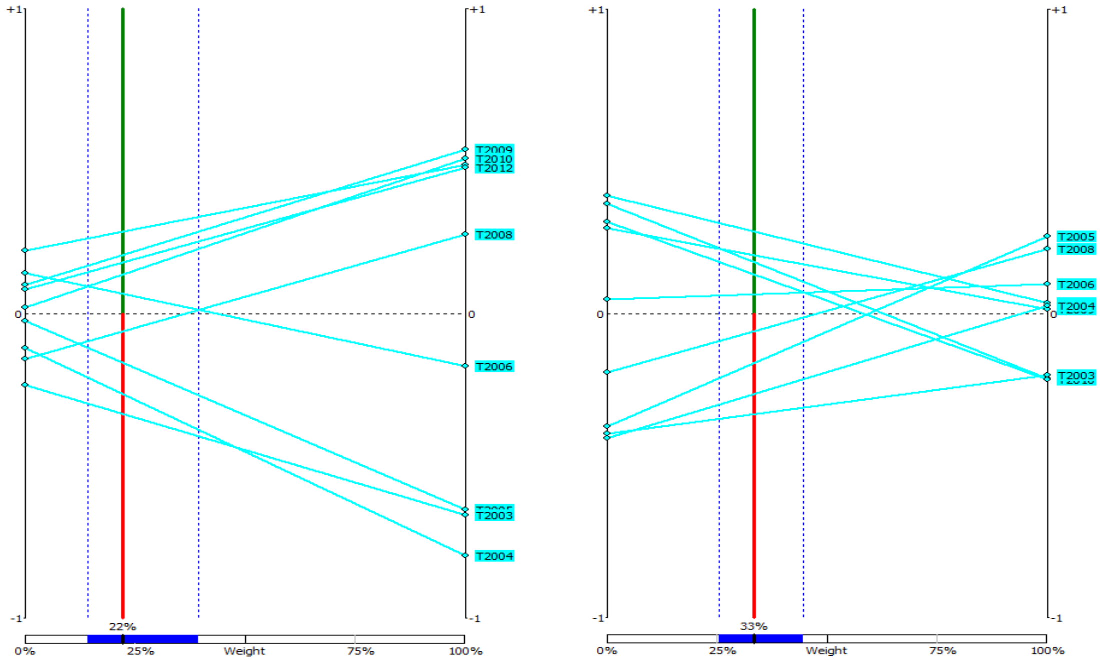
Figure 31: stability intervals for different aspects of TEDA with all indicators aggregated





Economic: 21.28%-39.13%

Positive: 0-20.74%



Negative: 14.16%-39.46%

Social: 25.44%-44.63%

Figure 32: stability intervals for different aspects of TEDA with non-scale indicators aggregated

4.5 Discussion

TEDA showed more steady improvement of its sustainability for both tests compared to BDA, while the latter did not improve much in its environmental aspects. The overall sustainability performance change of both tests for both EIPs using Phi value as the indication is shown in Figure 33.

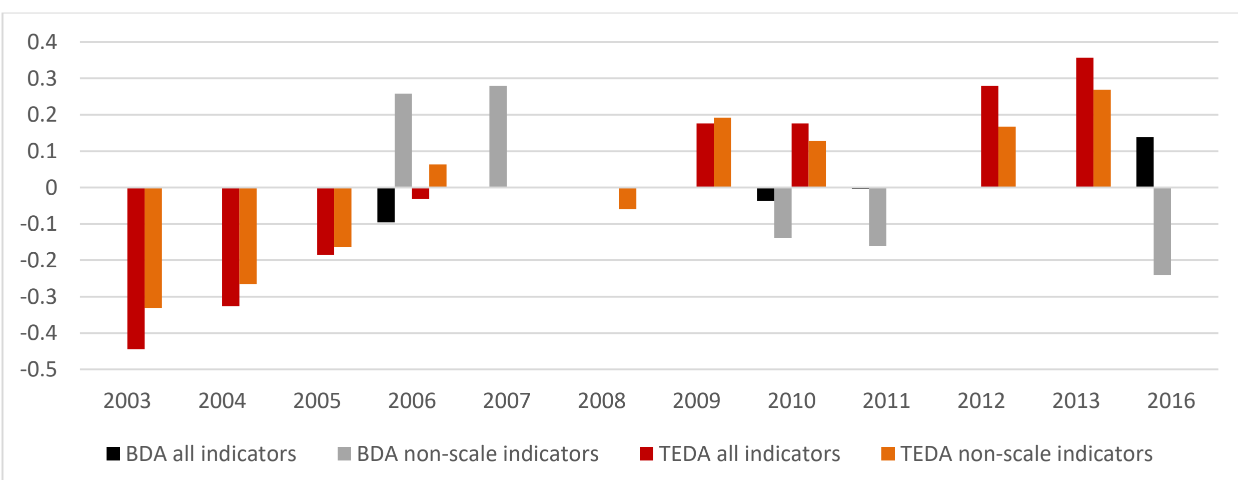


Figure 33: Phi value of Test Al and Test NS for BDA and TEDA

4.5.1 Factors affecting patterns

We identify four possible factors affecting the indicator patterns outlined in Section 3, namely (a) EIP economic and industrial structure, (b) EIP expansion patterns, (c) external pressure, and (d) regional and national policy. Below we discuss briefly each of these factors.

Firstly, economic and industrial structure of an EIP are likely to affect its sustainability performance (Tian et al., 2014). Different industrial sectors entail different raw materials, technologies and production procedures, which exert impacts in differing ways. The application of cleaner production and industrial symbiosis practices often have distinguished results as EIP upgrades (Guo et al., 2015, Fan et al., 2017b). Meanwhile, industrial parks are encouraged and incentivised to maintain technological competitiveness and economic momentum by structuring their economy toward higher value-addition industries (MEP et al., 2011, State Council, 2014). In addition, in the pursuit of lowering dependence on natural resources and reduce high emission and waste generation rates, EIPs have tried to expand tertiary sector industries. However, as Tian et al. (2014) pointed out in their paper, although some EIPs have seen an increase in the proportion of tertiary industry in their economic output, this change is not consistent, and could be the reverse for some EIPs.

In TEDA the share of tertiary industry has remained comparatively stable in the past a couple of decades, while BDA increased its share of tertiary industry rapidly up to 2008, and then remained relatively stable since (Figure 34). Better overall sustainability performance is not necessarily linked to higher tertiary industry. For example, from 2010, BDA has higher tertiary industry ratio, but its overall sustainability (particularly considering aggregated non-scale indicators) is lower in those years compared to 2006 and 2007. After 2010, BDA has higher residual heat reuse and reclaimed water sales (Figure 22) while other environmental indicators do not show clear improvement.

TEDA's pattern is more in line with higher tertiary industry ratio resulting in better overall sustainability. Its tertiary industry ratio has been above 21% since 2009, which corresponds to better sustainability. To be more specific, since 2008, TEDA tends to have better residual heat reuse, reclaimed water sales, energy use per unit economic output, energy use per unit area, water use per unit economic output, wastewater per unit economic output and wastewater per unit area (Figure 28 and 30). However, TEDA also has higher tertiary industry ration in 2003 compared to 2004, 2005 and 2006, but its overall sustainability in 2003 is lower than those years.

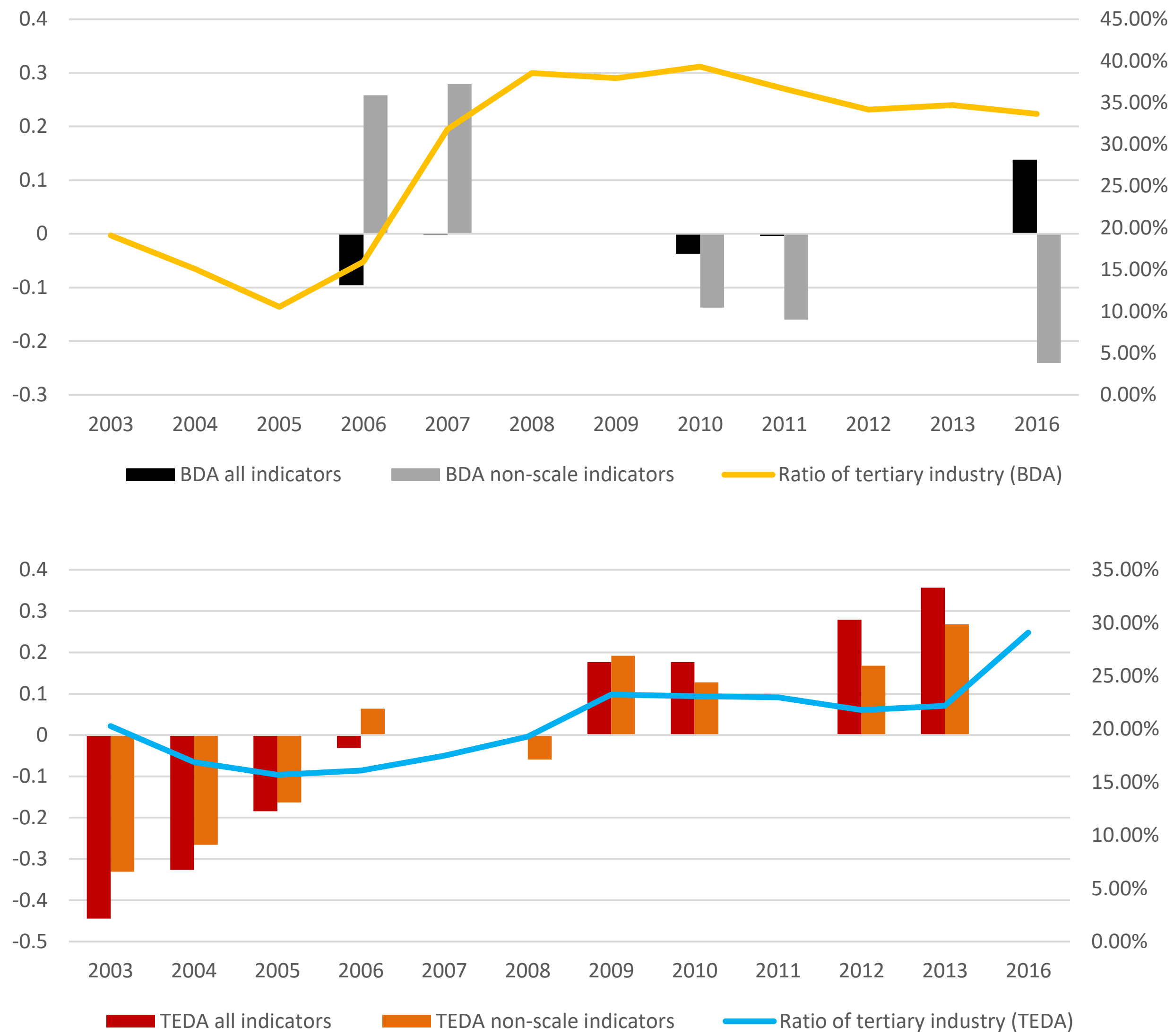


Figure 34: Phi value of EIPs of tests with all indicators, and non-scale indicators (left axis), and BDA and TEDA's tertiary industry ratio (right axis)

Growth of tertiary industry at BDA does not seem to bring better environmental performance. Sectors within tertiary industry, such as transportation, wholesale, retail, catering services and so on have also taken some progresses such as switch to cleaner fuel, and optimisation of supply chains and logistics. However, tertiary industry has grown speedily in Beijing, while commercial and household activities are still less incorporated into the industrial or urban symbiosis (Dong et al., 2017), which has caused the environmental effects of tertiary industry to remain substantial. On the other hand, TEDA had been more dedicated to advancing its technological efficiencies as also noted by Liu et al. (2015).

Secondly, both EIP expanded their boundaries gradually. However, BDA did not expand as much as TEDA did (Figure 35). As a result, land use, energy use per unit area and wastewater per unit area all showed worsening trend in both tests for BDA after 2010. On the contrary, although TEDA has worse land use, energy use per unit area and wastewater per unit area are nevertheless better in both tests since 2008 (Figure 28). This in part proves that the indicators selected in this study are able to counterbalance each other. Beijing is faced with constrained space for development while the incoming of population had been great (Tan et al., 2011). This potentially contributes to the worsening of monthly payment per employee to housing price per m^2 ratio in BDA since 2010 (Figure 22 and 24). In the contrary, TEDA has been integrating other industrial parks into its administration, and reclaiming sea for further development. Although the population of Tianjin, where TEDA is located has also been increasing quickly, the city is less inhibited by land shortage (Liu et al., 2020).

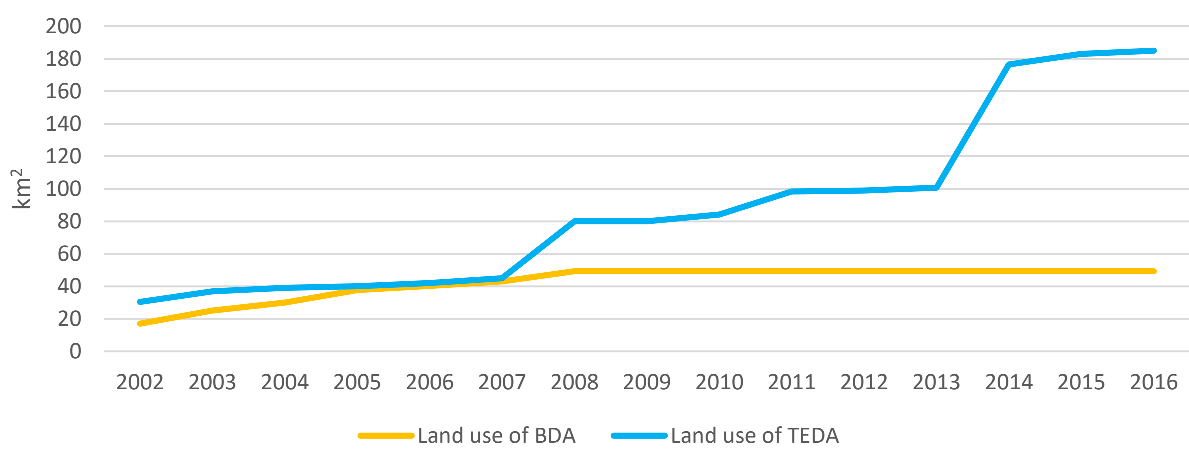


Figure 35. land use of BDA and TEDA from 2002 to 2016

Thirdly, BDA increased its use of residual heat and reclaimed water sales in later years, while its ratio of residual heat use and ratio of reclaimed water did not show clear improvement (Figure 22). Beijing has cold weathers in the winter that residual heat for central heating has always been utilised (BDA, 2002). As it expanded, heating area also increased. However, as it phased out heavy industries before the Beijing Olympics in 2008, it became technically challenging to increase the use of residual heat in other industries. Furthermore, Beijing also faces shortage of water, which urges industries to recycle water as much as possible. The increased use of water in the household sector, which is difficult to recycle might be one of the reasons for the stagnation of reclaimed water sales ratio.

On the other hand, TEDA improved its waste heat reuse, reclaimed water sales, residual heat use ratio and reclaimed water sales ratio since 2009 (except residual heat use ratio in 2013). Similar to Beijing, Tianjin also faces severe winter and shortage of water. But as opposed to Beijing, Tianjin has been pioneers in utilising desalinated water (GWI, 2007), while big enterprises tend to have their own water recycling plants too (refer to Table S4 in the Supplementary Material).

Lastly, for BDA, compulsory education enrolment rate has not improved even though compulsory education enrolment increased since 2010. As mentioned earlier, Beijing has a large inflow of population while it is constrained by land and other issues. Therefore, as a common practice of big cities in China, restricting children's access to education has been an effective way of controlling the growth of population (Zhou and Cheung, 2017). TEDA has worse ratio of healthcare coverage, ratio of pension coverage, and compulsory education enrolment rate since 2009 (Figure 30). Similar to Beijing, Tianjin is selective in who could settle down in the city. The two EIPs' ratio of healthcare coverage and ratio of pension coverage are consistent with the situation in both cities, which partly reflects the fact that the policy and implementation of the municipality has strong influence on district implementation.

For both EIPs, the social conditions of the cities they are located have dispensable influences on the operation of EIPs. As one of the most important cities in northern China with a big population, Beijing attracts a variety of industries and provide employments for all niches of the markets. This provides momentum for the economy to grow, but also causes urban issues such as congestion (Hua et al., 2013), high living costs (Tan et al., 2011), and challenges to provide services for the incoming population. This results in fluctuating performance of social aspect.

Tianjin is more industry orientated and faces pressures to compete with cities surrounding it. Being one of the first industrial parks in China with high foreign investment, TEDA has accumulated advantage to improve its industrial operation and efficiencies, which is reflected in the improved environmental aspects. For both EIPs, 2010 is a year that is frequently outperformed by at least one earlier year (except test AL for TEDA between 2009 and 2010 although the difference is small (Phi difference of 0.0009, Table 18 to 21). The aspects in different tests where 2010 is outperformed by earlier years are summarised in Table 22. One possible reason is that in face of the difficulties posed by the financial crisis starting in 2007, the Chinese government deployed 4 trillion RMB investment for the years starting in 2009, which is often considered to have inflated the economy (Wong 2011), allowed investments in inefficient technology, and resulted in higher energy consumption intensity (Zhou et al., 2011).

Table 22. aspect and years where the performance in 2010 is outperformed

EIP	Test	Aspect	Outperformed by
BDA	Test AL	Overall	2007
		Economic	-
		Environmental	2006, 2007
		Social	2006, 2007
	Test NS	Overall	2006, 2007
		Economic	2006, 2007
		Environmental	2006, 2007
		Social	2006, 2007
TEDA	Test AL	Overall	-
		Economic	-
		Environmental	2009
		Social	2005, 2008, 2009
	Test NS	Overall	2009
		Economic	2006
		Environmental	2009
		Social	2003, 2004, 2005, 2006, 2008,

4.6 Summary

MCDA in this study adopts a holistic indicator system based on existing literature while considering data availability to assess the sustainability performance of the two case study EIPs. The results show that both EIPs generally have improved their overall sustainability performance when all indicators are aggregated and considered. However, BDA's sustainability in general declined if only aggregated non-scale indicators are considered. This method also finds that 2010 has been a year that is worse than at least one earlier year for both EIPs, potentially linked to the economic stimulus package released in 2009, which made investments less effective. TEDA generally has more distant edges of stability intervals compared to BDA, i.e., more robust ranking results, which also means that the difference of BDA in different years is less significant.

Chapter Five

Causal Impact and Interrupted Time Series analysis

5.1 Background

The MCDA results presented in the last chapter gives us an idea of the sustainability performance of the case study sites over the years, and what might be the influencing factors for the change. MCDA assess the sustainability of the EIPs in a certain year in relation to other years. Therefore, it is desirable to have a closer look at individual indicators to evaluate whether the upgrading to an EIP improves their sustainability performance. We used Causal Impact analysis to see if upgrading to EIP improves the indicators' sustainability compared to baseline covariates (Section 2.4.4). The results are presented in Section 5.2 for BDA, and Section 5.3 for TEDA. Another method is Interrupted Time Series, which tests how the trend of the indicator before upgrade compares with the trend after the upgrade (Section 2.4.5). The results are given in Section 5.4 for BDA, and Section 5.5 for TEDA. Section 5.6 synthesises the findings based on these two methods.

5.2 Causal Impact results for BDA

Table 23 contains the results of the different tests for BDA with average relative effect of the treatment (EIP upgrade) expressed as % change, and beta value. Figure S1 in the Supplementary Material visually show the main patterns, while Table S5 the actual change expressed in the specific units of each indicator.

Table 23: effect of EIP upgrade on sustainability indicators for BDA, and beta value for respective covariates based on Causal Impact analysis

Scenario / Indicators	Test 1A (Another IP in the city as covariate with 2009 as the effective year)		Test 2A (Another IP in the city as covariate with 2011 as the effective year)		Test 1B (Industry/urban of city as covariate with 2009 as the effective year)		Test 2B (Industry/urban of city as covariate with 2011 as the effective year)	
	Relative effect (mean(SE))	beta	Relative effect (mean(SE))	beta	Relative effect (mean(SE))	beta	Relative effect (mean(SE))	beta
Economic output	-38.7% (2.7%)	0.938504	-35.4% (3.2%)	0.949249	-15.3% (1.6%)	0.986873	-13.3% (1.7%)	0.990733
Employee number	-12.3% (1.0%)	0.99243	-27.7% (2.2%)	0.973747	46.9% (3.9%)	0.954468	21.6% (6.2%)	0.926336
Economic output per employee	-40.2% (3.9%)	0.861561#	-27.6% (7.1%)	0.600234#	-41.4% (2.6%)	0.932991	-25.3% (5.8%)	0.809779
Economic output per unit area	34.7% (3.3%)	0.363879	30.3% (3.2%)	0.828721	-14.4% (2.2%)	0.959019	-4.6% (2.9%)	0.963952
Monthly payment per employee	25.6% (4.6%)	0.928297	16.9% (7.8%)	0.863438	-13.7% (1.4%)	0.976936	-13.4% (1.2%)	0.987923
Energy use	-32820.7% (1332.1%)	-0.901634	-551.1% (39.3%)	-0.626185	17.3% (4.5%)	0.876636	11.7% (3.9%)	0.949324
Freshwater use		*		*	42.2% (13.2%)	0.404397	-28.4% (8.4%)	0.690061
Land use	-181.4% (0.1%)	-0.999294	-145.6% (0.3%)	-0.987788	-0.7% (3.3%)	0.960934	-5.9% (5.2%)	0.896884
Energy use per unit economic output	4.3% (2.0%)	-0.97348	8.9% (2.1%)	-0.972949	18.9% (11.4%)	0.423082	7.4% (8.8%)	0.364785
Energy use per unit area	46.9% (6.1%)	-0.841951	38.8% (11.8%)	-0.487805	7.5% (4.7%)	0.659238	29.1% (5.8%)	0.847008
Freshwater use per unit economic output		*		*	14.6% (15.6%)	0.858322	-2.8% (15.7%)	0.843289
Waste heat use		*		*	-26.7% (4.4%)	0.850847^	-33.3% (4.7%)	0.847828^
Residual heat reuse ratio		*		*	-22.1% (6.1%)	-0.776564^	-7.3% (11.5%)	-0.700809^
Reclaimed water sales		*		*	51.7% (9.4%)	0.643829	23.6% (6.3%)	0.751883
Reclaimed water sales ratio		*		*	-12.9% (9.9%)	0.01428	-19.7% (6.8%)	-0.435936

GHG emissions		*		*	160.0% (9.7%)	0.804542	12.1% (1.4%)	0.990921#
GHG emissions per unit economic output		*		*	17.0% (5.3%)	-0.178124	5.6% (3.9%)	-0.59749
Wastewater discharge		*		*	95.9% (3.0%)	0.951186	50.8% (8.5%)	0.812303
Wastewater discharge per unit economic output		*		*	242.5% (29.1%)	0.85	123.3% (23.1%)	0.6912
Wastewater discharge per unit area		*		*	153.7% (5.7%)	-0.117009	50.1% (7.5%)	0.741891
Wastewater treatment capacity		*		*	71.2% (4.8%)	0.906752	52.0% (8.4%)	0.776481
Air quality		*		*	-11.2% (6.4%)	0.62477	-21.1% (7.1%)	0.771955
Monthly payment per employee to housing price per m^2 ratio		*		*	-38.0% (7.0%)	0.338753	-35.1% (11.7%)	0.475056
Healthcare coverage	2.0% (4.7%)	0.680599	-24.8% (3.2%)	0.917882	13.2% (0.8%)	0.99695	5.1% (1.5%)	0.994112
Healthcare coverage rate	-5.7% (1.9%)	0.523505#	4.6% (2.7%)	0.084131	-5.3% (4.1%)	0.564193	0.0% (4.5%)	0.463635
Pension coverage	49.2% (4.6%)	0.680599	-11.7% (3.3%)	0.924734	22.1% (2.5%)	0.944995	15.6% (2.0%)	0.982843
Pension coverage rate	43.4% (2.4%)	0.247224	22.7% (3.3%)	0.744687#	16.1% (5.4%)	0.591340#	26.2% (6.9%)	0.520164
Compulsory education enrolment		*		*	377.9% (95.4%)	-0.407512	342.5% (45.4%)	-0.368931
Compulsory education enrolment rate		*		*	-21.3% (12.1%)	-0.782082	-6.3% (22.3%)	-0.675514

Note: SE standard error; * no data/no enough data available for analysis; # time as the covariate is used; ^ data of the nation used.

Green means the indicator improved its performance after intervention of EIP upgrade, red means the indicator's performance deteriorated. Whether improvement of its performance means increase in the value of the indicator depends on the nature of the indicator. For example, land use improved its performance because its value decreased compared to covariate.

Test 1A and Test 2A using another park for the covariates were conducted for 13 indicators due to lack of equivalent data for the ZSP industrial park. Five indicators show improvement of performance statistically significant whether using 2009 or 2011 as the treatment year. These include economic output per unit area (+34.7% and +30.3% respectively), monthly payment (+25.6% and +16.9% respectively), energy use (-32820.7% and -551.1% respectively), and land use (-181.4% and -145.6% respectively). Number of people with pension increased by 49.2% (baseline 2009). Pension coverage rate increased by 22.7% (2011 baseline), while no significant difference was found when using 2009 as the intervention year.

The performance of six indicators decreased when using 2009 as the baseline, and seven indicators when using 2011. In more detail, the levels of the following indicators decreased for both 2009 and 2011 baselines: economic output (-38.7% and -35.4% respectively), number of employees (-12.3% and -27.7% respectively), economic output per employee (-40.2% and -27.6% respectively), energy use per unit economic output (+4.3% and +8.9% respectively), and energy use per unit area (+46.9% and +38.8% respectively). Healthcare insurance coverage rate decreased by 5.7% for the 2009 baseline, while there was no significant difference for the 2011 baseline. Conversely, healthcare insurance coverage (in terms of absolute number of people) declined by 24.8% for the 2011 baseline, while not showing any statistically significant difference for the 2009 baseline.

For one case we found different patterns for the different baselines. More specifically, pension coverage (in terms of absolute number of people) showed a relative increase of 49.2% for the 2009 baseline, and a decrease of 11.7% for the 2011 baseline. Improvement or deterioration does not necessarily mean that the trend of the indicator is generally increasing or decreasing, but that the trend is less pronounced as the trend of the predictions based on the covariate. Refer to Supplementary material S1 for the visual pattern of the results.

Energy use, energy use efficiency, and land use are negatively correlated with that of ZSP. More specifically, although BDA's use of energy did not increase as fast as that of ZSP, its energy efficiency did not improve as ZSP did either. Energy use, energy use efficiency, and land use have strong negative correlation between BDA and ZSP (-0.99 to -0.49). However, only three years' data were available for ZSP for these a few indicators before the intervention year (2009), which means that a temporary opposition trend, although producing strong correlation, could mistakenly indicate the direction of correlation. Particularly, for energy and land use, absolute and relative effects have opposite signs with predicted values going negative, which is impossible in reality. Therefore, we should interpret the results for these a few indicators with caution.

When the industrial/urban data were used as covariate, 29 indicators were all analysed, out of which seven indicators improved either 2009 or 2011 was considered the effective year, of which number of employees increased by 46.9% and 21.6% respectively, reclaimed water use by 51.7% and 23.6% respectively, wastewater treatment capacity increased by 71.2% and 52.0%. Number of people with healthcare insurance increased by 13.2% and 5.1% respectively, people with pension by 22.1% and 15.6%, and pension coverage rate increased by 16.1% and 26.2% respectively.

Number of students in compulsory education also increased greatly (377.9%) after BDA embarked on EIP upgrade, however, education enrolment rate showed no difference, and worsened if 2011 was tested as the effective year.

However, 14 indicators worsened with 2009 as the effective year, and 13 worsened for 2011. All economic indicators except number of employees showed deterioration. The amount of energy used also increased significantly (+17.3% and +11.7% respectively). Ratio of reclaimed water sales decreased by 26.7% and 33.3% respectively. GHG emissions increased by 160.0% and 12.1%, wastewater discharge by 95.9% and 50.8%, wastewater discharge per economic output by 242.5% and 123.3%, air quality by 11.2% and 21.1%, and monthly payment per employee to housing price per m2 ratio by 38.0% and 35.1%, respectively.

Land use showed improvement, energy use per unit economic output, and GHG emissions per unit economic output deteriorated for both baselines, but the change is not significant. Ratio of reclaimed water, and wastewater discharge per area deteriorated for both intervention years, however, all of the effects are not significant with 2009 as the baseline. Economic output per unit area, residual heat reuse ratio, and compulsory education enrolment rate worsened in both tests, however, the effect is not significant with 2011 as the intervention year. Number of students enrolled in compulsory education showed improvement with either year as the intervention, however, its change is not significant when 2011 acts as the intervention year. Only one indicator, freshwater use, showed opposite, which worsened by 42.2% with 2009 as the baseline, and improved by 28.4% with 2011 as the baseline.

5.3 Causal Impact results for TEDA

Table 24 contains the results of the different tests for TEDA with average relative effect of the treatment (EIP upgrade) expressed as % change, and beta value. Figure S2 in the Supplementary Material visually show the main patterns, while Table S6 the actual change expressed in the specific units of each indicator.

Table 24: effect of EIP upgrade on sustainability indicators for TEDA, and beta value for respective covariates based on Causal Impact analysis

Scenario	Test 1A (Another IP in the city as covariate with 2004 as the effective year)		Test 2A (Another IP in the city as covariate with 2008 as the effective year)		Test 1B (Industry/urban of city as covariate with 2004 as the effective year)		Test 2B (Industry/urban of city as covariate with 2008 as the effective year)	
Indicators	Relative effect (mean(SE))	beta	Relative effect (mean(SE))	beta	Relative effect (mean(SE))	beta	Relative effect (mean(SE))	beta
Economic output	-37.7% (0.9%)	0.959073	-15.3% (1.9%)	0.948682	-8.8% (0.4%)	0.995806	-0.6% (0.7%)	0.982195
Employee number	54.1% (4.3%)	-0.725417	41.5% (8.2%)	-0.53103	-43.0% (3.1%)	0.642009	-30.8% (3.6%)	0.811142
Economic output per employee	-70.6% (0.7%)	0.936484	-32.9% (3.4%)	0.722111	-6.7% (1.1%)	0.974709	3.0% (1.3%)	0.984468
Economic output per unit area	-57.0% (2.4%)	0.794652	-48.1% (5.1%)	0.634095	-52.8% (1.1%)	0.960698	-41.2% (3.4%)	0.873274
Monthly payment per employee	23.5% (2.8%)	0.767994	1.8% (2.4%)	0.949931	29.5% (2.6%)	0.791623	1.7% (2.3%)	0.957201
Energy use	*	*	*	*	-45.9% (1.8%)	0.920734	-7.5% (4.8%)	0.794371
Freshwater use	56.7% (19.8%)	0.628431	116.6% (17.4%)	0.771709~	88.6% (5.5%)	-0.877491	104.8% (8.7%)	-0.82949
Land use	66.5% (1.8%)	0.934462	81.1% (3.8%)	0.925709	83.4% (2.1%)	0.933811	59.5% (3.5%)	0.911
Energy use per unit economic output	*	*	*	*	-29.1% (32.8%)	0.849104	-15.2% (49.2%)	0.895004
Energy use per unit area	*	*	*	*	-24.8% (2.9%)	-0.650499	-19.9% (8.3%)	-0.42247
Freshwater use per unit economic output	-31.3% (3.0%)	0.919846	-29.5% (5.2%)	0.836166	-48.8% (6.8%)	0.489868	-45.6% (9.6%)	0.802142
Waste heat use	*	*	*	*	-64.4% (0.5%)	0.980571^	-6.7% (2.5%)	0.940126
Residual heat reuse ratio	*	*	*	*	158.1% (5.4%)	-0.503612^	-19.0% (7.8%)	0.602793
Reclaimed water sales	*	*	*	*	*	*	-121.9% (0.4%)	-0.60097

Reclaimed water sales ratio	*	*	*	*	*	*	77.3% (4.8%)	0.51802#
GHG emissions	*	*	*	*	*	*	19.1% (3.7%)	0.732741
GHG emissions per unit economic output	*	*	*	*	*	*	30.4% (15.3%)	0.919006
Wastewater discharge	*	*	85.6% (10.7%)	0.939856	-4.1% (3.5%)	0.639295	-2.9% (3.0%)	0.785455
Wastewater discharge per unit economic output	*	*	-25.5% (29.5%)	0.322498	-21.3% (16.0%)	0.617287	3.1% (18.3%)	0.87773
Wastewater discharge per unit area	*	*	-22.6% (11.7%)	0.476151#	-49.8% (5.2%)	0.402675	-58.1% (9.6%)	0.487505
Wastewater treatment capacity	*	*	*	*	-24.5% (2.9%)	0.517857	11.6% (4.1%)	0.596717
Air quality	*	*	*	*	-10.9% (1.1%)	0.93694	-12.1% (3.5%)	0.366315
Monthly payment per employee to housing price per m^2 ratio	*	*	16.4% (4.5%)	-0.57545	*	*	14.2% (4.6%)	-0.58745
Healthcare coverage	*	*	*	*	*	*	-2.7% (2.3%)	0.943958
Healthcare coverage rate	*	*	*	*	*	*	-7.9% (2.3%)	0.828931
Pension coverage	*	*	*	*	*	*	-35.9% (1.8%)	0.941991
Pension coverage rate	*	*	*	*	*	*	-26.1% (3.0%)	0.60184
Compulsory education enrolment	-14.7% (0.1%)	0.999742#	38.4% (5.3%)	0.562075#	25.4% (2.6%)	-0.935276	70.1% (6.6%)	-0.61115
Compulsory education enrolment rate	-29.4% (1.2%)	0.825982#	56.5% (10.4%)	-0.641773#	-23.5% (1.5%)	-0.877431	23.1% (10.0%)	0.477651

Note: SE standard error; * no data/no enough data available for analysis; ~ 2005 is treated as the first year of upgrade as 2004 has no data; # time as the covariate is used; ^ data of the nation used.

Green means the indicator improved its performance after intervention of EIP upgrade, red means the indicator's performance deteriorated.

Tests 1A and 2A using another park for the covariates were conducted for 14 indicators due to lack of equivalent data for BND. Two indicators improved their performance significantly in both tests, namely number of employees (+54.1% and +41.5% respectively), and freshwater use per economic output (-31.3% and -29.5% respectively). Monthly payment also increased for both tests; however, it is not significant when 2008 is considered the intervention year.

Five indicators worsened when either 2004 or 2008 was treated as the intervention year. Specifically, economic output decreased by 37.7% and 15.3% respectively, economic output per employee by 70.6% and 32.9%, economic output per area by 57.0% and 48.1%, freshwater use increased by 56.7% and 116.6%, and land use expanded by 66.5% and 81.1% respectively.

A few indicators were only analysed with 2008 as the intervention year due to unavailability of data for earlier years, of which wastewater discharge increased by 85.6%, wastewater discharge per area decreased by 22.6%, and monthly payment to housing price increased by 16.4%.

Two indicators showed opposite changes. Number of students enrolled in compulsory education declined by 14.7% when 2004 is the intervention year but increased by 38.4% when 2011 is the intervention year. Education enrolment rate showed similar trend (-29.4% and +56.5% respectively).

20 indicators were analysed with the industrial/urban data of Tianjin as the covariate with 2004 as the effective year, and 29 indicators analysed with 2008 as the effective year. Three indicators showed betterment for both tests. Specifically, freshwater use per unit economic output (-48.8% and -45.6% respectively), wastewater discharge per unit area (-49.8% and -58.1% respectively), and number of students enrolled in compulsory education (+25.4% and +70.1%). Monthly payment improved for both tests (+29.5% and +1.7%), however, it is not significant when 2008 is treated as the intervention year.

Six indicators worsened in both tests, among which, employee number decreased by 43.0% and 30.8%, economic output per unit area decreased by 52.8% and 41.2%, respectively. Freshwater use increased by 88.6% and 104.8%, and land use expanded by 83.4% and 59.5% respectively. Waste heat use decreased by 64.4% and 6.7%, and days of air quality better than level II dropped by 10.9% and 12.1% respectively.

A few indicators were not able to be analysed due to unavailability of earlier years' data. For those indicators that were analysed with 2008 as the intervention year, reclaimed water indicators, and monthly payment to housing price improved, but GHG emissions increased by 19.1%, GHG emissions per economic output by 30.4%, healthcare coverage rate, and two pension indicators also showed varying degrees of worsening.

Economic output per employee declined by 6.7% with 2004 as the effective year but showed improvement of 3.0% if 2008 was the effective year. Residual heat use ratio increased by more than 1.5 times if 2004 was treated as the effective year, but it worsened by 19% if 2008 was the effective year. On the other hand, wastewater treatment capacity (-24.5%), and compulsory education enrolment rate (-23.5%) worsened if 2004 was the effective year, while these two indicators showed improvement (+11.6% and +23.1% respectively) if 2008 was considered the effective year.

Amount of reclaimed water use showed opposite trend for TEDA in test B before 2008 (beta value is -0.60097) resulting in projected values being negative (Figure S2 in Supplementary Material). Therefore, analysis on this indicator should be interpreted with caution.

5.4 Interrupted Time Series results for BDA

The results for BDA are shown in Table 25. For graphic results of the indicators of each test, refer to Figure S3 in the Supplementary Material. For Test ST (starting upgrade year 2009 as the abrupt effective year), only one indicator significantly improved while five indicators significantly worsened. More specifically, inflation adjusted monthly payment increased 794.8 RMB per month due to EIP upgrade. Energy consumption increased by 220,051.1 tsce per year, freshwater use by +8,739,694 t per year, energy use per unit economic output by +61.45 kg/10,000 RMB, freshwater use per economic output by +3.24 t/10,000 RMB, and GHG emissions per unit economic output by +0,28 t CO_2e/10,000 RMB, respectively. Number of employees and waste heat use showed increasing trend, although not significant (P value is 0.076 and 0.213 respectively). Economic output per employee, residual heat reuse ratio, healthcare coverage rate, pension coverage rate and compulsory education enrolment rate showed deteriorating trend but not significant.

For Test GR (a gradual impact of EIP upgrade), six indicators improved and 12 deteriorated. In detail, number of employee increased by 51,952, nominal monthly payment per employee increased by 1,310.7 RMB per month, reclaimed water sales by +7,381,420 t per year, healthcare coverage by +54,385, pension coverage by +126,778, and pension coverage rate by +44.9% respectively. On the other hand, ratio of economic output to economic output of city, economic output per employee, energy use indicators, freshwater use per unit economic output, GHG emissions indicators, wastewater discharge indicators, and Monthly payment per employee to housing price per m^2 ratio worsened at varying degrees. Freshwater use, waste heat use, residual heat reuse ratio, healthcare coverage ratio and compulsory education enrolment rate also showed deteriorating trend although statistically not significant.

For Test VE (verification year 2011 as the abrupt effective year), three indicators showed improvement, namely, reclaimed water sales increased by +5,999,290 t/per year, healthcare coverage and pension coverage (by 30,846 and 86,502, respectively). On the other hand, eleven indicators worsened. Specifically, ratio of economic output to economic output of city, economic output per employee, energy use per unit economic output, freshwater use per unit economic output, reclaimed water sales ratio, GHG emissions indicators, wastewater discharge indicators and air quality have worsening of differing levels. Freshwater use, waste heat use, residual heat reuse ratio, healthcare coverage rate, and compulsory education enrolment rate also show degrading trend although not significant.

Employee number showed improved in all three tests although not consistently significant. Energy use per unit economic output, and freshwater use per economic output, and GHG emissions per unit economic output showed significant deterioration in all three tests. Economic output per employee, freshwater use, residual heat reuse ratio, healthcare coverage rate, and compulsory education enrolment rate although showed worsening trend, are not significant.

Table 25: ITS results for BDA

Scenario / Indicators	2009 as the effective year				2009-2011 as the gradual effective period				2011 as the effective year			
	Coef.	**Std. err**	**P**	**R^2**	**Coef.**	**Std. err**	**P**	**R^2**	**Coef.**	**Std. err**	**P**	**R^2**
Economic output	-2.06E+01	3.20E+01	0.529	0.9805	-7.74E+01	3.75E+01	0.057	0.9844	-5.58E+01	2.75E+01	0.06	0.9842
Ratio of economic output to economic output of city	-5.43E-03	7.95E-03	0.505	0.6803	-2.60E-02	8.15E-03	0.006	0.8035	-1.78E-02	6.20E-03	0.012	0.7876
Employee number	2.57E+04	1.35E+04	0.076	0.9862	5.20E+04	1.45E+04	3.00E-03	9.91E-01	2.54E+04	1.28E+04	0.067	0.9864
Economic output per employee	-5.90E+00	3.23E+00	0.088	0.2319	-1.45E+01	2.81E+00	0	0.6618	-8.54E+00	2.61E+00	0.005	0.4521
Economic output per unit area	-1.14E+00	7.17E-01	0.136	0.9624	-1.83E+00	1.01E+00	0.094	0.9642	-9.12E-01	7.42E-01	0.241	0.9598
Nominal monthly payment per employee	5.45E+02	3.74E+02	0.175	0.974	1.31E+03	5.54E+02	3.90E-02	9.80E-01	6.47E+02	4.07E+02	0.143	0.9748
Inflation adjusted monthly payment per employee	7.95E+02	3.10E+02	2.80E-02	9.56E-01	1.12E+03	5.69E+02	0.077	0.947	3.60E+02	4.27E+02	0.418	0.9313
Energy use	2.20E+05	5.47E+04	0.003	0.9889	3.80E+05	1.04E+05	0.005	0.9875	9.97E+04	9.43E+04	0.318	0.9724
Freshwater use	8.74E+06	2.78E+06	0.007	0.9723	5.67E+06	4.45E+06	0.221	0.9585	3.59E+06	3.29E+06	0.293	0.9573
Land use	1.36E+00	6.14E+00	0.829	0.6868	-1.57E+01	7.77E+00	0.065	0.7605	-1.10E+01	5.34E+00	0.059	0.7632
Energy use per unit economic output	6.15E-02	1.35E-02	0.001	0.6758 (u)	6.34E-02	1.52E-02	0.002	0.6354 (u)	4.99E-02	1.57E-02	0.01	0.5013 (u)
Energy use per unit area	3.15E+03	1.46E+03	0.06	0.976	8.33E+03	1.64E+03	0.001	0.9906	2.97E+03	1.70E+03	0.115	0.9728
Freshwater use per unit economic output	3.24E+00	1.27E+00	0.022	0.3893	4.77E+00	1.57E+00	0.008	0.4589	3.24E+00	1.25E+00	0.02	0.4004
Waste heat use	1.26E+05	9.60E+04	0.213	0.8342	-1.86E+05	1.37E+05	0.199	0.8357	-1.67E+05	8.69E+04	0.079	0.855
Residual heat reuse ratio	-1.19E-02	6.00E-03	0.079	0.947	-2.31E-02	1.03E-02	0.052	0.951	-7.23E-03	7.48E-03	0.359	0.931
Reclaimed water sales	1.63E+06	1.68E+06	0.364	0.8202	7.38E+06	5.87E+05	0.00E+00	0.9518 (u)	6.00E+06	8.92E+05	0.00E+00	0.8496 (u)

Reclaimed water sales ratio	1.35E-01	5.99E-02	0.059	0.8263	2.16E-01	1.07E-01	0.083	0.8103	-1.65E-01	6.01E-02	0.025	0.4841 (u)
GHG emissions	-7.17E+04	3.70E+05	0.851	0.9807	1.40E+06	4.72E+05	0.016	0.9902	8.24E+05	2.98E+05	0.022	0.9895
GHG emissions per unit economic output	2.85E-01	8.47E-02	0.007	0.5309 (u)	3.80E-01	5.40E-02	0	0.8319 (u)	3.28E-01	5.31E-02	0	0.793 (u)
Wastewater discharge	3.23E+06	4.55E+06	0.49	0.9067	2.02E+07	3.35E+06	0	0.973	1.61E+07	1.34E+06	0	0.9915
Wastewater discharge per unit economic output	1.84E+00	1.69E+00	0.294	0.0906	7.79E+00	1.22E+00	0	0.7479	5.56E+00	8.61E-01	0	0.7517
Wastewater discharge per unit area	4.62E+04	1.20E+05	0.706	0.7944	5.06E+05	3.63E+04	0	0.9329 (u)	4.73E+05	2.71E+04	0	0.956 (u)
Wastewater treatment capacity	-9.83E+06	7.22E+06	0.195	0.8646	6.40E+06	1.04E+07	0.548	0.8508	1.18E+07	6.79E+06	0.103	0.8741
Air quality better than level II	3.93E+01	5.59E+01	0.497	0.1745	-1.46E+02	7.14E+01	0.068	0.3884	-5.54E+01	2.43E+01	0.044	0.3203 (u)
Ratio of green area	6.00E-02	2.82E-01	0.851	0.195	-4.91E-02	1.65E-01	0.785	0.0288	-6.82E-02	1.43E-01	0.667	0.0702
Monthly payment per employee to housing price per m^2 ratio	-1.04E-01	5.01E-02	0.068	0.8621	-2.31E-01	4.45E-02	0	0.7297 (u)	3.01E-02	6.76E-02	0.666	0.8007
Healthcare coverage	2.37E+04	1.26E+04	0.081	0.9897	5.44E+04	1.28E+04	1.00E-03	9.94E-01	3.08E+04	1.10E+04	1.40E-02	9.92E-01
Healthcare coverage rate	-8.99E-02	1.51E-01	0.561	0.3206	-2.78E-01	1.96E-01	0.177	0.3914	-1.38E-01	1.44E-01	0.356	0.3459
Pension coverage	8.18E+03	3.16E+04	0.799	0.9542	1.27E+05	2.71E+04	0.00E+00	9.82E-01	8.65E+04	2.04E+04	1.00E-03	9.80E-01
Pension coverage rate	-2.38E-02	1.05E-01	0.824	0.8173	4.49E-01	5.72E-02	0.00E+00	0.8041 (u)	1.80E-01	9.04E-02	0.066	0.8572
Compulsory education enrolment	-2.10E+02	1.42E+02	0.182	0.9959	-1.83E+02	2.50E+02	0.489	0.9949	-5.12E+01	1.52E+02	0.746	0.9946
Compulsory education enrolment rate	-8.11E-03	4.93E-03	0.144	0.3321	-1.47E-02	7.41E-03	0.088	0.4067	-4.16E-03	5.23E-03	0.453	0.15

Note: u means regression uses the impact power of upgrade as the only variable; green shows improvement of indicator after intervention, red shows deterioration of indicator after intervention; u denotes upgrade impact power as the only variable.

5.5 Interrupted Time Series results for TEDA

The results for TEDA are shown in Table 26. For graphic results of the indicators of each test, refer to Figure S4 in the Supplementary Material. Four indicators in Test ST improved while two deteriorated. To be more specific, economic output per unit area increased by 36577.7 RMB/km^2 as a result of EIP upgrade, energy use per unit area decreased by 10,889.5 t/km^2, residual heat reuse ratio increased by 9.92%, and healthcare coverage rate by 9.69%. Energy use, healthcare coverage, pension coverage, and pension coverage rate showed improvement but not significant. Ratio of economic output to economic output of city, and economic output per employee declined by 3.98% and 21344.6 RMB per employee after EIP upgrade. Freshwater use, energy use per unit economic output, freshwater use per unit economic output, compulsory education enrolment, and compulsory education enrolment rate although showed deteriorating trend, are not significant.

11 indicators became better with four worsened in Test GR. Notably, employee number increased by 92,035, inflation adjusted monthly payment by 872.6 RMB per employee, energy use per unit area decreased by 30,895.5 tsce per km^2, waste heat use increased by 192,275.1 tsce per year, GHG emissions decreased by 8,302,022 t CO_2e, GHG emissions per unit economic output by 1.21 t CO_2e per 10,000 RMB, wastewater discharge declined by 9,497,810 t per year, and air quality better than Level II increase by 122.2 days per year. Energy use, healthcare coverage indicators and pension coverage indicators improved by certain degrees but not significantly. Ratio of economic output to economic output of city shrank by 9.3%, economic output per employee declined by 36,717 RMB per employee, students in compulsory education declined by 4746, and its ratio by 1.3%. Freshwater use and energy use per unit economic output showed signs of degrading but not significantly.

In Test VE, nine indicators improved while three indicators significantly deteriorated. Specifically, employee number increased by 65,877, nominal monthly payment and inflation adjusted monthly payment increased by 1,425.1 RMB and 459.7, respectively. Energy use per unit area and freshwater use per unit economic output declined by 16,584.9 tsce per km^2 and 2.2 t/10,000 RMB, respectively. Waste heat use increased by 96,787.3 tsce, and reclaimed water sales rate by 4.1%. Wastewater discharge and wastewater discharge per unit area decreased by 6,501,610 t per year and 293,165.7 t per km^2, respectively. Residual heat reuse ratio showed increase but not significantly (P value 0.223). Ratio of economic output to economic output of city, economic output per unit area, and land use worsened by 6.8%, 661.4 m RMB per km^2, and 38.4 km^2, respectively. Energy use, freshwater use, energy use per unit economic output, and all social indicators showed varying degrees of deterioration, but are not significant.

Ratio of economic output to city is the only indicator that showed significant decline in all three Tests. Energy use per unit area improved in all three tests.

Table 26: ITS results for TEDA

Scenario / Indicators	2004 as the effective year				2004-2008 as the gradual effective period				2008 as the effective year			
	Coef.	**Std. err**	**P**	**R^2**	**Coef.**	**Std. err**	**P**	**R^2**	**Coef.**	**Std. err**	**P**	**R^2**
Economic output	-1.86E+02	1.12E+02	0.11	0.9456					2.15E+02	1.06E+02	0.056	0.9486
Ratio of economic output to economic output of city	-3.98E-02	1.77E-02	0.033	0.8142	-9.34E-02	1.48E-02	0	0.9107	-6.76E-02	1.18E-02	0	0.9001
Employee number	2.47E+04	2.23E+04	0.281	0.9707	9.20E+04	2.17E+04	0.00E+00	9.83E-01	6.59E+04	1.62E+04	0.00E+00	9.82E-01
Economic output per employee	-2.13E+00	8.59E-01	0.022	0.9841	-3.67E+00	1.21E+00	0.006	0.9857	-1.57E+00	8.91E-01	0.093	0.9819
Economic output per unit area	3.66E+00	1.11E+00	3.00E-03	0.3417 (u)	-4.48E+00	3.25E+00	0.184	0.3583	-6.61E+00	1.68E+00	0.001	0.6051
Nominal monthly payment per employee	-7.14E+02	5.82E+02	0.234	0.9174	1.47E+03	8.33E+02	0.093	0.9231	1.43E+03	4.94E+02	9.00E-03	9.37E-01
Inflation adjusted monthly payment per employee	1.34E+02	1.55E+02	0.398	0.9361	8.73E+02	1.43E+02	0.00E+00	9.78E-01	4.60E+02	1.18E+02	1.00E-03	9.63E-01
Energy use	-1.86E+05	2.69E+05	0.497	0.8759	-7.43E+04	3.69E+05	0.842	0.8729	2.45E+05	2.35E+05	0.312	0.8798
Freshwater use	4.11E+06	4.38E+06	0.359	0.9732	3.45E+06	6.31E+06	0.591	0.9725	4.90E+05	4.26E+06	0.91	0.9721
Land use	-3.23E+01	1.98E+01	0.118	0.8128	1.72E+01	2.97E+01	0.57	0.7924	3.84E+01	1.82E+01	0.048	0.8258
Energy use per unit economic output	9.60E+01	1.29E+02	0.467	0.7412	3.11E+02	1.62E+02	0.071	0.7785	2.06E+02	1.06E+02	0.069	0.7792
Energy use per unit area	-1.09E+04	3.11E+03	2.00E-03	0.3921 (u)	-3.09E+04	4.37E+03	0.00E+00	8.46E-01	-1.66E+04	2.23E+03	0.00E+00	0.7441 (u)
Freshwater use per unit economic output	-7.95E-01	1.09E+00	0.475	0.7835	-5.45E+00	5.09E-01	0.00E+00	0.8391 (u)	-2.17E+00	9.44E-01	3.20E-02	8.23E-01
Waste heat use	2.76E+04	4.20E+04	0.523	0.9202	1.92E+05	4.85E+04	2.00E-03	9.63E-01	9.68E+04	3.43E+04	1.40E-02	9.49E-01
Residual heat reuse ratio	9.92E-02	4.12E-02	3.20E-02	3.10E-01	2.56E-01	4.39E-02	0.00E+00	7.25E-01	6.09E-02	4.76E-02	0.223	0.1142
Reclaimed water sales	-4.00E+05	3.54E+05	0.276	0.8682	5.04E+05	6.47E+05	0.448	0.8625	6.36E+05	3.84E+05	0.118	0.8791

Reclaimed water sales ratio	-5.01E-03	1.19E-02	0.681	0.6941	4.72E-02	6.61E-03	0.00E+00	0.7614 (u)	4.10E-02	5.79E-03	0.00E+00	0.7587 (u)
GHG emissions	-1.10E+06	1.23E+06	0.39	0.9105	-8.30E+06	1.52E+06	0.00E+00	9.76E-01	-9.52E+05	1.44E+06	0.523	0.9073
GHG emissions per unit economic output	-1.59E-01	2.24E-01	0.498	0.874	-1.21E+00	9.67E-02	0.00E+00	0.9454 (u)	-3.17E-02	2.31E-01	0.894	0.8663
Wastewater discharge	1.18E+06	2.66E+06	0.662	0.8209	-9.50E+06	4.12E+06	3.60E-02	8.66E-01	-6.50E+06	2.52E+06	2.10E-02	8.74E-01
Wastewater discharge per unit economic output	-1.14E+00	7.33E-01	0.14	0.903	-2.46E+00	1.27E+00	0.071	0.91	-3.03E-01	8.93E-01	0.739	0.8881
Wastewater discharge per unit area	6.60E+04	8.49E+04	0.449	0.8891	-2.62E+05	1.40E+05	0.081	0.9065	-2.93E+05	6.24E+04	0.00E+00	9.53E-01
Wastewater treatment capacity	2.33E+06	3.64E+06	0.532	0.7683	-9.69E+06	6.12E+06	0.134	0.7961	-5.75E+06	3.91E+06	0.162	0.792
Air quality better than level II					1.22E+02	4.90E+01	2.70E-02	5.54E-01	5.89E+01	3.54E+01	0.12	0.4554
Ratio of green area	-1.316666	2.59531	0.62	0.0181 (u)	-4.54E+00	2.30E+00	0.068	0.2177 (u)	-4.19E+00	1.99E+00	0.054	0.2396 (u)
Monthly payment per employee to housing price per m^2 ratio	-0.014022	0.039407	0.729	0.7745	1.31E-02	5.37E-02	0.812	0.7731	-6.88E-03	3.43E-02	0.845	0.7727
Healthcare coverage	32572.78	15211.58	0.055	0.9568	3.07E+04	2.28E+04	0.205	0.9475	-6.54E+03	1.56E+04	0.683	0.9398
Healthcare coverage rate	9.69E-02	3.86E-02	2.90E-02	4.07E-01	1.60E-02	6.56E-02	0.812	0.0725	-7.01E-02	3.62E-02	0.079	0.3045
Pension coverage	34811.92	16805.64	0.063	0.9401	4.47E+04	2.33E+04	0.082	0.9376	-1.12E+03	1.72E+04	0.949	0.9168
Pension coverage rate	0.0973148	0.0506964	0.081	0.3439	5.35E-02	7.79E-02	0.507	0.1601	-5.51E-02	4.80E-02	0.275	0.2178
Compulsory education enrolment	-1281.767	876.713	0.167	0.8732	-4.75E+03	9.84E+02	0	0.947	-1.12E+03	1.03E+03	0.296	0.8647
Compulsory education enrolment rate	-0.003164	0.002728	0.267	0.1222	-1.35E-02	3.28E-03	0.001	0.5783	-3.15E-03	3.14E-03	0.335	0.1007

Note: u means regression uses the impact power of upgrade as the only variable; green shows improvement of indicator after intervention, red shows deterioration of indicator after intervention; u denotes upgrade impact power as the only variable.

5.6 Discussion

5.6.1 Synthesis of results

Table 27 synthesizes the patterns for both EIPs across both methods for all tests and indicators. With the urban/industrial sector of the city as the covariate has enabled more indicators to be tested. The results suggest quite divergent patterns between indicators, with some indicators improving and others degrading based on the respective baseline years.

Mindful of the data gaps and the aggregated nature of many of the underlying datasets we can see almost all tests show more degraded indicators than improved ones except for TEDA when BND was set as the covariate and 2008 as the effective year, and all three tests of TEDA with ITS. Thus, the results show that EIP upgrade does not necessarily advance individual indicator's performance compared with the trend of either another industrial park in the same city, or the industrial/urban data of the same city.

Table 27. patterns of change across all indicators for both EIPs with all tests for both Causal Impact and Interrupted Time Series analysis

EIP/method/test	BDA							TEDA						
	Causal Impact				Interrupted Time Series			Causal Impact				Interrupted Time Series		
Indicator	Test 1A	Test 2A	Test 1B	Test 2B	Test ST	Test GR	Test VE	Test 1A	Test 2A	Test 1B	Test 2B	Test ST	Test GR	Test VE
Economic output														
Ratio of economic output to economic output of city														
Employee number														
Economic output per employee														
Economic output per unit area														
Nominal monthly payment per employee														
Inflation adjusted monthly payment per employee														
Energy use														
Freshwater use														
Land use														
Energy use per unit economic output														
Energy use per unit area														

Freshwater use per unit economic output														
Waste heat use														
Residual heat reuse ratio														
Reclaimed water sales														
Reclaimed water sales ratio														
GHG emissions														
GHG emissions per unit economic output														
Wastewater discharge														
Wastewater discharge per unit economic output														
Wastewater discharge per unit area														
Wastewater treatment capacity														
Air quality better than level II														
Ratio of green area														
Monthly payment per employee to housing price per m^2 ratio														
Healthcare coverage														
Healthcare coverage rate				*										

Pension coverage														
Pension coverage rate														
Compulsory education enrolment														
Compulsory education enrolment rate														
Improvement	5 (2)	5 (1)	7 (1)	7 (3)	1 (11)	6 (3)	3 (6)	3	6 (2)	7 (3)	10 (4)	4 (13)	11 (11)	9 (8)
Degradation	6	7	14 (7)	13 (5)	5 (15)	12 (11)	11 (12)	7	6	10	12 (3)	2 (13)	4 (6)	3 (12)
NO. of indicators tested	13	13	29	29	32	32	32	10	14	20	29	32	32	32

Note: Green shows improvement, red degradation; the number of indicators for these two changes are outside parentheses.

Light green shows improvement but statistically not significant or absolute beta value smaller than 0.3, beige shows degradation but statistically not significant or absolute beta value smaller than 0.3; the number of indicators for these two changes are in parentheses.

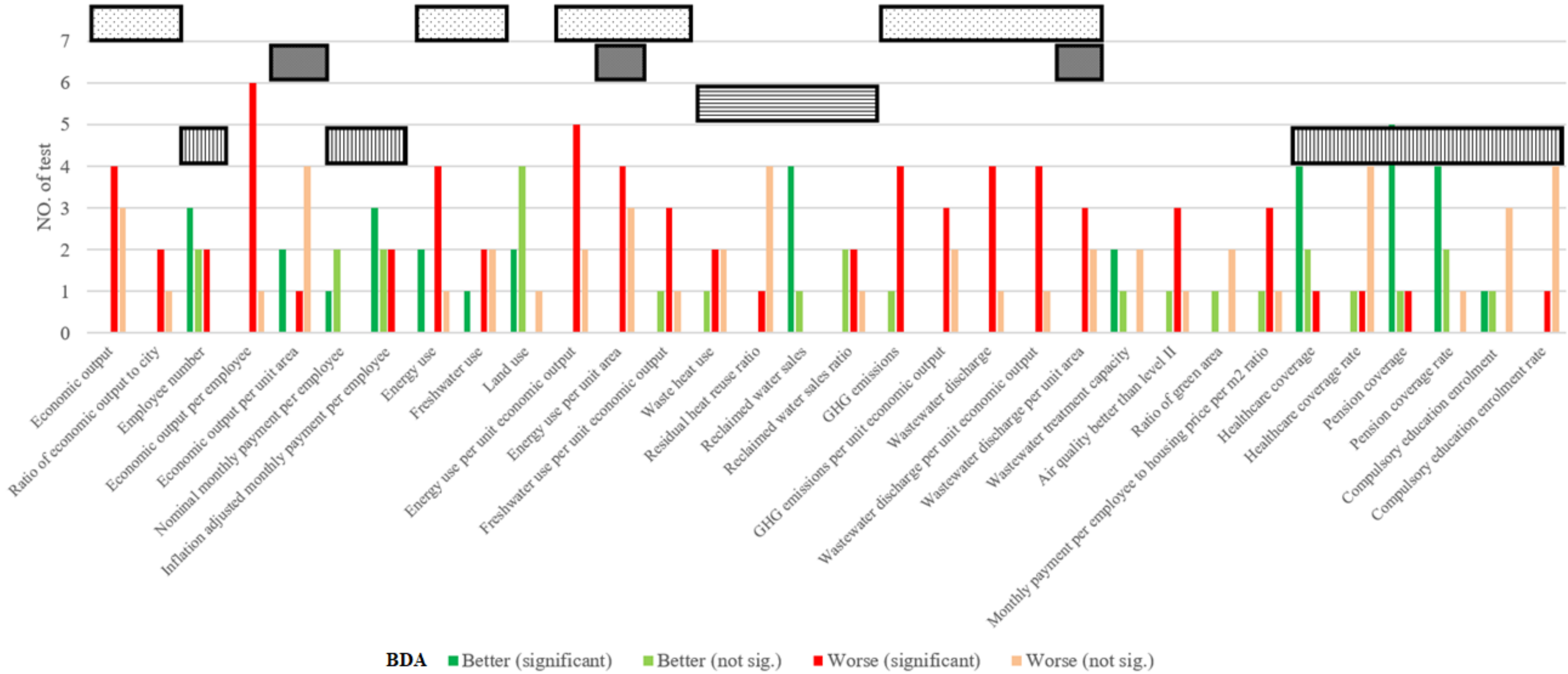
Grey means no tests performed due to data unavailability; black are the three indicators not analysed in Causal Impact analysis.

* the difference for this test on this indicator is 0, which cannot indicate improvement or degradation.

5.6.2 Factors affecting patterns

Based on the number of tests agreeing or disagreeing for a particular indicator (Section 2.4.6), four possible factors affecting the indicator patterns outlined in Section 5.2 to 5.5 are identified, namely (a) EIP economic and industrial structure, (b) EIP expansion patterns, (c) external pressure, and (d) regional and national policies. Indicators related to each of those factors are marked out in Figure 36. Below we discuss each of these factors.

Firstly, many studies have noted that an EIP's economic and industrial structure plays a major role in its performance pre- and post-upgrade (Tian et al., 2014). This is because different sub-sectors depend on different technologies and production processes, with the adoption of cleaner production and industrial symbiosis systems often having differentiated outcomes during the process of EIP upgrade and verification (Guo et al., 2015, Fan et al., 2017b). At the same time, there is a strong push and incentives for industrial parks to maintain technological and economic lead by shifting their economic structure toward higher value-addition and economic competitiveness (MEP et al., 2011, State Council, 2014). Furthermore, in an effort to reduce high dependence on natural resources and mitigate high emission and waste generation rates, many EIPs have tried to attract tertiary industry sectors. However, even though some EIPs have experienced a steady increase in the share of tertiary industry in their economic output, this change is not obvious, and could be the opposite for some EIPs (Tian et al., 2014). In TEDA the share of tertiary industry has remained relatively constant in the past decades, but in BDA it increased rapidly up to 2007, and then remained relatively constant since (Section 2.2).


NO. of test
0
1
2
3
4
5
6
7
Economic output
Ratio of economic output to city
Employee number
Economic output per employee
Economic output per unit area
Nominal monthly payment per employee
Inflation adjusted monthly payment per employee
Energy use
Freshwater use
Land use
Energy use per unit economic output
Energy use per unit area
Freshwater use per unit economic output
Waste heat use
Residual heat reuse ratio
Reclaimed water sales
Reclaimed water sales ratio
GHG emissions
GHG emissions per unit economic output
Wastewater discharge
Wastewater discharge per unit economic output
Wastewater discharge per unit area
Wastewater treatment capacity
Air quality better than level II
Ratio of green area
Monthly payment per employee to housing price per m2 ratio
Healthcare coverage
Healthcare coverage rate
Pension coverage
Pension coverage rate
Compulsory education enrolment
Compulsory education enrolment rate
BDA
Better (significant)
Better (not sig.)
Worse (significant)
Worse (not sig.)

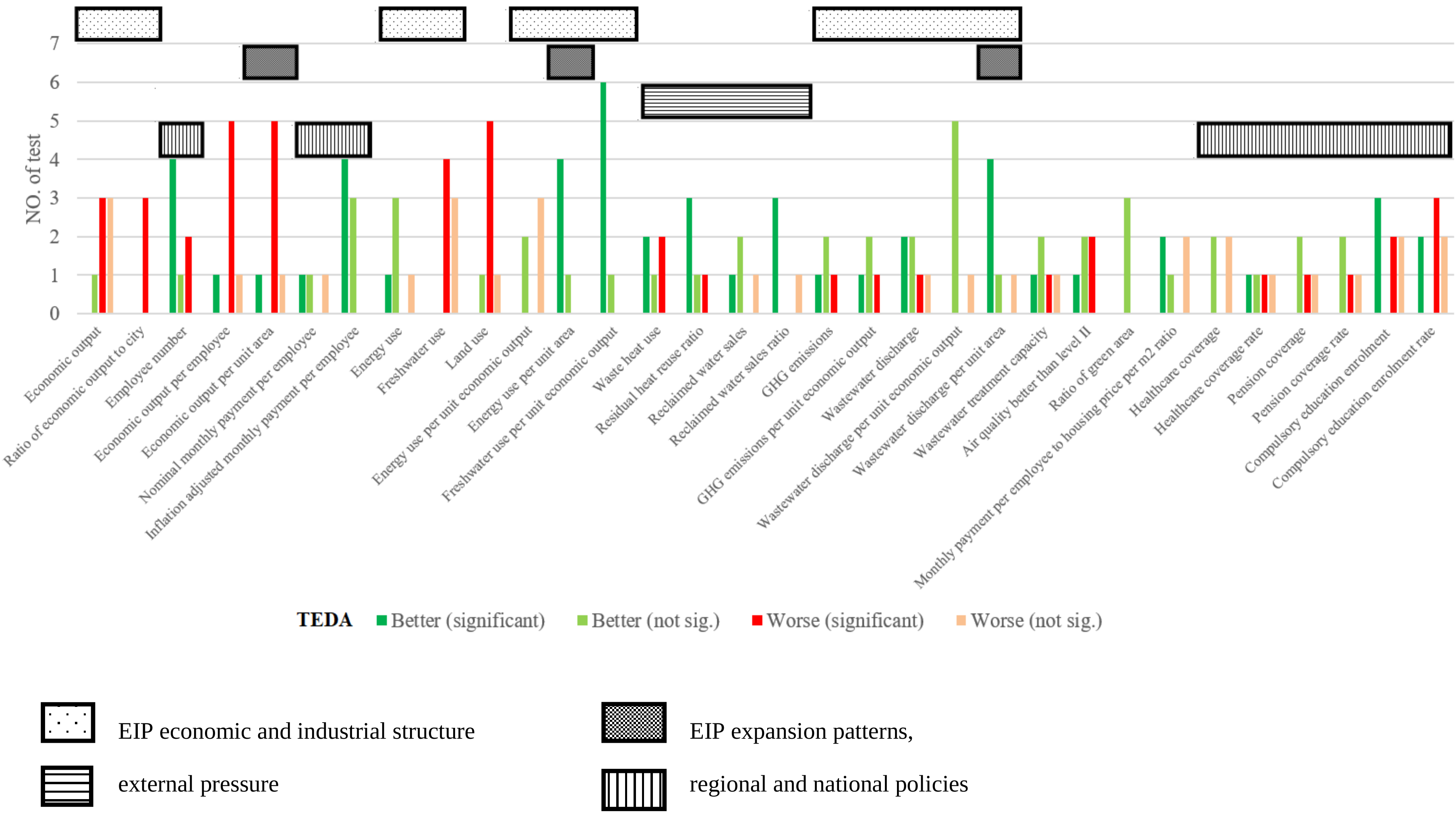


Figure 36. number of tests showing significantly and not significantly better or worse results for each indicator of BDA, and related influencing factor

Nevertheless, economic output (all tests for Causal Impact), economic output per employee (all tests for Causal Impact, Test GR and Test VE), energy use per unit economic output (Test 1A, Test 2A and all tests for ITS), energy use per unit area (Test 1A, Test 2A, Test 2B and Test GR), GHG emissions per unit economic output (all tests for ITS), and wastewater discharge indicators (Test 1B, Test 2B, Test GR and Test VE) of BDA did not show improvement in most of the tests for both methods. On the contrary, energy use per unit area (all tests for ITS), freshwater use per economic output (all tests for CI, Test GR and Test VE), and wastewater discharge per unit area (Test 2A, Test 1B, Test 2B and Test VE) of TEDA showed improvement. Therefore, higher proportion of tertiary industry does not necessarily translate into improved resource use intensity or waste generation intensity. It is possible that the substitution of industries and thus technologies does not lead to environmental improvement as much as advancement of technologies themselves for BDA, while TEDA had focused more on improving its technological efficiencies as also exemplified by Liu et al. (2015). Sectors within tertiary industry, including transportation, wholesale, retail, catering services etc. have also undergone some improvements such as cleaner fuel change, and optimisation of logistic chains. However, tertiary industry has grown rapidly in Beijing, and the fact that household activities are still less integrated into the industrial or urban symbiosis (Dong et al., 2017) has made tertiary industry's environmental impacts remain significant.

For the results of ITS, we do not observe higher ratio of economic output to economic output of city or higher economic output per employee for either EIP. It should be noted that transportation, wholesale, retail, catering services within the tertiary industry do not yield high value-addition services, and tertiary industry is still weak in competitiveness (Zhang and Evenett, 2010), while financial services tend to concentrate in city centre rather than in industrial areas (Pan et al., 2018) for Beijing, and Tianjin is facing outflows of capital (Tian and Zhou, 2010).

Secondly, the distinct expansion patterns of each EIP during its upgrading have probably affected the performance of some indicators. For example, BDA managed to maintain its economic development momentum without resorting to much expansion of land. As a result, economic output per area outperformed ZSP, but energy use and wastewater discharge intensity per area worsened at varying tests. This is probably due to the fact that Beijing is faced with limited space for development while the inflow of population had been increasing (Tan et al., 2011). This also partially explains the worsening trend of monthly payment to housing price in BDA, despite it has higher nominal monthly payment per employee in the same ITS test. ZSP was able to expand by integrating existing industrial parks into its administration.

In contrast, TEDA has a very different picture. It kept on integrating other industrial parks into its management, and reclaiming sea for use (Section 2.2.3). As a result, its economic output per area was outperformed by both BND and the city, while energy use per unit area improved for all tests in ITS, and wastewater discharge per area is better than the trend of BND and the city, and became significantly improved when 2008 is considered the effective upgrade year in ITS. TEDA was started on formerly marshland, although its population has also been increasing rapidly, the city is less constrained by its geodemographic conditions (Liu et al., 2020).

Thirdly, both EIPs have improved their use of reclaimed water to some extent, while the use of waste heat did not change much in the CI analysis. This pattern is similar for BDA in the ITS analysis, but TEDA improved both waste heat indicators and reclaimed water sales ratio in the ITS analysis. By-product recycling is a major and mandate feature of EIPs (MEP, 2015). Due to the clustering of industrial activities at BDA and TEDA, and the needs for central heating in winter, both EIPs have long been utilising residual heat. Kaituo Heating is the only provider of central heating for BDA, and has been operating this since 1996 (BDA, 2002; also refer to Kaituo Heating's homepage). It did not fully complete residual use technology implementation until 2017 (BDA, 2018). In addition, BDA (in fact whole Beijing) has not allowed heavy industry to remain since a few years before the Beijing summer Olympics in 2008, making the space for improvement more limited. Similarly, TEDA has not built new thermal plant since 2003 (refer to Supplementary material Table S4 and S7). On the other hand, both Beijing and Tianjin face severe freshwater shortage problems (Yi, 2011). BDA took actions to build and expand reclaimed water plants in 2009, 2011 and 2012. TEDA also progressed with a series of actions starting in 2001 (refer to Supplementary material Table S4 and S7), therefore, reclaimed water sales does not show significant growth, but with the improvement in wastewater discharge, its reclaimed water sales ratio also improved.

As pointed out earlier, the national guidelines have a focus on eco-efficiency when evaluating the environmental aspect of EIPs (MEP, 2015). As a developing country, China could still take advantage of the gap of consumption intensity compared to many developed countries. For example, China is not obligated to set a definite target for GHG emissions. This potentially contributes to the results that eco-efficiency indicators are mostly in par with the trend of the city the EIPs are located in, for example, energy use per economic out, freshwater use per economic output, or better than the city, for example, wastewater discharge per area of TEDA, while resource use, GHG emissions, wastewater discharge, and air quality tend to be worse than the change of the city.

Finally, regional and national policies seem to have had some effect on the performance of some indicators, as has also been suggested by other studies (Yu et al., 2015b). As integrated parts of rapidly growing cities, both BDA and TEDA with their relatively convenient location and transportation, and high job opportunities continued to attract multinational companies and multitudes of population seeking employment. In 2011, the Chinese government announced its plan to double the population's income per capita by 2021 based on the level of 2010 (Gang and He, 2013), which is the first time for the government to set a clear target for this indicator. The patterns of employee number (particularly in ITS analysis) and monthly payment per employee reflect the implementation of this national plan.

Regional and national policies are instrumental in influencing the operations of EIPs, especially the social aspect (Piatkowski et al., 2019). Big cities in China have very strict policies on who could transfer or register their household in the city. On the other hand, access to social services, such as healthcare insurance (Zhao et al., 2014b), pension (Chen and Fan, 2016), and compulsory education for school age children (Zhou and Cheung, 2017) are linked to household status. By restricting the access to local household registration, cities are able to control the movement of the population to a certain extent.

Companies might neglect to allow employees to join healthcare insurance and pension plans out of desires for saving costs, while some employees are not incentivised to participate in those social services either (Jiang and Yi, 2014). Nevertheless, New Rural Cooperative Medical System (NRCMS) was expected to have a full coverage for people with rural household status by 2010 (World Bank 2010). In 2011, the Social Insurance Law of China became effective, as a result, migrant workers, which took the majority of these two EIPs, might have better access to social insurance (Wei et al. 2014). With higher income, employees, and residents in the EIPs might be more willing to join social insurance schemes, as costs to both the employees and employers could hinder the willingness of participating in social insurance (Chen et al., 2020). As a result, we see BDA having more people with healthcare coverage in Test 1B, Test 2B, Test GR and Test VE, and pension coverage in Test 1A, Test 1B, Test 2B, Test GR and Test VE. Healthcare coverage rate and pension coverage rate (number of people with healthcare insurance and/or pension to number of employees) of BDA increased to over 100% (non-employees could join healthcare insurance and/pension locally too), showing saturation, and resulted in no difference in most ITS tests.

On the other hand, TEDA's healthcare insurance and pension coverage rates stagnated between 50% and 66% for most of the years. The rates are consistent with the situation in both cities respectively. The reasons behind might be difficult to disentangle, but it is possible that as the capital, Beijing has been implementing policies more strictly than other regions, and have been more innovative in meeting the needs of social services (Qin et al., 2014). Nevertheless, this still contradicts what Peng et al. (2010) found in their research that the majority of migrant workers did not have health insurance coverage.

Similarly, in order to control the growth of population in Beijing, the government has been trying to force migrants out the city by limiting access to education for kids whose family are not registered locally (Huang and Han, 2017). This potentially contributes to the decline in ratio of students enrolled in compulsory education at BDA (although not significant for ITS analysis). On the other hand, Tianjin is more relaxed about restricting migrants as it has faced difficulties in attracting talents human resources (Woodman, 2017). As a result, educational indicators of TEDA are better than its covariates in CI analysis especially after the upgrade to an EIP, although the trend of increasing did not last as earlier years (reflected by ITS analysis).

With a closer look at individual indicators, the social conditions of EIPs and the cities they are in could be clearly seen. The city of Beijing has grown to encompass a wide range of industries and activities, which are scattered across the city. While those activities maintain growth for the city, different functional areas in the city also compete with BDA (Pan et al., 2018). Therefore, BDA is not improving compared to other parts of the city. Furthermore, it also has to size down its provision of compulsory education as a means to control the unwanted population inflow.

On the other hand, TEDA takes a great share of the economic output of Tianjin, its position is less challenged by the rest of the city. Furthermore, Tianjin has a higher desire to attract talents for its needs of development (Woodman, 2017), and to strengthen its competition with cities surrounding it. As a result, TEDA has improved its provision of compulsory education for its population.

5.7 Summary

This chapter presents the results and discussion on CI and ITS analyses. The results show a mixed picture with more indicators worsening than improving for BDA with both methods, and TEDA with CI analysis, while TEDA has more indicators improving than degrading with ITS analysis. Based on a synthesis analysis linking existing literature, we identified four factors that potentially influence the patterns of the change of the indicators, 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.

Chapter Six

Policy Implication and Recommendation

6.1 Main findings

6.1.1 Main findings for objectives

This study aims to understand if EIP upgrade improves the sustainability of case study industrial parks in two cities in China (Section 1.5). Firstly, to answer our first objective, we conduct institutional analysis to understand the drivers, stakeholders, regulations, and guidelines pertaining to the take-off of the EIP development programme in China, and identify challenges facing it (Section 2.1). Severe environment degradations brought by rapid and unbalanced development and the desire to maintain economic competitiveness by upgrading of technology are the main drivers for the Chinese government to initiate the EIP development programme. As opposed to bottom-up approach in some developed countries, the Chinese way of implementation is top-down with a series of laws, regulations, guidelines, and standards being gradually released over the years (Section 3.2). Those documents also clarify the stakeholders including administrators and regulators and means to encourage mechanisms of funding (Section 3.3 and 3.4). We also find that national standards for EIP development have more focus on eco-efficiency indicators, while indicators to evaluate the social impacts of EIP development are not present, and rarely studied in previous research. Based on the impacts identified in the existing literature (Section 1.3) while considering data availability of case study sites, we are able to formulate an indicator framework relevant to evaluating the impacts on the sustainability of industrial parks brought by EIP upgrade (Section 2.3).

Secondly, to answer our second objective, we use MCDA to rank the sustainability performance of the case study EIPs for a series of sustainability aspects and indicators over time (Section 1.5 and 2.4.3). The results show that both EIPs have generally improved their overall sustainability with all indicators aggregated. Nevertheless, BDA’s sustainability mainly declined if only non-scale indicators are aggregated. The performance of the economic aspect generally improved for both EIPs except BDA when only non-scale indicators are analysed. In either test, the aggregated performance of the environmental aspects of BDA invariantly declined along the years. The aggregated performance of the social aspect tends to fluctuate for both EIPs. This method also finds that the overall sustainability of 2010 has been a year that is mostly worse than at least one earlier year for both EIPs, potentially linked to the economic stimulus package released in 2009, which allowed investments in less effective technologies. TEDA generally has the current weights of different sustainability aspects more distant from edges of their respective stability intervals compared to BDA, which implies more robust ranking results, and that the difference of the overall sustainability of BDA in different years is less significant (Chapter Four).

Thirdly, to answer our third objective, we utilise CI and ITS analyses to assess whether the upgrading to an EIP improves the sustainability performance of individual indicators (Section 1.5, 2.4.4 and 2.4.5). Both analyses yield varying results according to prior conditions set for each test in each method. General patterns are that more indicators worsened than improved for the majority of the tests except TEDA with CI analysis when the covariate is another industrial park in the same city and the effect of EIP upgrade is considered to be the year of verification, and TEDA with ITS analysis. For economic indicators, economic output and economic output intensity do not show clear improvement except employee number and monthly payment per employee for both EIPs. For environmental indicators, land use and reclaimed water sales are the only indicators that show signs of improvement for BDA, while energy use per unit area, freshwater use per unit economic output, reclaimed water sales indicators, and wastewater discharge per unit area of TEDA indicate improvement in various tests. Social indicators are again not consistent in different tests, but BDA seems to have better performance in healthcare and pension coverage, and TEDA has more students in compulsory education in CI analysis (Chapter Five).

6.1.2 Contribution to sustainable development

As a continued effort to reduce GHG emissions, the current president of China, Jinping Xi, announced that China would aim to achieve carbon neutrality by 2060. As the biggest emitter of GHG as of date, this step taken by China could greatly contribute to limiting the increase of global temperature by 2℃ according to Paris Agreement, while the goal of 1.5℃ is also possible. This announcement by the president also signals a determination to solve the issues related to over production of manufacturing and economic structuring within China (Tamura et al., 2020). Industrial parks play an important role in the Chinese industry and economy (Section 1.1), the endeavour to upgrade industrial parks is expected to continue in view of this newly stated ambition. Therefore, there are needs to closely evaluate and monitor the operations and impacts of industrial parks. This research also serves this purpose albeit not limited to GHG emissions.

6.2 Policy implication and recommendation

Based on the discussions of the results of the first three objectives, we are able to answer the fourth objective of this study, which is to propose recommendations on how to improve EIP development based on the major challenges identified (Section 3.5) and evaluation of the sustainability of case study EIPs (Chapter Four and Five). Recommendations are offered after , policy implications are discussed and drawn based on the findings.

Firstly, EIP upgrade does not necessarily lead to improvement of selected indicators of the framework formulated in this research. This implied that there is a lack of adherence to the existing EIP guidelines, standards, and assessment framework. Several reasons are likely to have contributed to this outcome.

As the implementation and verification of EIP practices is not legally binding, some EIPs might not have the incentive to meet those standards. This is also reflected in that many of the industrial parks approved for construction have not requested for verification after five years (Table S1 in Supplementary Material), which means they would have to restart the whole process according to the current regulations (MEP et al., 2015).

Despite challenges related to the willingness to engage in EIP processes, adopt appropriate technologies, and assume the initial costs, the EIP programme has taken off without specific financial support from government subsidies (Section 3.4). Even though many studies have recognised the needs for availability and adoption of applicable technologies (Mian et al., 2017) and financial support (Chen et al., 2017), so far market incentives have assisted the formation of industrial symbiosis. However, as the industries change within EIPs, the case study EIPs do not seem to keep up with new needs and circumstances, reflected in the fact that waste heat use did not increase much for both EIPs as BDA phased out heavy industries and TEDA has not built new thermal plant.

Therefore, the policy recommendation would be that in order to maintain and upscale the EIP programme the government should seek to further foster an enabling environment that encourages the trial and error of innovation, and facilitates capital flow and economic incentives (Wen et al., 2018).

As discussed in Sections 3.3 and 3.5, the current guidelines and standards can provide tangible tools to improve the sustainability performance of EIPs, but many sustainability impacts (especially environmental and social) are not well-reflected in the current standards and similar programmes (Zhu et al., 2015) (see Sections 1.3, 3.3, and 3.5). For instance, energy use, freshwater use, wastewater discharge, air quality and ratio of green area of BDA, and freshwater use, land use, air quality and ratio of green area of TEDA tend to degrade, reflecting a negligence of the carrying capacity of the environment (Section 5.6.2).

Therefore, the policy recommendation for this point would be for EIPs to also focus on the burdens of its operation on the environment and set appropriate targets. The government should expand the standards and associated performance indicator systems to include broader sustainability impacts, and if possible, mandate standards related to resource exploitation, environmental impacts, and social services for employees and surrounding residents.

Regional and national policies have various implications for EIP development. EIPs (and conventional industrial parks) are encouraged to grow the share of tertiary industry in their economy. Both EIPs see a growing employee population (Section 4.1) and tertiary industry output (Section 2.2), however, the integration of the communities into the existing industrial symbiosis still faces several problems (Hong and Gasparatos, 2020).

Therefore, the recommendation would be that future EIP development should also solve the issue of how to integrate more industrial sectors and activities into the industrial symbiosis of its operation. For example, encourage better municipality waste sorting to reduce the amount of waste going to landfill or incineration and for higher heat value of waste (Zhang et al., 2015), use of more clean energy in the EIPs and so on.

On the other hand, social services for the communities do not appear to catch up with the pace of the incoming employees. This could be seen from the results that BDA's compulsory education enrolment rate did not improve, and TEDA's healthcare and pension coverage rates did not grow either (Section 5.2-5.5). This might have reciprocations as to how well the employees are to participate in the continued optimisation of EIPs (UNIDO, 2014).

The recommendation would be to understand the needs of the wider region (incoming employees and surrounding communities) and how to meet those needs. Particularly, whether EIPs could be given more autonomous power to administrate its social services, and how to make sure its plans are implemented should be the focus for future improvement. Whether incoming employees are well accommodated, included, and educated would have important implications for how well EIPs could develop in the future.

Policies could also affect how efficient resources are used. Industrial lands are likely rented at a lower price by local government to attract investments. However, this is said to have resulted in lower land productivity (Huang et al., 2011a). Furthermore, supply of lands for residential and ecological purposes is limited (Liu et al., 2020). Therefore, EIPs should pursue better land use efficiency by means of price mechanism or setting productivity targets.

On a minor note, if the economic stimulus package effective in 2009 is one of the main causes for the declined sustainability of both EIPs in 2010 (Section 4.5), cautions should be taken to guard against such imprudent investment decisions in the future.

Secondly, results are sensitive to different methods and tests. One reason is that except national standards, there is no clearly defined evaluation framework, or robust methods recommended. Furthermore, although national standards require industrial parks to meet certain targets before they could be verified as EIPs (MEP, 2015), while in reality EIPs do not seem to advance in the pace as anticipated according to the standards. For example, industrial added value is expected to increase at a rate of 15% per year, which is unrealistic considering the slowing down of the Chinese economy in general.

Therefore, whereas it is imperative to have guidelines to assess EIPs' operations, recommendation would be that they should be more realistic, for example, set against a baseline, or be revised periodically as the conditions change.

Data quality is a key factor to how well the evaluation reflects the reality. However, despite the requirement to engage the public by means of publicity events and information disclosure, data availability of EIPs remains poor (MEE, 2018a). This affects what kind of evaluations could be performed, how they are performed, and how to interpret them. The scope of data disclosure of Chinese industrial parks is not possible to enable a deeper and more detailed evaluation of how product categories relate to resource use, waste generation and other aspects, while some other relevant indicators are impossible to be evaluated either.

Therefore, in order to assess the outcomes of EIP development, and provide constructive advice for its prospects, the recommendation would be that data disclosure should be better implemented for public engagement and research purposes.

Lastly, ongoing monitoring does not seem to be strict enough, which gives EIPs and to-be-EIPs the space to avoid complying with some standards. The government has carried out a re-examination of the verified EIPs since 2017 (MEE, 2019), but the details and implications of the results have not been properly articulated.

The recommendation proposed is that the government should better implement and monitor the EIP verification and operation process, possibly developing appropriate mechanisms to penalise non-compliance or underperformance, with differing degrees of severity based on the motives and outcomes. Furthermore, the government and other stakeholders should increase the awareness of the key stakeholders, particularly that of investors, who could potentially incentivise EIPs to improve their performance and better comply with relevant requirements.

6.3 Implication for future research

This study identifies four major research and practice gaps that need to be filled in the future. Firstly, knowledge should be generated for EIP impacts that have received less attention, such as social impacts and impact on ecosystem services and biodiversity (Figure 3, Geng and Côté, 2004), which have not been considered in national standards (Huang et al., 2019). In addition, more relevant indicators could be devised to assess certain aspects of the sustainability of EIPs, for example, medical costs spent by employees to evaluate the change of working environment of EIPs (Lee, 2019). A better understanding of these impacts, and the mechanisms through which they manifest, would be necessary to understand the actual sustainability outcomes of EIP development and operation in China.

Secondly, and linked to the previous point, more future studies should follow direct approaches to EIP impact assessment. Figure 3 suggests that many impact studies either use simulation and modelling, or proxy measures to assess the impacts of EIPs (see also Table S2, Supplementary Material). For example, estimating changes in air pollutant emissions (usually quantified through models and simulations) offers proxy indications of ambient air pollution, but studies assessing air quality changes around EIPs would offer more direct impact indications. Establishing causality between EIP processes and sustainability impacts is rather complicated as multiple phenomena might affect certain impact domains but can offer better reflections of the real sustainability outcomes of EIPs.

Thirdly, EIPs interact with other socioeconomic and ecological systems dynamically. The factors influencing EIPs' operation and performance could be well hidden under the surface. While EIPs in China do not disclose detailed activities, the reporting scopes are often not consistent, and the scale too big for accurate evaluation, it is desirable to create a more complete or representative description of activities, for example household participation in industrial symbiosis, and measure of input and output (e.g. similar to a basket of product output) as a means of capturing the complexities of EIP operations. This could potentially be achieved by Stakeholder Value Network analysis, Life Cycle Assessment and other methods.

Last but not least, there is a need to develop comprehensive assessment and evaluation frameworks for EIP performance. Methodologically and thematically there are still major gaps in current performance assessment and evaluation frameworks as many sustainability impacts, especially social and environmental, are often missing. Future research efforts should seek to develop indicators for these non-represented impacts and integrate them meaningfully in comprehensive performance frameworks. Subsequently, such comprehensive frameworks should be applied to establish under which circumstances EIPs are more likely to be successful (van Beers et al., 2019), and how to maintain their stability in the face of changing economic and industrial structures (Wang et al., 2018). Institutionally, as already discussed in Sections 1.2, there are a few concurrent programmes of the Chinese government with similar aims to upgrade conventional industrial parks. These programmes are administrated through different ministries and commissions, which might have aligning or conflicting interests (Piatkowski et al., 2019). In this sense, any effort to develop truly comprehensive and universal frameworks for EIP performance assessment and evaluation should keep in mind these different aspects in order to enhance inputs from different stakeholders and avoid catering to specific vested interests.

6.4 Reflection on the concept of sustainability

Based on the findings, the relation between the aforementioned concept of sustainability (Section 2.1) and this research could be further explained. For holistic treatment, this research looks at the development of EIP and its impacts from various aspects, and within each aspects several indicators were identified, for examples, within environmental aspect, resource use, resource use intensity, waste generation/Greenhouse Gas emissions, and environmental quality are reflected by selected indicators.

The guidelines issued by the government, and the majority of earlier research on the evaluation of EIP impacts have a similar approach to understanding sustainability. For instance, the governmental guidelines also have categories covering economic development, environmental aspects, and information disclosure. However, social impacts to some extent have been neglected. This research also attempts to understand this aspect taking into account the employees and residents in the case study EIPs.

For trans-boundary thinking, this research recognises that many factors work collectively to shape EIPs' development. For instance, national policies have implications for the employment environment of the EIPs. Foreign investment has been important in helping the development of industrial parks in China (Global Times, 2020; Zeng, 2016). Better management of the industrial parks, for example, being certified with ISO 14001 standards, is a means to attract foreign investment (Geng & Zhao, 2009). There are also cases where EIPs are the specific targets of foreign investment (ADB, 2019).

Reference:

Akoglu, H. 2018. User's guide to correlation coefficients. *Turkish Journal of Emergency Medicine*, 18(3), 91–93. https://doi.org/10.1016/j.tjem.2018.08.001

Asian Development Bank. 2019. ADB Expands Circular Economy with SUS's Low Carbon Eco-Industrial Parks in People's Republic of China. Retrieved from https://www.adb.org/news/adb-expands-circular-economy-sus-s-low-carbon-eco-industrial-parks-people-s-republic-china Accessed on 1st October 2020.

Bai, L., Qiao, Q., Yao, Y., Guo, J. & Xie, M. 2014. Insights on the development progress of National Demonstration eco-industrial parks in China. *Journal of Cleaner Production,* 70, 4-14.

BDA. 2002. Measures on Central Heating of Beijing Economic and Technological Development Area (trial). Retrieved from: http://kfqgw.beijing.gov.cn/zwgk/zfxxgk/zfxxgkpt/fdzdgknr/jzyj/gfxwj/202001/t20200117_1617122.html (in Chinese). Accessed 25th July 2020.

BDA. 2018. Working report of BDA in 2017. Retrieved from http://kfqgw.beijing.gov.cn/zwgk/ghjh/zfgzbg/201811/t20181114_83820.html Accessed 27th July 2020.

Bellantuono, N., Carbonara, N., Pontrandolfo, P. 2017. The organisation of eco-industrial parks and their sustainable practices. *Journal of Cleaner Production,* 161, 362-375.

Bernal, J., Soumerai, S., Gasparrini, A. 2018. A Methodological Framework for Model Selection in Interrupted Time Series Studies. *Journal of Clinical Epidemiology*, 103, 82-91.

Brans, J. P., & P. Vincke. 1985. A Preference Ranking Organization Method: The PROMETHEE Method for MCDM. *Management Science*, 31 (6): 647–656.

Brodersen, K.H., Gallusser, F., Koehler, J., Remy, N. & Scott, S.L. 2015. Inferring causal impact using Bayesian structural time-series models. *Annals of Applied Statistics*, 9(1), 247-274.

Cai, X., Zhang, Q. & Wang, Q. 2007. Study on the paradox, reason and its solution of eco-industry park. *Science and Technology Progress and Policy*, 24 (3), 41-45 (in Chinese).

CBJ (China Business Journal), Jiazhen ZHANG, published on 19th January 2013. Up to 90% vacancy rate, tens of thousands of hectare of industrial lands in Wuhan trapped in "Empty City Crisis". Retrieved from: http://www.cb.com.cn/economy/2013_0119/441988.html (in Chinese). Access 3rd September 2019.

CBJ (China Business Journal), Weilai LI, published on 25th December 2016. Investigation on the industrial development of Langfang Longhe Hi-tech Industrial Park: selling villas at an innovative park. Retrieved from: http://www.cb.com.cn/difangjingji/2016_1225/1174718.html (in Chinese). Accessed 11th January 2019.

Chen, C., & Fan, C. 2016. China's Hukou Puzzle: Why Don't Rural Migrants Want Urban Hukou? *China Review*, *16* (3), 9-39. Retrieved from www.jstor.org/stable/43974667

Chen, S., Chen, Y., Feng, Z., Chen, X., Wang, Z., Zhu, J., Jin, J., Yao, Q., Xiang, L., Yao, L., Sun, J., Zhao, L., Fung, H., Wong, E.L., Dong, D. 2020. Barriers of effective health insurance coverage for rural-to-urban migrant workers in China: a systematic review and policy gap analysis. *BMC Public Health*, 20, 408. https://doi.org/10.1186/s12889-020-8448-8

Chen, W. & Ma, Y. 2008. Discussion on the evaluation indice system of eco-industrial parks' cyclical economics. *Chinese Consulting Engineers*, Issue 10 (Total 98), 11-14 (in Chinese).

Chen, X. & Meyer, A. K. 2011. Management Models of Industrial Parks in China - Overview of the current situation and draft concept for an international forum. GIZ. Retrieved from: https://www.sia-toolbox.net/sites/default/files/11-06-22_management_models_industrial_parks_china.pdf Accessed 29th September 2019.

Chertow M. 2000. Industrial Symbiosis: Literature and Taxonomy. *Annual Review of Energy and the Environment*, 25, 313–337.

Chien, S.-S. 2006. *Policy innovation, asymmetric decentralisation and local economic development in post-Mao China -- Case studies of China-Singapore Suzhou Industrial Park and Kunshan Economic and Technological Development Zone*. PhD thesis, London School of Economics and Political Science, United Kingdom.

Childress, L., published on 8th December 2017. Lessons from China's industrial symbiosis leadership. Retrieved from: https://www.greenbiz.com/article/lessons-chinas-industrial-symbiosis-leadership Accessed 9th December 2019.

China5e. 2017, published on 22nd November 2017. News investigation: Ways of operation of Gas Turbine Power Plants. Retrieved from https://www.china5e.com/news/news-1010953-1.html Accessed 7th June 2020.

China Daily, published on 15th November 2017. Zhongguancun Science Park. Retrieved from http://govt.chinadaily.com.cn/s/201711/15/WS5b77f3be498e855160e89aa1/zhongguancun-science-park.html Accessed on 1st November 2020.

CMMA (China Machinery Marketing Academy), published on 11th January 2019. Understanding the current situation of EIP development and its challenges. Retrieved from: http://www.reportway.org/hangyexinwen/1101201922128.html (in Chinese). Accessed 10th December 2019.

Dechema, e. V. Industrial park profiles in China, AchemAsia. 2007. 7th International Exhibition-Congress on Chemical Engineering and Biotechnology, Trend Report No. 5. Retrieved from: http://dechema.de/dechema_media/tb05_industrial_park_profiles_in_China-p-1033.pdf Accessed 23rd November 2017.

Dennis Wei, Y.H., Lu, Y., & Chen, W. 2009. Globalising Regional Development in Sunan, China: Does Suzhou Industrial Park Fit a Neo-Marshallian District Model? *Regional Studies*, 43(3), 409-427.

Dong, L., Fujita, T., Dai, M., Geng, Y., Ren, J., Fujii, M., Wang, Y. & Ohnishi, S. 2016. Towards preventative eco-industrial development: an industrial and urban symbiosis case in one typical industrial city in China. *Journal of Cleaner Production,* 114, 387-400.

Dong, L., Liang, H. W., Zhang, L. G., Liu, Z. W., Gao, Z. Q. & Hu, M. M. 2017. Highlighting regional eco-industrial development: Life cycle benefits of an urban industrial symbiosis and implications in China. *Ecological Modelling*, 361, 164-176.

EICC (Electronic Industry Citizenship Coalition), 2016. Assessing and reducing F-GHGs in the electronics supply chan. Retrieved from www.responsiblebusiness.org/media/docs/publications/EICC_F-GHG_Report_2016.pdf Accessed 22nd May 2020.

Elabras Veiga, L.B. & Magrini, A. 2009. Eco-industrial park development in Rio de Janeiro, Brazil: a tool for sustainable development. *Journal of Cleaner Production,* 17(7), 653-661.

EPA. 2007. Guideline for the Establishment of Eco-Industrial Parks Planning. Retrieved from: http://kjs.mee.gov.cn/hjbhbz/bzwb/other/qt/200712/W020111214545788755131.pdf (in Chinese). Accessed 18th July 2017.

EPA, MOFCOM, MOST. 2007, Administrative Measures on National Demonstrative Eco-Industrial Parks (Trial). Retrieved from: http://www.mee.gov.cn/gkml/zj/wj/200910/t20091022_172490.htm (in Chinese). Accessed 16th March 2020.

Fan, Y., Bai, B., Qiao, Q., Kang, P., Zhang Y. & Guo, J. 2017b. Study on eco-efficiency of industrial parks in China based on data envelopment analysis. *Journal of Environmental Management,* 192, 107-115.

Fan, Y., Qiao, Q., Fang, L. & Yao, Y. 2017c. Emergy analysis on industrial symbiosis of an industrial park – A case study of Hefei economic and technological development area. *Journal of Cleaner Production*, 141, 791-798.

Fang, D.L., Chen, B., Hayat, T. & Alsaedi, A. 2017. Emergy evaluation for a low-carbon industrial park. *Journal of Cleaner Production*, 163, S392-S400.

Fang, Y., Côté, R.P. & Qin, R. 2007. Industrial sustainability in China: Practice and prospects for eco-industrial development. *Journal of Environmental Management*, 83(3), 315-328.

Food and Agriculture Organisation of the United Nations. 2010. China National Biodiversity Conservation Strategy and Action Plan (2011-2030). Retrieved from http://www.fao.org/faolex/results/details/en/c/LEX-FAOC163531/ Accessed 1st September 2020.

Gang, F. & He, L. 2013. China's 12th Five-Year Plan. Krane Shares. Available at: https://kraneshares.com/resources/2013_10_kfyp_fan_gang_white_paper.pdf Accessed in May 2020.

Gao, Y., Audit Bureau of Huangdao District, Qingdao City, pubslehd on 5th June 2013. Research on the existing problems and solutions of environment outcome audit in China, retrived from http://www.audit.gov.cn/n6/n41/c21059/content.html (in Chinese). Accessed 29th July 2019.

Geng, Y. & Côté, R. 2003. Environmental Management Systems at the Industrial Park Level in China. *Environmental Management*, 31(6), 784-794.

Geng, Y., Fu, J., Sarkis, J. & Xue, B. 2012. Towards a national circular economy indicator system in China: an evaluation and critical analysis. *Journal of Cleaner Production*, 23(1), 216-224.

Geng, Y., Haight, M. & Zhu, Q. 2006. Empirical analysis of eco-industrial development in China. *Sustainable Development*, 15(2), 121-133.

Geng, Y., Liu, Z., Xue, B., Dong, H., Fujita, T. & Chiu, A. 2014. Emergy-based assessment on industrial symbiosis: a case of Shenyang Economic and Technological Development Zone. *Environmental Science and Pollution Research*, 21, 13572-13587.

Geng, Y., Zhang, P., Côté, R. P. & Fujita, T. 2009. Assessment of the National Eco-Industrial Park Standard for Promoting Industrial Symbiosis in China. *Journal of Industrial Ecology*, 13, 15-26.

Geng, Y., Zhang, P., Côté, R. & Qi, Y. 2008. Evaluating the applicability of the Chinese eco-industrial park standard in two industrial zones. *International Journal of Sustainable Development & World Ecology*, 15, 543-552.

Geng, Y. and Zhao, H. 2009. Industrial park management in the Chinese environment. *Journal of Cleaner Production*, 17, 14, 1289-1294.

Global Times, published on 15th October 2020. China-foreign cooperative parks a key for economic success. Retrieved from https://www.globaltimes.cn/content/1203629.shtml Accessed on 22nd October 2020.

Gu, H. 2016. NIMBYism in China: Issues and prospects of public participation in facility siting. *Land Use Policy*, 52, 527-534.

Gu, Y., Wong, T.W., Law, C.K., Dong, G.H., Ho, K.F., Yang, Y. & Yim, S.H.L. 2018. Impacts of sectoral emissions in China and the implications: air quality, public health, crop production, and economic costs. *Environmeantal Research Letters*, 13(8), 084008, 1-13.

Guo, J., Qiao, Q. & Sun, Q. H. 2015. Analysis of green development, circular development, low□carbon development and practices in industrial parks. *Journal of Environmental Engineer*, 5 (6): 531-538 (in Chinese).

Guo L., Malesu, L. & Hu, X. 2008. The Paradox of Industrial Symbiosis and Technology Innovation: the Discussion on Efficiency Improvement of Chinese Eco-Industrial Parks. *Science of Science and Management of Science of Technology*, 58-63 (in Chinese).

GWI (Global Water Intelligence). 2007. GWI market access: desalination in China. Retrieved from https://edhec.infrastructure.institute/wp-content/uploads/publications/blanc-brude_2007c.pdf Accessed 25th August 2020.

Han, F., Yu, F. & Cui, Z. 2016. Industrial metabolism of copper and sulfur in a copper-specific eco-industrial park in China. *Journal of Cleaner Production*, 133, 459-466.

Heeres, R. R., Vermeulen, W. J. V. & de Walle, F. B. 2004, Eco-industrial park initiatives in the USA and the Netherlands: first lessons. *Journal of Cleaner Production*, 12, 985-995.

Hindriks, F. & Guala, F. 2015. Institutions, rules, and equilibria: a unified theory. *Journal of Institutional Economics*, 11(3), 459-480.

Hodgson, G.M. 2006. What Are Institutions? *Journal of Economic Issues*, 40(1), 1-25.

Honaker, J. & King, G. 2010. What to do About Missing Values in Time Series Cross-Section Data. *American Journal of Political Science*, 54, 3, 561-581.

Honaker, J., King, G. & Blackwell, M. 2012. AMELIA II: A Program for Missing Data, p. 38. Retrieved from https://r.iq.harvard.edu/docs/amelia/amelia.pdf Accessed in April 2019.

Hong, H. & Gasparatos, A. 2020. Eco-industrial parks in China: Key institutional aspects, sustainability impacts, and implementation challenges. *Journal of Cleaner Production*, 274, 122853. https://doi.org/10.1016/j.jclepro.2020.122853

Hsu, A., de Sherbinin, A. & Shi, H. 2012. Seeking truth from facts: The challenge of environmental indicator development in China. *Environmental Development* 3, 39-51.

Hua, S., Wang, J. & Zhu, Y. 2013. Cause Analysis and Countermeasures of Beijing city Congestion. *Procedia - Social and Behavioral Sciences 96*, 1426 – 1432.

Huang, B., Yong, G., Zhao, J., Domenech, T., Liu, Z., Chiu, S.F., McDowall, W., Bleischwitz, R., Liu, J. & Yao, Y. 2019. Review of the development of China's Eco-industrial Park standard system. *Resources, Conservation and Recycling*, 140, 137-144.

Huang, D., Wan, W., Dai, T. & Liang, J. 2011a. Assessment of industrial land use intensity: A case study of Beijing economic-technological development area. *Chinese Geographical Science*, 21(2), 222-229.

Huang, K., Chen, S., Zhou, Z. & Qi, X. 2004. A study on the comprehensive assessment of eco-industrial parks 69. *Science Research Management*, 25 (6), 92–95 (in Chinese).

Huang, P., Bai, C. & Wu, Z. 2009. Improvement of auditing for environmental performance by applying contingent valuation method: a case study of inland waterway pollution control. *Ecological Economy*, 02, 47-50 (in Chinese).

Huang, Z. & Han, W. 2017, Schools for Migrant Children Vanishing as Beijing Combats Population Growth. Caixin. Retrieved from: https://www.caixinglobal.com/2017-08-21/schools-for-migrant-children-vanishing-as-beijing-combats-population-growth-101132981.html Accessed 26th July 2020.

Hyde, K., Maier, H. & Colby, C. 2003. Incorporating uncertainty in the PROMETHEE MCDA method. *Journal of Multi-Criteria Decision Analysis*, 12, 245-259.

IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Volume 3, Chapter 6, 6.1-6.32. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_6_Ch6_Electronics_Industry.pdf Accessed 20th June 2020.

IPCC. 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/05/ar4_wg1_full_report-1.pdf Accessed 24th May 2020.

Ivanovski, Z., Milenkovski, A. & Narasanov, Z. 2018. Time Series Forecasting Using a Moving Average Model for Extrapolation of Number of Tourist. *UTMS Journal of Economics*, 9 (2), 121-132.

Jiang, Y. & Yi, F. 2014. Discussion on solutions to incentivise rural migrant workers to join urban healthcare insurance. Economic Science, 5, 79-89.

Jiaozuo Daily, published on 6th August 2012. Decoding the secrets of the rapid development of Jiaozuo West Industrial Cluster, http://www.henan.gov.cn/10ztzl/system/2012/08/06/010324283.shtml (in Chinese). Accessed 8th Augst 2019.

Jung, H.S. & Chen, J.L. 2019. Causes, Consequences and Impact of the Great Leap Forward in China. *Asian Culture and History*, 11, 2, 58-65.

Kor, Y. Y. 2006. Direct and interaction effects of top management team and board compositions on R&D investment strategy. *Strategic Management Journal,* 27, 1081-1099.

LBNL (Lawrence Berkeley National Laboratory). 2012. Key China Energy Statistics. Retrieved from https://china.lbl.gov/sites/all/files/key-china-energy-statistics-2012-june-2012.pdf Accessed 17th May 2020.

Leblanc, R., Tranchant, C., Gagnon, Y. & Côté, R. 2016. Potential for eco-industrial park development in Moncton, New Brunswick (Canada): a comparative analysis. *Sustainability*, 8(5), 472, 1-18.

Lee, Young. 2019. Workplace Health and Its Impact on Human Capital: Seven Key Performance Indicators of Workplace Health. Chapters, in: Orhan Korhan (ed.), Indoor Environment and Health, IntechOpen. DOI: 10.5772/intechopen.85936

Li, H., Wei, Y. D. & Zhou, Y. 2017a. Spatiotemporal analysis of land development in transitional China. *Habitat International,* 67, 79-95.

Li, K. 2004. The legal background, current status, and future plan for the Environmental Protection Law. Collection of Thesis of the Research Institute of Environmental Law, Wuhan Univ., Hubei, China. Retrieved from: http://aff.whu.edu.cn/riel/article.asp?id=26318 (in Chinese). Accessed 19th March 2020.

Li, W., & Lin, W. 2016, 'Circular Economy Policies in China', in Anbumozhi, V. and J. Kim (eds.), Towards a Circular Economy: Corporate Management and Policy Pathways. ERIA Research Project

Report 2014-44, Jakarta: ERIA, 95-111. Retrieved from: http://www.eria.org/RPR_FY2014_No.44_Chapter_7.pdf Accessed 18th October 2019.

Li, Y. & Bao, C. 2017. Environmental protection could harmoniously co-exist with economic development. China Environment News. Published on 27th September 2017. Retrieved from https://www.cenews.com.cn/opinion/201709/t20170927_852961.html Accessed 31st August 2020.

Li, Z.D., Zhang, S.S., Zhang, Y. & Wei, L. 2011. Evaluation of cleaner production audit in pharmaceutical production industry: case study of the pharmaceutical plant in Dalian, P. R. China. *Clean Technologies and Environmental Policy*, 13(1), 195-206.

Liang, C.-S., Duan, F.-K., He, K.-B. & Ma, Y.-L. 2016. Review on recent progress in observations, source identifications and countermeasures of PM2.5. *Environment International,* 86, 150-170.

Lin, Y., Liu, Z., Liu, R., Yu, X. & Zhang, L. 2019. Uncovering driving forces of co-benefits achieved by eco-industrial development strategies at the scale of industrial park. *Energy & Environment,* 31 (2), 275-290.

Lin, Y. J., Zhang, Z., Wu, F. & Deng, N. S. 2004. Development of Ecological Industrial Parks in China. *Fresenius Environmental Bulletin,* 13, 600-606.

Liu, C. & Côté, R. 2017. A Framework for Integrating Ecosystem Services into China's Circular Economy: The Case of Eco-Industrial Parks. *Sustainability,* 9.

Liu, C., Zhang H. & Huang, W. 2014a. External environment of resources and environment audit: structure, impact and optimisation. *Auditing Research,* 3, 38-42 (in Chinese).

Liu, H., Liu, J., Yang, W., Chen, J., & Zhu, M. 2020. Analysis and Prediction of Land Use in Beijing-Tianjin-Hebei Region: A Study Based on the Improved Convolutional Neural Network Model. *Sustainability,* 12, 7: 3002.

Liu, J. & Diamond, J. 2005. China's environment in a globalizing world. *Nature*, 435, 1179-1186.

Liu, J., Li, J., Vonwiller, M., Liu, D., Cheng, H., Shen, K., Salazar, G., Agrios, K., Zhang, Y., He, Q., Ding, X., Zhong, G., Wang, X., Szidat, S. & Zhang, G. 2016a. The importance of non-fossil sources in carbonaceous aerosols in a megacity of central China during the 2013 winter haze episode: A source apportionment constrained by radiocarbon and organic tracers. *Atmospheric Environment,* 144, 60-68.

Liu, W., Tian, J. & Chen, L. 2014b. Greenhouse gas emissions in China's eco-industrial parks: a case study of the Beijing Economic Technological Development Area. *Journal of Cleaner Production*, 66, 384-391.

Liu, W., Tian, J., Chen, L., Lu, W. & Gao, Y. 2015. Environmental Performance Analysis of Eco-Industrial Parks in China: A Data Envelopment Analysis Approach. *Journal of Industrial Ecology*, 19(6), 1070-1081.

Liu, W., Zhan, J., Li, Z., Jia, S., Zhang, F. & Li, Y. 2018a. Eco-Efficiency Evaluation of Regional Circular Economy: A Case Study in Zengcheng, Guangzhou. *Sustainability*, 10(2), 453, 1-16.

Liu, Z., Adams, M., Cote, R. P., Geng, Y., Ren, J., Chen, Q., Liu, W. & Zhu, X. 2017b. Co-benefits accounting for the implementation of eco-industrial development strategies in the scale of industrial park based on emergy analysis. *Renewable and Sustainable Energy Reviews*, 81(1), 1522-1529.

Liu, Z., Adams, M., Wen, Z., Massard, G. & Dong, H. 2019. Review of eco-industrial development around the globe: Recent progress and continuing challenges. *Resources, Conservaton and Recycling*, 143, 111-113.

Liu, Z., Zheng, B., Zhang, Q. & Guan, D. New dynamics of energy use and CO_2 emissions in China. *Nature*. Submitted.

Lopez Bernal, J., Cummins, S. & Gasparrini, A. 2017. Interrupted time series regression for the evaluation of public health interventions: A tutorial. *International Journal of Epidemiology*, 46(1), 348-355.

Lowe, E. A. 2001. A Handbook for Eco-Industrial Parks in Asia Developing Countries. A Report to Asian Development Bank, available at http://www.Indigodev.com/ADBHBdownloads.html

Luo, J., Zhang, X., Wu, Y., Shen, J., Shen, L. & Xing, X. 2018. Urban land expansion and the floating population in China: For production or for living? *Cities*, 74, 219-228.

Mathews, J. A. & Tan, H. 2011. Progress Toward a Circular Economy in China. *Journal of Industrial Ecology*, 15, 435-457.

MEE. 2017. Notice on the release of the results of the re-examination of national demonstrative EIPs. Retrieved from https://www.mee.gov.cn/gkml/hbb/bgth/201702/t20170228_397912.htm (in Chinese). Accessed on 22nd October 2020.

MEE. 2018a. Notice on announcement of the outcomes of Re-examination and evaluation of national demonstrative EIPs. Retrieved from http://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/201907/t20190704_708598.html (in Chinese). Accessed 16th March 2020.

MEE. 2018b. Notice on the release of the results of the re-examination of national demonstrative EIPs in 2017. Retrieved from http://www.mee.gov.cn/gkml/hbb/bgth/201801/t20180130_430563.htm (in Chinese). Accessed on 22nd October 2020.

MEE. 2019. Notice on Announcement of the Outcomes of Re-examination and Evaluation of National Demonstrative EIPs, 2018. Retrieved from: http://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/201907/t20190704_708598.html (in Chinese). Accessed 16th March 2020.

Meng, W., Li, H., Wang, X., Li, S. & Wu, X. 2010. Wetland Degradation Status and Restoration Models in Binhai New Area of Tianjin. *Research of Soil and Water Conservation*, 17, 3, 144-147 (in Chinese).

MEP. 2015. Standard for national demonstration eco-industrial parks (HJ 274-2015). Retrieved from http://bz.mep.gov.cn/bzwb/other/qt/201512/W020151229415317224209.pdf (in Chinese). Accessed 1st May 2017.

MEP. 2016. Administrative Sanction Decision (Qingdao Xintiandi Solid Waste Treatment Company). Retrieved from: http://www.mee.gov.cn/gkml/sthjbgw/qt/201612/t20161219_369248.htm (in Chinese). and Notice on Revocation of NDEIP Status of Qingdao Xintiandi Venous Industrial Park. Retrieved from: http://www.mee.gov.cn/gkml/hbb/bgth/201612/t20161212_368966.htm (in Chinese). Accessed 16th March 2020.

MEP, MOFCOM & MOST. 2011. Instructions on Strengthening the Development of National Demonstration Eco-Industrial Parks. Retrieved from: http://www.mee.gov.cn/gkml/hbb/bwj/201112/t20111208_221112.htm (in Chinese). Accessed 16th March 2020.

MEP, MOST & MOFCOM. 2015. Administrative Measures on National Demonstrative Eco-Industrial Parks. Retrieved from: http://www.mee.gov.cn/gkml/hbb/bwj/201512/t20151224_320098.htm (in Chinese). Accessed 16th March 2020.

MIIT. 2016. Requirement for the Evaluation of Green Industrial Parks, under the Notice on the Establishment of a Green Manufacturing System. Retrieved from: http://www.miit.gov.cn/n1146285/n1146352/n3054355/n3057542/n3057544/c5258400/content.html (in Chinese). Accessed 16th March 2020.

MIIT & NDRC. 2013. Notice on the work of organising and implementing Pilo Low Carbon Industrial Parks. Retrieved from http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757016/c3762117/content.html (in Chinese). Accessed 27th August 2020.

Mino, T. & Kudo, S. 2020. Framing in Sustainability Science-Theoretical and Practical Approaches. Science for Sustainable Societies, Springer, Singapore. Available at: https://link.springer.com/book/10.1007%2F978-981-13-9061-6

MOE (Ministry of the Environment of Japan). 2018. Report on China-Japan-Korea Tripartite Environmental Cooperation and its Outlook. Retrieved from https://www.env.go.jp/earth/coop/temm/archive/pdf/report_tripartitecooperation_E.pdf Accessed 1st September 2020.

MOFCOM. 2018. Results of the examination and evaluation of the general development level of national economic and technological development areas in 2018. Retrieved from http://www.mofcom.gov.cn/article/ae/ai/201812/20181202821904.shtml (in Chinese). Accessed on 22nd October 2020.

MOFCOM. 2019. New release on the Results of the examination and evaluation of the general development level of national economic and technological development areas by MOFCOM in 2019. Retrieved from www.mofcom.gov.cn//xwfbh//202001172.shtml (in Chinese). Accessed on 22nd October 2020.

MOST. 2017. MOST General Office Issues Guideline of Application for National Sustainable Development Agenda Demonstrative Innovative Zones. Retrieved from http://www.safea.gov.cn/kjbgz/201704/t20170427_132558.htm (in Chinese). Accessed 29th April 2017.

NBSC (National Bureau of Statistics of China). 2011. National Bureau of Statistics of China announces the adjustment of the baseline for industrial and investment census. Retrieved from http://www.gov.cn/gzdt/2011-03/08/content_1820277.htm (in Chinese) Accessed June 2020.

NDRC, EPA, MOST, MOF, MOFCOM & BOS. 2005. Notice on the work of organising and implementing Pilo Circular Economy (1st Batch). Retrieved from https://www.ndrc.gov.cn/fggz/hjyzy/fzxhjj/200510/t20051031_1203265.html (in Chinese). Accessed 27th August 2020.

NDRC & MOF. 2017. Notice on the End-of-term Evaluation and Capital Settlement of the National Demonstration Industrial Parks of Circular Economy Upgrade and Urban Mining Demonstration Pilots. Retrieved from: https://www.ndrc.gov.cn/xxgk/zcfb/tz/201702/t20170216_962904.html (in Chinese). Accessed 16th March 2020.

Ni, C. 2007. China's Natural Gas Industry and Gas to Power Generation. The Institute of Energy Economics, Japan. Retrieved from https://eneken.ieej.or.jp/en/data/pdf/397.pdf Accessed 7th June 2020.

OECD. 2008. Handbook on constructing composite indicators: methodology and user guide. Retrieved from https://www.oecd.org/sdd/42495745.pdf Accessed 19th July 2016.

Onoye, E. 1982. Readjustment and reform in the Chinese economy: a comparison of the post-Mao and post-Great Leap Forward periods. *The Developing Economies*, 20: 359-373. doi:10.1111/j.1746-1049.1982.tb00447.x

Ortiz, G., Domínguez-Gómez, J.A., Aledo, A. & Urgeghe, A.M. 2018. Participatory multi-criteria decision analysis for prioritizing impacts in environmental and social impact assessments. *Sustainability: Science, Practice and Policy*, 14(1), 6-21.

Pan, F., Hall, S. & Zhang, H. 2018. The geographies of financial activities within an emerging international financial center: the case of Beijing. Fingeo, Financial Geography Working Paper #10. Retrieved from http://www.fingeo.net/wordpress/wp-content/uploads/2018/01/WP10_The-geographies-of-financial-activities_IFC-Beijing.pdf Accessed 30th August 2020.

Pan, H., Zhang, X., Wang, Y., Qi, Y., Wu, J., Lin, L., Peng, H., Qi, H., Yu, X. & Zhang, Y. 2016. Emergy evaluation of an industrial park in Sichuan Province, China: A modified emergy approach and its application. *Journal of Cleaner Production*, 135, 105-118.

Peng, Y., Chang, W., Zhou, H., Hu, H. & Liang, W. 2010. Factors associated with health-seeking behavior among migrant workers in Beijing, China. *BMC Health Services Research*, 10, 69-78. 10:69. doi:10.1186/1472-6963-10-69

Piatkowski, M. M., Coste, A, Shi, L, Du, Y. & Cai, Z. 2019. Enhancing China's Regulatory Framework for Eco-Industrial Parks : Comparative Analysis of Chinese and International Green Standards (English). Washington, D.C. : World Bank Group. Retrieved from: http://documents.worldbank.org/curated/en/950911554814522228/Enhancing-China-s-Regulatory-Framework-for-Eco-Industrial-Parks-Comparative-Analysis-of-Chinese-and-International-Green-Standards Accessed 31st July 2019.

Pilouk, S. & Koottatep, T. 2017. Environmental performance indicators as the key for eco-industrial parks in Thailand. *Journal of Cleaner Production*, 156, 614-623.

Pui, D. Y. H., Chen, S.-C. & Zuo, Z. 2014. PM2.5 in China: Measurements, sources, visibility and health effects, and mitigation. *Particuology*, 13, 1-26.

Pycausalimpact, v0.012, 2019. Available at https://github.com/dafiti/causalimpact

Qin, X., Pan, J. & Liu, G. G. 2014. Does participating in health insurance benefit the migrant workers in China? An empirical investigation. *China Economic Review*, 30, 263–278.

Qu, Y., Li, M. & Qin, L. 2015a. Environmental practice and its effect on the Sustainable Development of eco-industrial parks in China. *International Journal of Sustainable Development and Planning*, 10, 685-700.

Qu, Y., Liu, Y., Nayak, R.R. & Li, M. 2015b. Sustainable Development of eco-industrial parks in China: effects of managers' environmental awareness on the relationships between practice and performance. *Journal of Cleaner Production*, 87, 328-338.

Rinaldi, F. 2017. Causal Impact Analysis on VolksWagen Emissions Scandal. Retrieved from https://rpubs.com/rinaldif/volkswagen-causal-impact Accessed 25th March 2020.

Shan, H., Yang, J. & Wei, G. 2019. Industrial Symbiosis Systems: Promoting Carbon Emission Reduction Activities. *International journal of environmental research and public health*, 16(7), 1093, 1-23.

Shan, Y., Guan, D., Zheng, H., Ou, J., Li, Y., Meng, J., Mi, Z., Liu, Z., & Zhang, Q. 2018. China CO_2 emission accounts 1997–2015. *Scientific Data*, 5, 170201. https://doi.org/10.1038/sdata.2017.201

Shi, H., Chertow, M. & Song, Y. 2010. Developing country experience with eco-industrial parks: a case study of the Tianjin Economic-Technological Development Area in China. *Journal of Cleaner Production*, 18, 191-199.

Shi, H., Tian, J. & Chen, L. 2012a. China's Quest for Eco-industrial Parks, Part I. *Journal of Industrial Ecolology*, 16(1), 8-10.

Shi, H., Tian, J., & Chen, L. 2012b. China’s quest for eco-industrial parks, Part II. *Journal of Industrial Ecology*, 16(3), 290–292.

Shi, L. & Yu, B. 2014. Eco-Industrial Parks from Strategic Niches to Development Mainstream: The Cases of China. *Sustainability*, 6(9), 6325-6331.

Shi, L., & Zhou, H. 2007. The organisational scale, geographical scale and their policy implications for China's Circular Economy. *Journal of Geo-Information Science*, 9(1), 61-64 (in Chinese).

Shi, L., Liu, G., & Guo, S. 2012c. International comparison and policy recommendation on the development model of industrial symbiosis in China. *Acta Ecologica Sinica*, 32(12), 3950-3957 (in Chinese).

Shi, Y., Liu, J., Shi, H., Li, H., & Li, Q. 2017. The ecosystem service value as a new eco-efficiency indicator for industrial parks. *Journal of Cleaner Production*, 164, 597-605.

SIA (Semiconductor Industry Association). 2003. Overall roadmap technology characteristics. Retrieved from https://www.semiconductors.org/wp-content/uploads/2018/08/2003Overall-Roadmap-Technology-Characteristics.pdf Accessed June 2020.

Song, X., Geng, Y., Dong, H., & Chen, W. 2018. Social network analysis on industrial symbiosis: A case of Gujiao eco-industrial park. *Journal of Cleaner Production*, 193, 414-423.

STATA, SE 14.2, 2018. Available at www.stata.com

State Council. 1998. Regulations on the Administration of Construction Project Environmental Protection. Retrieved from http://www.fdi.gov.cn/1800000121_39_2765_0_7.html Accessed on 1st November 2020.

State Council. 2013. Circular Economy Development Strategy and Near-Term Action Plan. Retrieved from: http://www.gov.cn/zwgk/2013-02/05/content_2327562.htm Accessed 16th March 2020.

State Council. 2014. Opinions on Promoting the Innovative Development of the Reforming and Upgrading of National Economic and Technological Development Zones. Retrieved from http://politics.people.com.cn/n/2014/1121/c1001-26068354.html (in Chinese). Accessed 18th July 2017.

State Council. 2016. Notice on Issue of Scheme for Demonstrative Innovative Zones Construction as China Implements 2030 Agenda for Sustainable Development. Retrieved from http://www.gov.cn/gongbao/content/2017/content_5157175.htm (in Chinese). Accessed 29th April 2017

Sun, D., Zeng, S., Lin, H., Meng, X., & Yu, B. 2019. Can transportation infrastructure pave a green way? A city-level examination in China. *Journal of Cleaner Production*, 226, 669-678.

Susur, E., Martin-Carrillo, D., Chiaroni, D., & Hidalgo, A. 2019. Unfolding eco-industrial parks through niche experimentation: Insights from three Italian cases. *Journal of Cleaner Production*, 239, 118069, 1-12.

Tamura, K., Liu, X., Jin, Z. & Arino, Y. 2020. Commentary on the statement of carbon neutrality by 2060 of China. Working paper of IGES. Retrieved from https://www.iges.or.jp/jp/publication_documents/pub/workingpaper/jp/10997/2060 年炭素中立_final.pdf (in Japanese). Accessed on 26th October 2020.

Tan, M., Guy, M.R., & Li, X. 2011. Urban spatial development and land use in Beijing: Implications from London's experiences. *Journal of Geographical Sciences*, 21, 49–64. https://doi.org/10.1007/s11442-011-0828-7

Tan, X. 2010. Clean technology R&D and innovation in emerging countries—Experience from China. *Energy Policy*, 38(6), 2916-2926.

Teng, L., & Wei, J. 2008. Research on the analytic method of EIP environment impact factors based on Bayesian networks. *Industrial Technological Economics*, 27(12), 78-80 (in Chinese).

Thieriot, H., & Sawyer, D. 2015. Development of Eco-Efficient Industrial Parks in China: A review. IISD. Available at: https://www.iisd.org/sites/default/files/publications/development-eco-efficient-industrial-parks-china-review-en.pdf Accessed 11th October 2016.

Tian, J., Liu, W., Lai, B., Li, X., & Chen, L. 2014. Study of the performance of eco-industrial park development in China. *Journal of Cleaner Production*, 64, 486-494.

Tian, Y., & Zhou, Z. 2010. The research of Tianjin financial services sector's degree of contribution to the national economy. *2nd International Conference on Industrial and Information Systems*, Dalian, pp. 495-497, doi: 10.1109/INDUSIS.2010.5565801.

Unger, J., & Siu, K. 2019. Chinese migrant factory workers across four decades: shifts in work conditions, urbanisation, and family strategies. *Labor History*, 60(6), 765-778.

United Nations. 2020. 8. a Cartagena Protocol on Biosafety to the Convention on Biological Diversity. Retrieved from https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-8-a&chapter=27&clang=_en#2 Accessed 1st September 2020.

UNIDO (United Nations Industrial Development Organisation). 2014. Inclusive and Sustainable Industrial Development. Retrieved from https://www.unido.org/sites/default/files/2014-03/ISID_Brochure_web_singlesided_12_03_0.pdf. Accessed on 26th October 2020.

UNIDO. 2016. Global assessment of eco-industrial parks in developing and emerging countries. Retrieved from: https://www.unido.org/sites/default/files/2017-02/2016_Unido_Global_Assessment_of_Eco-Industrial_Parks_in_Developing_Countries-Global_RECP_programme_0.pdf Accessed 23rd November 2017.

UNIDO, World Bank Group, & GIZ. 2017. An international framework for eco-industrial parks. Retrieved from: http://documents.worldbank.org/curated/en/429091513840815462/pdf/122179-WP-PUBLIC-AnInternationalFrameworkforEcoIndustrialParks.pdf Accessed 23rd August 2018.

Valenzuela-Venegas, G., Henriquez-Henriquez, F., Boix, M., Montastruc, L., Arenas-Araya, F., Miranda-Perez, J., & Diaz-Alvarado, F. A. 2018. A resilience indicator for Eco-Industrial Parks. *Journal of Cleaner Production*, 174, 807-820.

Visual PROMETHEE, 1.4 Academic Edition, 2013. http://www.promethee-gaia.net/vpa.html

Wang, D. 2011. Reinforcing government audit on resources and environment to play a greater role in promoting transformation of economic development mode. *Auditing Research*, 5, 18-23 (in Chinese).

Wang, J., Zeng, Q., Zhao, J., & Wang, P. 2015. Eco-transformation strategy for traditional industrial parks in china: perspectives from system engineering theory. *Environmental Engineering and Management Journal*, 14(10), 2309-2317.

Wang, L., Wang, L., Tao, W., Smardon, R. C., Shi, X., & Lu, X. 2016. Characteristics, sources, and health risk of polycyclic aromatic hydrocarbons in urban surface dust: a case study of the city of Xi'an in Northwest China. *Environmental Science and Pollution Research*, 23, 13389-13402.

Wang, Q., Deutz, P., & Chen, Y. 2017. Building institutional capacity for industrial symbiosis development: A case study of an industrial symbiosis coordination network in China. *Journal of Cleaner Production*, 142, Part 4, 1571-1582.

Wang, S., Ling, L., Shen, Y., & Lu, Y. 2006. Study on Eco-melioration of Xinzhuang Industrial Park. *Journal of Tongji University (Natural Science)*, 34(3), 388-392 (in Chinese).

Wang, S., Lu, C., Gao, Y., Wang, K., & Zhang, R. 2019. Life cycle assessment of reduction of environmental impacts via industrial symbiosis in an energy-intensive industrial park in China. *Journal of Cleaner Production*, 241, 118358, 1-12.

Wang, Y., Ren, H., Dong, L., Park, H.-S., Zhang, Y., & Xu, Y. 2019. Smart solutions shape for sustainable low-carbon future: A review on smart cities and industrial parks in China. *Technological Forecasting and Social Change*, 144, 103-117.

Wang Z., Shi L., & Sun D. 2009. Debates in the research and practice of eco-industrial park in China: the utilisation of metaphor. *Acta Ecologica Sinica*, 29(11), 6199-6206 (in Chinese).

Wei, H., Su, H., & Li, F. 2014. Report on the Citizenisation of Migrant Workers. Retrieved from: http://www.ceweekly.cn/2014/0310/76878.shtml Accessed May 2020.

Wen, Y. 2016. China's Rapid Rise From Backward Agrarian Society to Industrial Powerhouse in Just 35 Years. The Regional Economist, April, 8-14. Retrieved from https://www.stlouisfed.org/~/media/publications/regional-economist/2016/april/lead.pdf Accessed August 2020.

Wen, Z., Hu, Y., Lee, J.C.K., Luo, E., Li, H., & Ke, S. 2018. Approaches and policies for promoting industrial park recycling transformation (IPRT) in China: Practices and lessons. *Journal Cleaner Production*, 172, 1370-1380.

Wong, C. 2011. The Fiscal Stimulus Programme and Public Governance Issues in China. *OECD Journal on Budgeting*, vol. 11/3, https://doi.org/10.1787/budget-11-5kg3nhljqrjl.

Wong, R., Smieliauskas, F., Pan, I.W., & Lam, S. 2015. Interrupted time-series analysis: Studying trends in neurosurgery. *Neurosurgical Focus*, 39(6), E6.

Woodman, S. 2017. Legitimating exclusion and inclusion: "culture', education and entitlement to local urban citizenship in Tianjin and Lanzhou. *Citizenship Studies*, 21(7), 755-772.

World Bank. 2007. Discussion paper on the final report for research on circular economy legislation. Retrieved from http://documents1.worldbank.org/curated/en/787621496400582046/pdf/115177-WP-CHINESE-CN-CIRCUL-3-Legislative-OUO-9.pdf (in Chinese). Accessed 31st August 2020.

World Bank. 2010. The Path to Integrated Insurance Systems in China, China Health Policy Notes. Retrieved from: http://documents.worldbank.org/curated/zh/926821468024660940/pdf/584120NWP0V20P1Integrated0Insurance.pdf Accessed 20th August 2019.

Wu, F. 2002. New partners or old brothers? GONGOs in transnational environmental advocacy in China. *China Environmental Series*, 5, 45-58.

Xiao, Z., Cao, B., Zhou, G., & Sun, J. 2017. The monitoring and research of unstable locations in eco-industrial networks. *Computer & Industrial Engineering*, 105, 234-246.

Xie, L., Pumain, D., & Swerts, E. 2018. Economic Development Zones and Urban Growth in China. CyberGeo. Retrieved from: DOI : 10.4000/cybergeo.30143 Accessed 2nd October 2019.

Xing, R., Hanaoka, T., Kanamori, Y. & Masui, T. 2017. Greenhouse Gas and Air Pollutant Emissions of China's Residential Sector: The Importance of Considering Energy Transition. *Sustainability*, 9, 614. doi:10.3390/su9040614.

Yang, J., Chen, B., Qi, J., Zhou, S. & Jiang, M.M. 2012. Life-Cycle-Based Multicriteria Sustainability Evaluation of Industrial Parks: A Case Study in China. *The Scientific World Journal,* (8):917830.

Yang, T., Ren, Y., Shi, L., & Wang, G. 2018. The circular transformation of chemical industrial parks: An integrated evaluation framework and 20 cases in China. *Journal of Cleaner Production*, 196, 763-772.

Yi, L., Jiao, W., Chen, X. & Chen, W. 2011. An overview of reclaimed water reuse in China. *Journal of Environmental Sciences (China),* 23, 1585-1593.

Yong, G. 2011. Improve China's sustainability targets. *Nature*, 477, 162.

Yu, C., Davis, C., & Dijkema, G. P. J. 2014a. Understanding the Evolution of Industrial Symbiosis Research. *Journal of Industrial Ecology,* 18, 280-293.

Yu, C., de Jong, M., & Dijkema, G. P. J. 2014b Process analysis of eco-industrial park development – the case of Tianjin, China. *Journal of Cleaner Production*, 64, 464-477.

Yu, C., Dijkema, G. P. J., de Jong, M., & Shi, H. 2015b. From an eco-industrial park towards an eco-city: a case study in Suzhou, China. *Journal of Cleaner Production*, 102, 264-274.

Yu, F., Han, F., & Cui, Z. 2015c. Evolution of industrial symbiosis in an eco-industrial park in China. *Journal of Cleaner Production,* 87, 339-347.

Yu, F., Han, F., & Cui, Z. 2015d. Reducing carbon emissions through industrial symbiosis: a case study of a large enterprise group in China. *Journal of Cleaner Production*, 103, 811-818.

Zeng, D. 2016. Building a Competitive City through Innovation and Global Knowledge - The Case of Sino-Singapore Suzhou Industrial Park. Policy Research Working Paper 7570, Trade and Competitiveness Global Practice Group, World Bank. Retrieved from http://documents1.worldbank.org/curated/en/234971468196142758/pdf/WPS7570-REVISED-Building-competitive-cities-through-innovation-and-global-knowledge.pdf Accessed on 22nd October 2020.

Zeng, Z., & Shi L. 2018. China's Green Transformation through Eco-Industrial Parks, Retrieved from https://www.greengrowthknowledge.org/sites/default/files/China%20Green%20Transformation%20Synthesis%20Note%20-%20Douglas%20Zeng_AP-revision_Lay....pdf Accessed 31st July 2019.

Zhang, F., & Huang, K. 2017. The role of government in industrial energy conservation in China: Lessons from the iron and steel industry. *Energy for Sustainable Development*, 39, 101-114.

Zhang, H., Hara, K., Yabar, H., Yamaguchi, Y., Uwasu, M., & Morioka, T. 2009. Comparative analysis of socio-economic and environmental performances for Chinese EIPs: case studies in Baotou, Suzhou, and Shanghai. *Sustainability Science*, 4, 263-279.

Zhang, H., & Xiao Z. 2007. The construction of the evaluation indices system for effect auditing of public environmental investment projects based on AHP. *Auditing Research*, 1, 32-38 (in Chinese).

Zhang, K., & Sun, R. 1999. Analysis of status and trends on the investment to environmental pollution control in China. *China Environmental Science*, 19(2):97-101 (in Chinese).

Zheng, J., & Peng, X. 2019. Does an Ecological Industry Chain Improve the Eco-Efficiency of an Industrial Cluster? Based on Empirical Study of an Energy-Intensive Industrial Cluster in China. *Sustainability*, 11(6), 1651, 1-18.

Zhang, L., Yuan, Z., Bi, J., Zhang, B., & Liu, B. 2010. Eco-industrial parks: national pilot practices in China. *Journal of Cleaner Production*, 18, 504-509.

Zhang, M.M., Zhou, D.Q., Ding, H., & Jin, J.L. 2016. Biomass Power Generation Investment in China: A Real Options Evaluation. *Sustainability*, 8(6), 563, 1-22.

Zhang, Z., & Evenett, S. 2010. The Growth of China's Services Sector and Associated Trade: Complementarities between Structural Change and sustanability. IISD. Retrived from https://www.iisd.org/sites/default/files/publications/sts_4_growth_china_services_sector.pdf Accessed 30th August 2020.

Zhao, H.R., & Guo, S. 2018. Comprehensive benefit evaluation of eco-industrial parks by employing the best-worst method based on circular economy and sustainability. *Environment, Development and Sustainability*, 20(3), 1229-1253.

Zhao, L. Y., Wang, X. P., & Zhu, K. 2014a. Industrial Development Zone: China's Contemporary Characteristic City Development Pattern. *Proceedings of the 50th Isocarp Congress: Urban Transformations: Cities and Water*, 7.

Zhao, Y., Shang, J. C., Chen, C., & Wu, H. N. 2008. Simulation and evaluation on the eco-industrial system of Changchun Economic and Technological Development Zone, China. *Environmental Monitoring and Assessment*, 139, 339-349.

Zhao, Y., Kang, B., Liu, Y., Li, Y., Shi, G., Shen, T., Jiang, Y., Zhang, M., Zhou, M. & Wang, L. 2014b. Health Insurance Coverage and Its Impact on Medical Cost: Observations from the Floating Population in China. *PLoS ONE*, 9(11), 1-9.

Zhou, S. & Cheung, M. 2017. Hukou system effects on migrant children's education in China: Learning from past disparities. *International Social Work*, 60(6), 1327-1342.

Zhou, S., Shi, M., Li, N., & Yuan, Y. 2011. Effects of Chinese Economic Stimulus Package on Economic Growth in the Post-Crisis China. *Economics Research International*, 2011, Article ID 492325.

Zhou, Y. 2010. The offside power of industrial associations and its confinement. *Academic Exchange*, 198(9), 76-78 (in Chinese).

Zhu, Q., Geng, Y., Sarkis, J., & Lai, K.-H. 2015. Barriers to Promoting Eco-Industrial Parks Development in China. *Journal of Industrial Ecology*, 19(3), 457-467.

Supplementary Material

Table S1: characteristics of ND-EIPs in China

Name	City	Administrative Type	Time of Initial Construction*	Time of Approval / Upgrade	Verification & Denomination	Type	Planned Size (km^2)**	Percentage of Economic Output of the Domicile City***	Status Note
Guigang National Eco-Industrial (Sugar Manufacturing) Demonstrative Zone	Guigang	Key enterprise led	1956	2001.08.14	Verification application not submitted after five years of approval.	Sector	1.55	4.43%(IAV, 2014)	
Guangzhou Nanhai National Eco-Industrial Development Demonstrative Park / South China Environmental Protection Technology Industrial Park	Guangzhou	Government led	2001*	2001.11.29		Integrated	35		
Baotou National Eco-Industrial (Aluminium) Development Demonstrative Park	Baotou	Government led	2003*	2003.04.18		Sector	70	3.07%(IAV, 2018.1)	
Changsha Huangxing National Eco-Industrial Development Demonstrative Park	Changsha			2003.04.29		Integrated			Integrated into Changsha Economic Development Area.
Shandong Lubei Group Eco-Industrial Park	Binzhou	Key enterprise led	1984	2003.11.18		Sector	23.66	0.23%(Economic output, 2017)	
Tianjian Economic and Development Area National Eco-Industrial Demonstrative Park	Tianjin	Government led	1984	2004.04.26	2008.03.31	Integrated	408	17.05%(GDP, 2016)	Re-examination conducted in April 2017
Fushun Mining Group EIP	Fushun	Key enterprise led	2002	2004.04.26	Verification application not submitted	Sector		8.98%(Economic output, 2016)	

Dalian Development Area EIP	Dalian		1984	2004.04.26		Integrated	738.7/1040	29.88%(GDO, 2017)	
Suzhou New District National Eco-Industrial Demonstrative Park	Suzhou	Government led	1990	2004.04.26	2008.03.31	Integrated	258	6.82%(GDP, 2017)	Re-examination conducted in April 2017
Suzhou Industrial Park Eco-Industrial Demonstrative Park	Suzhou	Government led	1994	2004.04.26	2008.03.31	Integrated	278.18	14.05%(2017)	
Guiyang Kaiyang Phosphorus-Coal-Chemical Engineering (National) Eco-Industrial Demonstrative Base	Guiyang	Key enterprise led	1958	2004.11.22	Verification application not submitted	Sector	16	10.64%(IAV, 2011)	
Yantai Economic Development Area National Eco-Industrial Demonstrative Park	Yantai	Government led	1984	2004.11.29	2010.04.01	Integrated	340	18.61%(GDP, 2017)	Re-examination conducted in January 2016
Weifang Binhai Economic Development Area National Eco-Industrial Demonstrative Park / Weifang Ocean Chemical Engineering High-Tech Industrial Development Area National Eco-Industrial Demonstrative Park	Weifang	Government led	1995	2005.03.31	2010.04.01	Sector	677	5.49%(GDP, 2016)	
Zhengzhou Shangjie District Eco-Industrial Demonstrative Park	Zhengzhou	Government led	1957	2005.04.21	Verification application not submitted	Integrated	64.7	1.52%(GDP, 2017)	
Baotou Steel Eco-Industrial Park	Baotou	Key enterprise led	1954	2005.12.08		Sector		19.77%(Revenue/GDP, 2017)	
Shanxi Antai Group Eco-Industrial Park	Jinzhou	Key enterprise led	1983	2006.05.18		Sector	4	4.92%(Revenue/GDP, 2017)	
Qingdao Xintiandi Venous Industrial Park	Qingdao		2006*	2006.09.11	2014.09.30	Venous	2.2		Disqualified.
Suzhou Zhangjiagang Tax Free Area / Yangtze River International Chemical	Suzhou	Government led	1992	2006.10.24	2010.11.29	Integrated	19.78	4.16%(GDP, 2017)	Re-examination conducted in

Engineering Area National Eco-Industrial Demonstrative Park									January 2016
Suzhou Kunshan Economic Development Area National Eco-Industrial Demonstrative Park	Suzhou	Government led	1984	2006.10.24	2010.11.29	Integrated	20/115	7.65%(GDP, 2017)	
Fuzhou Economic Development Area National Eco-Industrial Demonstrative Park	Fuzhou	Government led	1984	2006.10.24	2015.07.31	Integrated	23	6.50%(GDP, 2017)	
Wuxi New District Internaitonal Eco-Industrial Demonstrative Park	Wuxi	Government led	1992	2006.11.22	2010.04.01	Integrated	197.28/ 220	15.38%(GDP, 2017)	Re-examination conducted in January 2016
Shaoxing Paojiang Industrial Area Eco-Industrial Demonstrative Park	Shaoxing	Government led	2000	2006.12.04	Verification application not submitted	Integrated	33.69	4.84%(GDP, 2016)	
Rizhao Economic Development Area National Eco-Industrial Demonstrative Park	Rizhao	Government led	1991	2006.12.29	2010.08.26	Integrated	8.5/115.6	18.48%(GDP, 2016)	Re-examination conducted in January 2016
Shanghai Xinzhuang Industrial Park National Eco-Industrial Demonstrative Park	Shanghai	Government led	1995	2007.01.19	2010.08.26	Integrated	17.88	1.18%(GDP, 2016)	
Qingdao High-Tech Area Shibei New Industrial Park Eco-Industrial Demonstrative Park	Qingdao	Government led	1992	2007.05.16	2014.09.30	Integrated	9.95/53.49	1.39(Industrial output, 2017)	
Yangzhou Economic Development Area National Eco-Industrial Demonstrative Park	Yangzhou	Government led	1992	2007.05.17	2010.11.29	Integrated	122.2	12.6%(GDP, 2016)	Re-examination conducted in January 2016
Shanghai Jinqiao Export Processing Area National Eco-Industrial Demonstrative Park	Shanghai	Government led	1990	2008.08.25	2011.04.02	Integrated	18.48	5.50%(Industrial output, 2015)	
Nanjing Economic Development Area National Eco-Industrial Demonstrative Park	Nanjing	Government led	1992	2008.08.25	2012.03.19	Integrated	16.23	7.99%(GDP, 2017)	Re-examination conducted in April 2017

Tianjin Binhai High-Tech Industrial Area Huayuan Technology Park National Eco-Industrial Demonstrative Park	Tianjin	Government led	1988	2008.08.25	2012.12.26	Integrated	11.58	7.86%(IAV, 2010)	
Kunming High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Kunming	Government led	1992	2008.08.25	Verification application not submitted	Integrated	91.88	15.21%(Industrial output, 2017.01-06)	
Beijing Economic Development Area National Eco-Industrial Demonstrative Park	Beijing	Government led	1992	2009.01.07	2011.04.25	Integrated	58.8	4.7%(GDP, 2016)	Re-examination conducted in January 2016
Guangzhou Economic Development Area National Eco-Industrial Demonstrative Park	Guangzhou	Government led	1984	2009.01.07	2011.12.05	Integrated	78.92	14.88%(GDP, 2017)	
Hangzhou Xiaoshan Economic Development Area National Eco-Industrial Demonstrative Park	Hangzhou	Government led	1990	2009.01.07	Verification application not submitted	Integrated	110	1.8%(GDP, 2015)	
Ningbo Economic Development Area National Eco-Industrial Demonstrative Park	Ningbo	Government led	1984	2010.04.01	2014.03.20	Integrated	29.6	13.5%(GDP, 2016)	
Shanghai Zhangjiang High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Shanghai	Government led	1992	2010.04.01	2014.03.20	Integrated	79.7	8.05%(Above scale industrial output, 2015)	
Nanchang High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Nanchang	Government led	1991	2010.04.01	Verification application not submitted	Integrated	32/231	11.9%(GDP, 2017)	
Wenzhou Economic Development Area National Eco-Industrial Demonstrative Park	Wenzhou	Government led	1992	2010.08.26	2016.08.22	Integrated	33.61	4.10%(GDP, 2017)	
Xi'an High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Xi'an	Government led	1991	2010.08.26	2018.03.23	Integrated	307	16.06%(GDP, 2017)	

Shanghai Chemical Engineering Economic Development Area National Eco-Industrial Demonstrative Park	Shanghai	Government led	1996	2010.08.26	2013.02.06	Sector	29.4	3.52%(Industrial output, 2017)	Re-examination conducted in April 2017
Shanghai Caohejing New Technology Area Eco-Industrial Demonstrative Park	Shanghai	Government led	1984	2010.09.20	2012.12.26	Integrated	5.8	3.76%(GDP, 2017)	
Changzhou Zhonglou Economic Development Area National Eco-Industrial Demonstrative Park	Changzhou	Government led	2002	2010.09.20	2013.09.15	Integrated	17.3	4.07%(Above scale industrial output, 2017)	
Hefei High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Hefei	Government led	1991	2010.09.20	2014.09.30	Integrated	78	9.0%(GDP, 2016)	
Shanghai Minhang Economic Development Area National Eco-Industrial Demonstrative Park	Shanghai	Government led	1986	2010.11.04	2014.03.20	Integrated	3.5	1.52%(Industrial output, 2016)	
Chongqing Yongchuan Gangqiao Industrial Park Eco-Industrial Park	Chongqing	Government led	2002	2010.11.04	Verification application not submitted	Integrated	30.1	0.64%(Above scale industrial output, 2015)	
Zhengzhou Economic Development Area National Eco-Industrial Demonstrative Park	Zhengzhou	Government led	1993	2010.11.04	2016.11.25	Integrated	158.7	6.7%(GDP, 2016)	
Hefei Economic Development Area National Eco-Industrial Demonstrative Park	Hefei	Government led	1993	2010.11.04	Verification application not submitted	Integrated	53	15%(GDP, 2016)	
Dongying Economic Development Area National Eco-Industrial Demonstrative Park	Dongying	Government led	1992	2010.12.25		Integrated	153	10.59%(GDP, 2017)	
Nantong Economic Development Area National Eco-Industrial Demonstrative Park	Nantong	Government led	1984	2010.12.25	2014.12.25	Integrated	24.68/146.98	7.7%(GDP, 2016)	

Zhuzhou High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Zhuzhou	Government led	1992	2010.12.25	Verification application not submitted	Integrated	60	11.9%(GDP, 2016)	
Ningbo National High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Ningbo	Government led	1999	2010.12.25	2015.07.31	Integrated	18.9	1.83%(GDP, 2017)	
Taiyuan Economic Development Area National Eco-Industrial Demonstrative Park	Taiyuan	Government led	1992	2011.04.02	Verification application not submitted	Integrated	49.6	8.1%(GDP, 2016)	
Nanchang Economic Development Area National Eco-Industrial Demonstrative Park	Nanchang	Government led	1992	2011.04.02	Verification application not submitted	Integrated	229	8.57%(GDP, 2017)	
Wuxi Jiangyin High-Tech Industrial Development Area / Jiangyin Economic Development Area National Eco-Industrial Demonstrative Park	Wuxi	Government led	1992	2011.04.02	2013.09.15	Integrated	53	24.23%(GDP, 2015)	Re-examination conducted in April 2017
Changsha Economic Development Area National Eco-Industrial Demonstrative Park	Changsha	Government led	1992	2011.04.02	2016.08.03	Integrated	100	21.0%(GDP, 2016)	
Shandong Yangguxiangguang Eco-Industrial Park	Liaocheng	Key enterprise led	2009	2011.06.28	2013.02.06	Sector	14	10.25%(IAV, 2016)	Re-examination conducted in April 2017
Linyi Economic Development Area National Eco-Industrial Demonstrative Park	Linyi	Government led	2003	2011.06.28	2013.02.06	Integrated	223	11.5%(GDP, 2016)	
Wuhan Economic Development Area National Eco-Industrial Demonstrative Park	Wuhan	Government led	1991	2011.10.10	Verification application not submitted	Integrated	202.7	9.8%(GDP, 2016)	
Hangzhou Economic Development Area National Eco-Industrial Demonstrative Park	Hangzhou	Government led	1993	2011.10.10	2015.07.31	Integrated	15.79/104.7	5.0%(GDP, 2016)	
Guiyang Economic Development Area National Eco-Industrial Demonstrative Park	Guiyang	Government led	1993	2011.10.10	Verification application not submitted	Integrated	63.13	6.8%(GDP, 2016)	

Nanjing High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Nanjing	Government led	1988	2011.10.10	2014.09.30	Integrated	16.5/160	6.1%(GDP, 2016)	
Xuzhou Economic Development Area National Eco-Industrial Demonstrative Park	Xuzhou	Government led	1992	2012.05.30	2014.09.30	Integrated	56.6	11.2%(GDP, 2016)	
Suzhou Changshu Economic Development Area National Eco-Industrial Demonstrative Park	Suzhou	Government led	1992	2012.05.30	2014.12.25	Integrated	59.38	5.38%(GDP, 2016)	
Changzhou National High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Changzhou	Government led	1992	2012.05.30	2014.12.25	Integrated	46.4	19.7%(GDP, 2016)	
Guangzhou Nansha Economic Development Area National Eco-Industrial Demonstrative Park	Guangzhou	Government led	2005	2012.05.30	Verification application not submitted	Integrated	797	6.47%(GDP, 2017)	
Shanghai Shibei High-Tech Service Industrial Area Eco-Industrial Park	Shanghai	Government led	1992	2012.09.03	2016.08.03	Sector	3.13		
Zhaoqing High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Zhaoqing	Government led	1958	2012.09.03	Verification application not submitted	Integrated	96.7	9.21%(GDP, 2017)	
Qingdao Economic Development Area National Eco-Industrial Demonstrative Park	Qingdao	Government led	1984	2013.02.05	Verification application not submitted	Integrated	274.1	27.6%(GDP, 2016)	
Changzhou Wujin High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Changzhou	Government led	1997	2013.02.05	2016.08.03	Integrated	27.4	10.3%(GDP, 2016)	
Tianjin Port Tax Free Area / Airport Economic Area Eco-Industrial Demonstrative Park	Tianjin	Government led	1991	2013.02.06	Verification application not submitted	Integrated	87.4	9.53%(GDP, 2016)	
Shenyang Economic Development Area National Eco-Industrial Demonstrative Park	Shenyang	Government led	1988	2013.02.06	2014.01.10	Integrated	444	13.05(GDP, 2011)	

Shenyang High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Shenyang	Government led	1988	2013.02.06	Verification application not submitted	Integrated	34.2	5.8%(GDP, 2016)	
Suzhou Wujiang Economic Development Area National Eco-Industrial Demonstrative Park	Suzhou	Government led	1992	2013.02.06	Verification application not submitted	Integrated	173	2.55%(GDP, 2017)	
Huai'an Economic Development Area National Eco-Industrial Demonstrative Park	Huai'an	Government led	1992	2013.02.06	2016.11.25	Integrated	166	21.68%(IAV, 2017)	
Changchun Economic Development Area National Eco-Industrial Demonstrative Park	Changchun	Government led	1993	2013.04.09	Verification application not submitted	Integrated	112	9.7%(GDP, 2016)	
Changchun Auto Economic Development Area National Eco-Industrial Demonstrative Park	Changchun	Government led	2005	2013.04.09	2016.11.25	Sector	110	9.46%(GDP, 2017)	
Changzhou Wujin Economic Development Area National Eco-Industrial Demonstrative Park	Changzhou	Government led	1997	2013.04.09	2016.08.03	Integrated	20.14	1.13%(GDP, 2017)	Name changed to Changzhou Xitaihu Technology Industrial Park
Nanjing Jiangning Economic Development Area National Eco-Industrial Demonstrative Park	Nanjing	Government led	1992	2013.04.18	2016.08.03	Integrated	58.72	9.9%(GDP, 2016)	
Yancheng Economic Development Area National Eco-Industrial Demonstrative Park	Yancheng	Government led	1992	2013.04.18	2016.08.22	Integrated	80.6/250	7.9%(GDP, 2016)	
Lianyungang Economic Development Area National Eco-Industrial Demonstrative Park	Lianyungang	Government led	1984	2013.04.18	2016.11.25	Integrated	162	25.3%(GDP, 2016)	
Dongguan Eco-Industrial Park	Dongguan	Government led	2006	2013.04.18	Verification application not submitted	Integrated	31	5.09%(GDP, 2017)	Integrated with Dongguan Songshanhu High-Tech

									Industrial Park in the end of 2014.
Hangzhou Bay Shangyu Industrial Area Eco-Industrial Demonstrative Park	Hangzhou	Government led	1998	2013.04.18	Verification application not submitted	Integrated	275	8.85%(Industrial output, 2014)	
Shanghai Qingpu Industrial Area Eco-Industrial Demonstrative Park	Shanghai	Government led	1995	2013.12.20	2019.07.05	Integrated	16.1	1.67(Above scale industrial output, 2014)	
Suzhou Kunshan High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Suzhou	Government led	1992	2013.12.20	Verification application not submitted	Integrated	117.7	4.20%(GDP, 2016)	
Ganzhou Economic Development Area National Eco-Industrial Demonstrative Park	Ganzhou	Government led	1990	2013.12.20	Verification application not submitted	Integrated	219	10.10%(GDP , 2016)	
Urumqi Economic Development Area National Eco-Industrial Demonstrative Park	Urumqi	Government led	1994	2013.12.20	2018.03.23	Integrated	133/480	17.40%(GDP , 2016)	
Chengdu Economic Development Area National Eco-Industrial Demonstrative Park	Chengdu	Government led	2000	2014.10.14	2019.07.05	Integrated	56.34	8.9%(GDP, 2016)	
Ma'anshan Economic Development Area National Eco-Industrial Demonstrative Park	Ma'anshan	Government led	1995	2014.10.14	Verification application not submitted	Integrated	34.47	9.9%(GDP, 2016)	
Zhangjiagang Economic Development Area National Eco-Industrial Demonstrative Park	Zhangjiajie	Government led	1993	2014.10.14	Verification application not submitted	Integrated	12.13/153	5.1%(GDP, 2016)	
Zhuhai High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Zhuhai	Government led	1992	2014.10.14	Verification application not submitted	Integrated	139	8.37%(GDP, 2017)	

Ganzhou High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Ganzhou	Government led	2001	2014.10.14	Verification application not submitted	Integrated	48.1	9.05(IAV, 2017)	
Erdos Shanghaimiao Economic Development Area National Eco-Industrial Demonstrative Park	Erdos	Government led	2001	2014.10.14	Verification application not submitted	Sector	682	2.72%(Industrial output, 2017)	
Liaocheng Chiping Economic Development Area Xinfa Industrial Park National Eco-Industrial Demonstrative Park	Liaocheng	Key enterprise led	1972	2014.10.14	Verification application not submitted	Sector	30	1.80%(Industrial output, 2017)	
Langfang Economic Development Area National Eco-Industrial Demonstrative Park	Langfang	Government led	1992	2014.10.14	2018.03.23	Integrated	38	14.9(GDP, 2016)	
Yangzhou Weiyang Economic Development Area National Eco-Industrial Demonstrative Park	Yangzhou	Government led	2001	2014.12.18	2016.08.22	Integrated	9.67/30	4.83%(GDP, 2016)	
Lianyungang Xuwei New District Eco-Industrial Demonstrative Park	Lianyungang	Government led	2008	2014.12.18	2019.07.05	Integrated	229	19.65%(GDP, 2012)	
Wuhu Economic Development Area National Eco-Industrial Demonstrative Park	Wuhu	Government led	1993	2014.12.18	Verification application not submitted	Integrated	121.68	36.3%(GDP, 2016)	
Weifang Economic Development Area National Eco-Industrial Demonstrative Park	Weifang	Government led	1993	2014.12.18	Verification application not submitted	Integrated	57.8	0.83%(GDP, 2017)	
Kunming Economic Development Area National Eco-Industrial Demonstrative Park	Kunming	Government led	1992	2015.07.03	Verification application not submitted	Integrated	11.8/156.6	7.9%(GDP, 2016)	
Shanghai General Indstrial Area Eco-Industrial Demonstrative Park	Shanghai	Government led	1994	2015.07.03	2019.07.05	Integrated	20.8	1.05%(Industrial output, 2017)	

West Mongolia High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Erdos	Government led	2001	2015.07.03	Verification application not submitted	Integrated	140	5.30%(Industrial output, 2017)	
Jiaxing Gang District Eco-Industrial Demonstrative Park	Jiaxing	Government led	2001	2015.07.03	Verification application not submitted	Integrated	54	3.70%(GDP, 2017)	
Hangzhou Qianjiang Economic Development Area National Eco-Industrial Demonstrative Park	Hangzhou	Government led	2006	2015.07.03	Verification application not submitted	Integrated	25.6	4.13%(Above scale industrial output, 201	Integrated with Yuhang EDA in end of 2015.
Hangzhou Xiaoshan Linjiang High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Hangzhou	Government led	2003	2015.07.03	Verification application not submitted	Integrated	3.55/160	6.55%(Industrial output, 2015)	
Xuzhou High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Xuzhou	Government led	1992	2015.09.21	Verification application not submitted	Integrated	180	9.2%(GDP, 2016)	
Wuxi Xishan Economic Development Area National Eco-Industrial Demonstrative Park	Wuxi	Government led	1992	2015.09.21	Verification application not submitted	Integrated	79.38	5.6%(GDP, 2016)	
Suzhou Wuzhong Economic Development Area National Eco-Industrial Demonstrative Park	Suzhou	Government led	1993	2015.09.21	Verification application not submitted	Integrated	150	2.31%(GDP, 2016)	
Tianjin Ziya Economic Development Area National Eco-Industrial Demonstrative Park	Tianjin	Government led	2003	2015.09.21	Verification application not submitted	Integrated	49.34	0.23%(GDP, 2016)	
Changsha High-Tech Indstrial Area Eco-Industrial Demonstrative Park	Changsha	Government led	1988	2015.09.21	Verification application not submitted	Integrated	140	42.68(Above scale IAV, 2016)	

* EIP development is planned from scratch;

** numerator is the size of industrial area, denominator is the size of the administered area where applicable;

*** GDP is preferred to reflect the economic output of the whole area; wherever available, the latest data are used.

Table S2: main research studies, methods and directions of impact

Impacts	Indicators	Modeled				Observed			
		+	~	-	Study Sites	+	~	-	Study Sites
Economics	Economic output/Industrial added value	Lin et al., 2004			NEIP	Shi & Yu, 2014;			TEDA, FEDA;
		Teng & Wei, 2008				Yu et al., 2015b			SIP;
						Tian et al., 2014			17 EIPs
						Starfelt et al., 2008			CHP
						Liu Z. et al., 2018;			DDA;
						Liu W. et al., 2018;			Zengcheng
							Yang et al., 2018		20 Chemical IPs
	Industrial added value per capita		Bai et al., 2014		33 NDEIPs	Tian et al., 2014			17 EIPs;
							Wang et al., 2006		SHXIP
							Fan et al., 2017a		40 NDEIPs;
	Industrial added value per area					Tian et al., 2014			17 EIPs;
			Bai et al., 2014		33 NDEIPs		Wang et al., 2006		SHXIP
							Yang et al., 2018		20 Chemical IPs
	Economic generation per area					Yang et al., 2012			BDA
							Zhang et al., 2009;		Baotou, SIP and SHXIP
	Eco-productivity index	Zhou et al., 2012				Fan et al., 2017b			HEDA
	Job creation/Employee		Bai et al., 2014		33 NDEIPs	Tian et al., 2014			17 EIPs
			Zhao et al., 2018		Five EIPs				
	Employee productivity					He et al., 2017			BDA
							Zhang et al., 2009		Baotou, SIP and SHXIP
	Ratio of environmental investment						Wang et al., 2006;		SHXIP;
							Zhang et al., 2009		Baotou, SIP and SHXIP
	Industrial output proportion of local city						Zhang et al., 2009		Baotou, SIP and SHXIP
Resource Consumption	Energy consumption					Fan et al., 2017b			HEDA;
						Geng et al. 2014			SETDZ;
						Fan et al., 2017c			HEDA

					Yu et al., 2014			TEDA
					Dong et al., 2016			Guiyang
					Li & Zeng, 2018			Pulp & paper industry SMEs
						Fan et al., 2017a		40 NDEIPs;
						He et al., 2017		BDA
							Yu et al., 2015b	SIP;
							Yang et al., 2012	BDA
							He et al., 2017	BDA
	Water consumption	Liang, 2011		YEDZ;	Fan et al., 2017b			HEDA;
					Geng et al. 2014			SETDZ;
					Fan et al., 2017c			HEDA
					Lin et al., 2004			TEIP
					Liu Z. et al., 2018;			DDA;
					Yu et al., 2014			TEDA
						Fan et al., 2017a		40 NDEIPs;
							Yu et al., 2015b	SIP
	Freshwater use intensity	Liang, 2011		YEDZ;	Li & Zeng, 2018			Pulp & paper industry SMEs
			Bai et al., 2014	33 NDEIPs	Liu Z. et al., 2018;			DDA;
					Tian et al., 2014;			17 EIPs;
					Yu et al., 2015a			TEDA, DDA;
						Shi & Yu, 2014;		FEDA;
						Wang et al., 2006;		SHXIP;
						Zhang et al., 2009		Baotou, SIP and SHXIP
						Yang et al., 2018		20 Chemical IPs
	Coal/energy use intensity		Zhao et al., 2018	Five EIPs	Yang et al., 2012			BDA
					Zeng & Shi, 2018			Overall EIPs in China

					Li & Zeng, 2018			Pulp & paper industry SMEs
						Zhang et al, 2009;		Baotou, SIP and SHXIP
						Yang et al., 2018		20 Chemical IPs
	Energy consumption per industrial added value		Bai et al., 2014	33 NDEIPs;	Tian et al., 2014			17 EIPs;
					Yu et al., 2015a			TEDA, DDA;
						Liu Z. et al., 2018;		DDA;
						Wang et al., 2006;		SHXIP;
					Yu et al., 2015b			SIP;
					He et al., 2017			BDA
	Raw material reduction				Geng et al. 2014			SETDZ;
					Fan et al., 2017c			HEDA
					Liu Z. et al., 2018;			DDA;
					Sun et al., 2017			Liuzhou
					Yu et al., 2014			TEDA
					Dong et al., 2016			Guiyang
						Shi & Yu, 2014		TEDA, FEDA
						Pauliuk et al., 2012		Steel Industry
							Liu W. et al., 2018	Zengcheng
	Resource productivity index	Zhou et al., 2012						
	Ratio of clean energy				Geng et al. 2014			SETDZ;
						Wang et al., 2006		SHXIP
	Land use				Yang et al., 2012			BDA
						Fan et al., 2017a		40 NDEIPs;
						Shi et al., 2017		GKIP
						Yang et al., 2018		20 Chemical IPs
	Ecologjical footprint				Fan et al., 2017c			HEDA
Reuse /Recycle	Energy generated from waste/byproduct				Li & Zeng, 2018			Pulp & paper industry SMEs
					Lin et al., 2004			TEIP

	Ratio of waste steam reuse					Zhang et al, 2009		Baotou, SIP and SHXIP
	Ratio of industrial wastewater utilization	Liang, 2011		YEDZ;	Yang et al., 2012			BDA
			Bai et al., 2014	33 NDEIPs	Zeng & Shi, 2018			Overall EIPs in China
			Zhao et al., 2018	Five EIPs		Yu et al., 2015		TEDA, DDA;
						Wang et al., 2006;		SHXIP;
						Zhang et al., 2009		Baotou, SIP and SHXIP
	Ratio of industrial solid waste reuse		Zhao et al., 2018	Five EIPs	Pauliuk et al., 2012			Steel Industry
			Bai et al., 2014	33 NDEIPs	Zeng & Shi, 2018			Overall EIPs in China
						Yu et al., 2015		TEDA, DDA;
						Wang et al., 2006;		SHXIP;
						Zhang et al., 2009		Baotou, SIP and SHXIP
	Ratio of centralised heating					Wang et al., 2006		SHXIP
Waste	Waste gas emission						Liu W. et al., 2018	Zengcheng
	Waste gas emission intensity		Zhou et al., 2012			Wang et al., 2006;		SHXIP;
						Yang et al., 2018		20 Chemical IPs
						Zhang et al., 2009		Baotou, SIP and SHXIP;
	GHG emission		Zhao et al., 2018	Five EIPs	Liu Z. et al., 2018;			DDA;
					Sun et al., 2017			Liuzhou
					Yu et al., 2014			TEDA
					Yu et al., 2015			REDA
					Dong et al., 2016			Guiyang
					Starfelt et al., 2008			CHP
						Shi & Yu, 2014		TEDA, FEDA
							Liu et al., 2014	BDA;
	GHG emission intensity				Yang et al., 2012			BDA
						Liu et al., 2014		BDA

	SO2 emissions				Yu et al., 2015b			SIP
					Fan et al., 2017c			HEDA
					Liu Z. et al., 2018;			DDA;
						Fan et al., 2017a		40 NDEIPs;
	SO2 emissions per industrial added value		Bai et al., 2014	33 NDEIPs	Yu et al., 2015b			SIP;
					Tian et al., 2014			17 EIPs;
					Yu et al., 2015a			TEDA, DDA
						Yang et al., 2018		20 Chemical IPs
	COD emissions						Yu et al., 2015b	SIP
						Fan et al., 2017a		40 NDEIPs;
	COD emissions per industrial added value		Zhao et al., 2018	Five EIPs	Yu et al., 2015b			SIP;
			Bai et al., 2014	33 NDEIPs	Tian et al., 2014			17 EIPs;
						Yang et al., 2018		20 Chemical IPs
						Yu et al., 2015a		TEDA, DDA
	Air quality compliance rate					Wang et al., 2006		SHXIP;
							Yu et al., 2015b	SIP
	Noise compliance coverage ratio					Wang et al., 2006		SHXIP
	Wastewater discharge	Liang, 2011		YEDZ	Yu et al., 2015a			SIP;
					Fan et al., 2017b			HEDA;
					Geng et al. 2014			SETDZ;
					Fan et al., 2017c			HEDA
					He et al., 2017			BDA
					Shi et al., 2010			TEDA
					Liu W. et al., 2018			Zengcheng
					Li & Zeng, 2018			Pulp & paper industry SMEs
						Shi & Yu, 2014		FEDA
						Fan et al., 2017a		40 NDEIPs;
	Industrial wastewater	Liang, 2011		YEDZ;	Tian et al., 2014;			17 EIPs;

discharge intensity	Bai et al., 2014	33 NDEIPs		Yang et al., 2018		20 Chemical IPs
				Yu et al., 2015a		TEDA, DDA;
				Wang et al., 2006;		SHXIP;
				Zhang et al., 2009		Baotou, SIP and SHXIP
Quality of surface water on site				Wang et al., 2006		SHXIP,
Solid waste			Fan et al., 2017b			HEDA;
			Geng et al. 2014			SETDZ;
			Fan et al., 2017c			HEDA
			He et al., 2017			BDA
			Sun et al., 2017			Liuzhou
			Yu et al., 2014			TEDA
			Yu et al., 2015			REDA
			Dong et al., 2016			Guiyang
			Shi et al., 2010			TEDA
				Shi & Yu, 2014		TEDA, FEDA,
				Fan et al., 2017a		40 NDEIPs;
					Liu W. et al., 2018	Zengcheng
Industrial solid waste generation intensity	Bai et al., 2014	33 NDEIPs	Tian et al., 2014			17 EIPs;
				Yang et al., 2018		20 Chemical IPs
				Yu et al., 2015a		TEDA, DDA;
				Wang et al., 2006;		SHXIP;
				Zhang et al., 2009		Baotou, SIP and SHXIP
Hazardous waste			Geng et al. 2014			SETDZ;
				Shi & Yu, 2014		FEDA
				Yang et al., 2018		20 Chemical IPs
Ratio of centralised treatment of domestic sewage				Zhang et al, 2009		Baotou, SIP and SHXIP

Technology	Completeness/industrial symbiosis index	Zhang et al., 2016;		TEDA, Lubei, Shihezi and Guitang		Shi & Yu, 2014,	TEDA, FEDA
		Zhou et al., 2012					
			Zhao et al., 2018	Five EIPs			
	Connectedness/link density	(Tiejun, 2010) (data probably outdated and not presentative);		Guitang, Nanhai, Lubei, Shihezi, Tuopai, Shenyang Tiexi, Fushun & Tonghua;	Lu et al., 2015		BDA
		Zhou et al., 2012		TEDA, Lubei, Shihezi and Guitang			
			Zhao et al., 2018	Five EIPs			
	Ecological connectedness (comparing to non-EIPs)	(Tiejun, 2010) (data probably outdated and not presentative)		Guitang, Nanhai, Lubei, Shihezi, Tuopai, Shenyang Tiexi, Fushun & Tonghua			
	Ratio of high-tech industries					Wang et al., 2006;	SHXIP;
						Zhang et al., 2009	Baotou, SIP and SHXIP
	Ratio of International Machinery					Wang et al., 2006;	SHXIP;
						Zhang et al., 2009	Baotou, SIP and SHXIP
	Number of complete industrial chains					Wang et al., 2006;	SHXIP;
						Zhang et al., 2009	Baotou, SIP and SHXIP

	Ratio of enterprises with cleaner production					Wang et al., 2006;		SHXIP;
						Zhang et al., 2009		Baotou, SIP and SHXIP
	Flexibility (substitute goods)/Resilience		Li & Xiao, 2017	NCEIP		Wang et al., 2006		SHXIP
			Wang et al., 2013	Hypothetical coal symbiosis system				
						Xiao et al., 2017		YIZ
						Lu et al., 2015		BDA
Management Capacity	Environmental policy				Fan et al., 2017a			40 NDEIPs
	Management capacity (ration of ISO certificate)	Bai et al., 2014		33 NDEIPs		Zhang et al., 2009		Baotou, SIP and SHXIP;
						Wang et al., 2006		SHXIP
	Managers' awareness	Qu et al., 2015		13 EIPs				
	Instituting environmental norms	Qu et al., 2015		13 EIPs				
	Building industrial symbiosis	Qu et al., 2015		13 EIPs	Wang et al., 2017			TEDA
	Guidance for key enterprises	Qu et al., 2015		13 EIPs				
	Ratio of green area coverage					Wang et al., 2006;		SHXIP;
						Zhang et al., 2009		Baotou, SIP and SHXIP
Emergy	Emergy yield ratio				Fan et al., 2017b			HEDA;
					Fang et al., 2017			BDAI
					Geng et al. 2014			SETDZ;
							He et al., 2017	BDA

Note: Modelled studies are those using theoretical data; observed are those using observed data.

+: indicator improvement during study span; ~: no difference for indicator during study span; -: indicator deterioration during study span.

Baotou	Baotou National Demonstrative Eco-Industrial Park (Aluminum)
BDA	Beijing economic- technological development area
BDAI	Beijing economic- technological development area international business park

CHP	Gas turbine-based combined heat and power (CHP) plant in Dongguan EIP
DDA	Dalian economic- technological development area
FEDA	Fuzhou Economic and technological development area
GKIP	Gangkou Industrial Park
GDD	Guangzhou development district
HEDA	Hefei economic and technological development area
JQEPZ	Shanghai Jinqiao export processing zone
KETD	Kunshan economic and technological development zone
LEDZ	Linyi economic technological development area
NCEIP	Ningdong Coal Chemical Eco-industrial Park
NEIP	Nanhai National Demonstration Eco-industrial Park
NETD	Nanjing economic and technological development zone
REDA	Rizhao economic-technological development area
SETDA	Shenyang economic and technological development area
SHCHJ	Shanghai Caohejing hi-tech park
SHXIP	Shanghai Xinzhuang industrial park
SIPAC	China-Singapore Suzhou industrial park
SND	Suzhou national new & hi-tech industrial development zone
TEDA	Tianjin economic-technological development area
TEIP	Tuopai brewing EIP, Sichuan
TJHY	Tianjin hi-tech zone Huayuan science park
WND	Wuxi new district
YEDA	Yantai economic-technological development zone
YEDZ	Yixing economic-technological development zone
YIZ	Yushen Industrial Zone
YZETDZ	Yangzhou economic and technological development zone / Yangzhou export processing zone
ZJGFTZ	Zhangjiagang free trade zone

Table S3. summary and relevant impact categories for each reviewed study

Study	**Main findings**	**Impact studied**									
		Economic performance	**Technology adoption**	**Industrial transition**	**Broader regional**	**Resource use**	**Waste and pollution**	**Land use change and**	**Health**	**Social services**	**Social conflicts**

					economic effects	savings	prevention	biodiversity loss			
Bai et al., 2014	The study examined the progress of EIP development in China, did comparison of the development of 33 EIPs across different regions in China, and found that Western China lags behind in EIP development.	√				√	√				
Fan et al., 2017a	Eco-efficiency of 40 EIPs was analysed, with 20% showing relative efficiency, and 47% being inefficient in scale efficiency. Roles of economic output per person, industrial structure, policy, and scale were studied.	√				√	√	√			
Fan et al., 2017b	Industrial symbiosis helped the emergy of the studied EIP to improve by 33%. Non-renewable inputs were saved by 99.71%, while imported resource inputs by 25.64%, associated services by 9.82%, and cost savings amounting to 29.71% of total gross domestic production of the park.	√				√	√				
Fan et al., 2017c	The study used a modified ecological footprint accounting model, and applied it to a smaller scale case. The results show that the ecological footprint greatly exceeds the EIP's carrying capacity, but eco-industrial actions decreased the ecological footprint by 15.9%.					√	√				
Fang et al., 2017	The study on an industrial park in Beijing shows embodied carbon emissions are mostly in outside inputs, waste management, and water recycling. Embodied carbon-related sustainability indicator suggests that the environmental capacity is sufficient to support park activities.	√				√	√				
Geng et al., 2014	Indicators such as emergy savings and emdollar value of total emergy savings which reflect the holistic picture of industrial symbiosis were used. These two indicators reach 25.58% and 34.38% savings. Results also show that non-renewable inputs, imported resource inputs, and associated services were saved by 89.3%, 32.51%, and 15.7%. Industrial symbiosis	√				√	√				

	decreases material and energy use.										
He et al., 2017	The case study mostly depends on labour and service inputs, although having a relatively high economic efficiency. However, large consumption of external resources reduces its stability.	√				√	√				
Liang et al., 2011	Water resource management model, with focus on improving technologies related to manufacturing of textiles, raw chemical materials, chemical products, and production of electric and heat power, for industrial parks could improve water use and efficiency greatly.					√	√				
Liu et al., 2014	GHG emissions intensity reduced greatly by 20% between 2005 and 2010 for the case study, because of optimisation of energy structure, and energy efficiency. However total GHG emissions increased significantly by 94%. EIP efforts could lower GHG emissions below 2010 level, but energy and material efficiency need to be improved.					√	√				
Liu et al., 2017	This study used an emergy accounting-based method to evaluate the co-benefits and EIP development, and shows that co-benefits of EIP development are not restricted to only economic development.	√				√	√				
Shi & Yu, 2014	Transition of three case studies, and their outcomes are presented. The study shows that technology, space for experiment, government's role as an enabler, and regional embeddedness are key factors to the transition of EIPs.	√	√	√		√	√	√			
Teng & Wei, 2008	Using Bayesian networks modelling the study finds that utilising by-products and wastes of EIPs could reduce waste generation, however more business activities also bring more pollution.	√				√	√				

Tian et al., 2014	Ten indicators were studied for 17 EIPs, showing different patterns of change. In general, industrial added value, energy use, freshwater use, industrial wastewater generation, and solid waste generation all increased to different degrees. However, raw material consumption intensity, and waste production intensity both decreased. COD and SO2 emissions achieved both less total value and intensity.	√				√	√				
Tiejun, 2010	Eco-connectedness and recycling rates are used to evaluate selected case studies. Measures for future planning and building of EIPs were proposed.		√			√					
Wang et al., 2006	Analytic hierarchy process and Delphi were used to construct an evaluation system, which was then used to assess the development of an EIP. Eco-development, resource-recycling, and green service industries are proposed to be the main measures for the future development of the studied case.	√	√	√		√	√	√			
Yu et al., 2015a	Instruments to help the development of EIPs, and their effects were analysed. Order of preference by similarity to ideal solution was applied to understand the roles of policy instruments. The results show that planned EIP model is useful in the beginning of an EIP development, however, a facilitated model should be introduced for long-term transformation.					√	√				
Yu et al., 2015b	Decoupling was achieved for most eco-efficiency indicators. Factors, such as strict regulatory and economic instruments, increasing share of tertiary industry, urban service, residential activities, and synergies between an EIP's infrastructure for industrial and residential area, for an EIP to develop into an eco-city were also discussed.	√	√	√	√	√	√				
Zhang et al., 2009	Overall outcomes of the three case studies were good regarding socio-economics, resources, and materials, however, green management was	√	√		√	√	√				

	weak.										
Zhang et al., 2015	Density and network degree centralisation were compared across eight industrial symbiosis, and three types of networks were discovered and discussed.		√								
Zhou et al., 2012	Scenario optimisation and linear programming shows that resource- and eco-productivity, symbiosis index, and link density could be increased by varying degrees.	√	√			√	√				
Li & Xiao 2017	Topological characteristics analysis of a case study was performed, revealing that importance of node has more weight than node-level index in sustaining the resilience of a network.		√								
Zhao et al., 2017	26 indicators were formed based on grey-Delphi according to expert feedbacks, and then evaluated based on multi-criteria decision making (MCDM) on six EIPs in China.	√	√			√	√				
Sun et al., 2017	Material flows analysis and emergy evaluation were used to calculate resource use and emissions reduction as a result of urban industrial symbiosis of a city in China.	√				√	√				
Yu et al., 2015c	The development stages of a case study is explained, which resulted in 31 inter-firm symbioses. Stricter environmental standards, tax preference, material substitution, and financial subsidies are reasons for participation and economic benefits. The environmental benefits of the EIP were also discussed.						√				
Yu et al., 2014	Five major activities, namely institutional activity, technical facilitation, economic and financial enablers, informational activity, and company activity, are identified and discussed that influence the case study to develop as an EIP.	√	√			√	√				
Lu et al., 2015	Metabolic system of the study case is greatly influenced by primary raw material supply from outside, and final demands, which should be mitigated in order to improve the carbon metabolic system.		√								

Dong et al., 2016	Quantitative assessment on the environmental benefits of life cycle of the case study found that resource savings and carbon dioxide emissions reduction could be achieved with eco-industrial development.					√	√				
Shi et al., 2010	81 inter-firm symbiotic relationships of the case study were identified, and the environmental benefits of the major symbiotic exchanges assessed.		√			√	√				
Xiao et al., 2017	Unstable sources in an eco-industrial relationship were detected using a combinations of methods, including Signed Directed Graph, fault diagnosis technology for the complex system, Principal Component Analysis, and entropy theory, which was then applied to a case study to test its consistency.		√								
Yang et al., 2012	Studied EIP has better energy-saving and GHG emissions mitigations than other industrial parks, however, investment per constructed area is high.	√			√	√	√	√			
Liu et al., 2018	The case study has both higher emergy utilisation and eco-efficiency, implying that it is dependent on resource consumption, especially non-renewable materials.	√	√			√	√				
Pauliuk et al., 2012	Future demands for steel were projected to peak between 2015 and 2020, and drop by as much as 40% by 2050. Recycled material could replace as high as 80% of demands by 2050. This implies that there is need for advancement for technology, and adjustment for market.		√			√	√				
Starfelt & Yan, 2008	A gas turbine-based cogeneration system could reduce carbon emissions significantly compared to the baseline. It is also economically viable.	√	√				√				
Shi et al., 2017	Ecosystem services value was used as eco-efficiency indicators for a case study, and the results show that while total ESV increased, regulating and supporting services value decreased.							√			

Yang et al., 2018	Three core elements, namely industrial chain system, infrastructure system, and management system, as the qualitative indicators, and 15 quantitative indicators were evaluated for 20 chemical industrial parks undergoing circular transformation in China.	√	√	√		√	√	√			
Wang et al., 2013	Asymmetric distribution coefficient was applied to analyse the symbiosis profit and symbiosis cost of a hypothetical coal-based symbiosis system. Influences of changes to the system structure, and external environment were examined.		√								
Zeng & Shi, 2018	Based on the summary of EIP development in China, some progress, challenges, and future implications were discussed.					√					
Li & Zeng, 2018	A comprehensive report on how circular economy could help SMEs to achieve better manufacturing processes, and recycling performance.		√			√	√		√		
Zhao & Guo, 2018	Based on a hybrid framework, nine quantitative and four qualitative indicators were constructed using grey-Delphi. The best-worst method, a comparison-based method, was used to decide the weights of sub-criteria, and applied to evaluate the performance of five case studies.	√	√			√	√				
Lin et al., 2004	Three EIPs in China are introduced, with their development and achievements.	√	√			√	√				
Zheng & Peng, 2019	This study decomposes eco-efficiency into resource efficiency and environment efficiency. Three layers, namely energy-intensive industries, ecological industry chains, and industrial clusters of a few industries were analysed. The results show that eco-efficiency of all three layers improved, and industrial clusters and chains are much better than single system in energy-intensive industries.	√				√	√				

References for Table S2 and S3:

Bai, L., Qiao, Q., Yao, Y., Guo, J., & Xie, M., 2014. Insights on the development progress of National Demonstration eco-industrial parks in China. J. Clean. Prod. 70, 4-14.

Dong, L., Fujita, T., Dai, M., Geng, Y., Ren, J., Fujii, M., Wang, Y., & Ohnishi, S., 2016. Towards preventative eco-industrial development: an industrial and urban symbiosis case in one typical industrial city in China. J. Clean. Prod. 114, 387-400.

Fan, Y., Bai, B., Qiao, Q., Kang, P., Zhang, Y., & Guo, J., 2017a. Study on eco-efficiency of industrial parks in China based on data envelopment analysis. J. Environ. Manag. 192, 107-115.

Fan, Y., Qiao, Q., Fang, L., & Yao, Y., 2017b. Emergy analysis on industrial symbiosis of an industrial park – A case study of Hefei economic and technological development area. J. Clean. Prod. 141, 791-798.

Fan, Y., Qiao, Q., Xian, C., Xiao, Y., & Fang, L., 2017c. A modified ecological footprint method to evaluate environmental impacts of industrial parks. Resour. Conserv. Recycl. 125, 293-299.

Fang, D.L., Chen, B., Hayat, T., & Alsaedi, A., 2017. Emergy evaluation for a low-carbon industrial park. J. Clean. Prod. 163, S392-S400.

Geng, Y., Liu, Z., Xue, B., Dong, H., Fujita, T., & Chiu, A., 2014. Emergy-based assessment on industrial symbiosis: a case of Shenyang Economic and Technological Development Zone. Environ. Sci. Pollut. Res. 21(23), 13572-13587.

He, G., Yang, J., Lu, Y., Wang, S., Chen, B., Hayat, T., Alsaedi, A., & Ahmad, B., 2017. Ternary emergetic environmental performance auditing of a typical industrial park in Beijing. J. Clean. Prod. 163, 128-135.

Li. J., & Zeng. X., 2018. Circular Economic Opportunities for Greening SMEs – The Chinese Experience. Eighth Regional 3R Forum in Asia and the Pacific. United Nations Centre for Regional Development. Available at: https://www.uncrd.or.jp/content/documents/6465FINAL-Bckground%20paper-Prof.%20Jinhui%20Li.pdf (Accessed 6th Sep. 2019).

Li, X., & Xiao, R., 2017. Analyzing network topological characteristics of eco-industrial parks from the perspective of resilience: A case study. Ecol. Indica. 74, 403-413.

Liang, S., Shi, L., & Zhang, T., 2011. Achieving Dewaterization in Industrial Parks. J. of Ind. Ecol. 15(4), 597-613.

Lin, Y.J., Zhang, Z., Wu, F., & Deng, N.S., 2004. Development of Ecological Industrial Parks in China. Fresenius Environ. Bull. 13(7), 600-606.

Liu, W., Tian, J., & Chen, L., 2014. Greenhouse gas emissions in China's eco-industrial parks: a case study of the Beijing Economic Technological Development Area. J. Clean. Prod. 66, 384-391.

Liu, W., Zhan, J., Li, Z., Jia, S., Zhang, F., & Li, Y., 2018. Eco-Efficiency Evaluation of Regional Circular Economy: A Case Study in Zengcheng, Guangzhou. Sustainability 10(2), 453-453.

Liu, Z., Adams, M., Cote, R.P., Geng, Y., Ren, J., Chen, Q., Liu, W., & Zhu, X., 2017. Co-benefits accounting for the implementation of eco-industrial development strategies in the scale of industrial park based on emergy analysis. Renew. Sustain. Energy Rev. 81, 1522-1529.

Lu, Y., Chen, B., Feng, K.S., & Hubacek, K., 2015. Ecological Network Analysis for Carbon Metabolism of Eco-industrial Parks: A Case Study of a Typical Eco-industrial Park in Beijing. Environ. Sci. Technol. 49(12), 7254-7264.

Pauliuk, S., Wang, T., & Müller, D.B., 2012. Moving Toward the Circular Economy: The Role of Stocks in the Chinese Steel Cycle. Environ. Sci. Technol. 46(1), 148-154.

Qu, Y., Liu, Y., Nayak, R.R., & Li, M., 2015. Sustainable development of eco-industrial parks in China: effects of managers' environmental awareness on the relationships between practice and performance. J. Clean. Prod. 87, 328-338.

Shi, H., Chertow, M., & Song, Y., 2010. Developing country experience with eco-industrial parks: a case study of the Tianjin Economic-Technological Development Area in China. J. Clean. Prod. 18(3), 191-199.

Shi, L., & Yu, B., 2014. Eco-Industrial Parks from Strategic Niches to Development Mainstream: The Cases of China. Sustainability 6(9), 6325-6331.

Shi, Y., Liu, J., Shi, H., Li, H., & Li, Q., 2017. The ecosystem service value as a new eco-efficiency indicator for industrial parks. J. Clean. Prod. 164, 597-605.

Starfelt, F., & Yan, J.Y., 2008. Case study of energy systems with gas turbine cogeneration technology for an eco-industrial park. Int J. Energy Res. 32(12), 1128-1135.

Sun, L., Li, H., Dong, L., Fang, K., Ren, J., Geng, Y., Fujii, M., Zhang, W., Zhang, N., & Liu, Z., 2017. Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: A case of Liuzhou city, China. Resour. Conserv. Recycl. 119, 78-88.

Teng, L. & Wei, J., 2008. Research on the analytic method of EIP environment impact factors based on Bayesian networks, Ind. Technol. Econ. 27(12), 78-80. (In Chinese)

Tian, J., Liu, W., Lai, B., Li, X., & Chen, L., 2014. Study of the performance of eco-industrial park development in China. J. Clean. Prod. 64, 486-494.

Tiejun, D., 2010. Two quantitative indices for the planning and evaluation of eco-industrial parks. Resour. Conserv. Recycl. 54(7), 442-448.

Wang, G., Feng, X., & Chu, K.H., 2013. A novel approach for stability analysis of industrial symbiosis systems. J. Clean. Prod. 39, 9-16.

Wang, Q., Deutz, P., & Chen, Y., 2017. Building institutional capacity for industrial symbiosis development: A case study of an industrial symbiosis coordination network in China. J. Clean. Prod. 142, Part 4, 1571-1582.

Wang, S., Ling, L., Shen, Y., & Lu, Y., 2006. Study on Eco-melioration of Xinzhuang Industrial Park. J. Tongji Univ. (Nat. Sci.), 34(3), 388-392. (In Chinese)

Xiao, Z., Cao, B., Zhou, G., & Sun, J., 2017. The monitoring and research of unstable locations in eco-industrial networks. Comput. Ind. Eng. 105, 234-246.

Yang, J., Chen, B., Qi, J., Zhou, S., & Jiang, M.M., 2012. Life-Cycle-Based Multicriteria Sustainability Evaluation of Industrial Parks: A Case Study in China. Sci. World J. 2012.

Yang, T., Ren, Y., Shi, L., & Wang, G., 2018. The circular transformation of chemical industrial parks: An integrated evaluation framework and 20 cases in China. J. Clean. Prod. 196, 763-772.

Yu, C., de Jong, M., & Dijkema, G.P.J., 2014. Process analysis of eco-industrial park development – the case of Tianjin, China. J. Clean. Prod. 64, 464-477.

Yu, C., Dijkema, G.P.J., & de Jong, M., 2015a. What Makes Eco-Transformation of Industrial Parks Take Off in China? J. Ind. Ecol. 19(3), 441-456.

Yu, C., Dijkema, G.P.J., & de Jong, M., Shi, H., 2015b. From an eco-industrial park towards an eco-city: a case study in Suzhou, China. J. Clean. Prod. 102, 264-274.

Yu, F., Han, F., & Cui, Z., 2015. Evolution of industrial symbiosis in an eco-industrial park in China. J. Clean. Prod. 87, 339-347.

Zeng, D.Z., & Shi, L., 2018. China's Green Transformation through Eco-Industrial Parks. Green transformation and competitive advantage: Evidence from developing countries, Bonn, June 2018. Available at:

https://www.die-gdi.de/fileadmin/user_upload/pdfs/veranstaltungen/2018/20180618_green_transformation/China_Green_Transformation_Synthesis_Note_-_Douglas_Zeng_AP-revision_Lay....pdf (Accessed 31st Jul. 2019).

Zhang, H., Hara, K., Yabar, H., Yamaguchi, Y., Uwasu, M., & Morioka, T., 2009. Comparative analysis of socio-economic and environmental performances for Chinese EIPs: case studies in Baotou, Suzhou, and Shanghai. Sustainability Sci. 4(2), 263-279.

Zhang, Y., Zheng, H., Shi, H., Yu, X., Liu, G., Su, M., Li, Y., & Chai, Y., 2015. Network analysis of eight industrial symbiosis systems. Front. Earth. Sci. 10, 352–365.

Zhao, H., Zhao, H., & Guo, S., 2017. Evaluating the comprehensive benefit of eco-industrial parks by employing multi-criteria decision making approach for circular economy. J. Clean. Prod. 142(Part 4), 2262-2276.

Zhao, H.R., & Guo, S., 2018. Comprehensive benefit evaluation of eco-industrial parks by employing the best-worst method based on circular economy and sustainability. Environ. Dev. Sustainability 20(3), 1229-1253.

Zheng, J., & Peng, X., 2019. Does an Ecological Industry Chain Improve the Eco-Efficiency of an Industrial Cluster? Based on Empirical Study of an Energy-Intensive Industrial Cluster in China. Sustainability 11(6).

Zhou, L., Hu, S.y., Li, Y., Jin, Y., & Zhang, X., 2012. Modeling and Optimization of a Coal-Chemical Eco-industrial System in China. J. Ind. Ecol. 16(1), 105-118.

Table S4: major infrastructure and environmental actions taken by TEDA (continued)

EIP	**Field of action**	**1987**	**1989**	**1992**	**1994**	**1995**	**1998**	**1999**
TEDA	Infrastructure	Three thermal stations	Power plant (2*9500kw)	Rain/wastewater treatment; NO. 4 thermal plant	Tap water supply plant (50000t/d)	Wastewater treatment plant phase 1; Huayuan thermal plant; Rain/wastewater treatment phase 2; expansion of NO. 4 thermal plant	Heat supply center for new district;	wastewater treatment and purification phase 2 (10t/d);
	Others				Combined Heat and Power project			
	Wastewater treatment				Wastewater treatment plant started construction (4.9m USD loan)			

Table S4: Major infrastructure and environmental actions taken by TEDA (continued)

Field of action	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Infrastructure	Expansion of Guohua power plant; electroplating wastewater treatment plant (1000T/d);		Reclaimed water plant phase 1;	Thermal plant phase 5;			
Green area construction				Green project (92.52M investment)	186.52M invested		
Clean energy					Natural gas pipe network (15.31M investment), and wastewater treatment	Gas-fueled buses implemented	Natural gas implementation projects (66.6351M investment), Vistas

					plant (7.8M investment) for the light rail		Wind Power started operation
Desalination					Desalination plant started construction (75.2951M investment)		Desalination phase one started operation
Others				Sound-proof project for the light rail (89.70M invested)	Construction of waste information platform		Yuelong water diversion project finished
Desulfurisation			Desulfurisation of Guohua Energy (8M RMB)	Circulating fluidized bed combustion (save 47000t coal and 328000m3 water per year) and bag dust-cleaning technologies introduced (300M RMB investment) (including 5th thermo-power project phase one (146.83M investment))		5th thermo-power project phase one, and 2nd Heat stream project expanded (desulfurisation facilities for power plant constructed (8M investment, total capacity 70t))	5th thermo-power project phase two (Circulating fluidized bed combustion, external desulphurization and bag dust-cleaning technologies) (163.6496M investment)
Waste utilisation					Lead reuse, electronic waste reuse incorporated		
Wastewater treatment		Electroplating wastewater treatment centre started operation (capacity 1000t/d)		Sewage project (120.72M)	Reclaimed water commercialised	Cistern for Novozymes and Nestle built (capacity 500t/d)	Reclaimed water capacity reached 25000t/d; wastewater treatment plant in West Zone started operation
			Micro Filter Membrance wastewater treatment plant (30000t/d, 60M RMB investment); Reverse osmosis grey water				Munipical wastewater treatment project (120.8094M investment)

			treatment plant (10000t/d)				
Solid wate treatment					Shuanggang Waste Incineration plant start operation (155.8M investment)		Shuanggang Waste Incineration plant reached capacity of 1200t/d, generated electricity 88.64Mkwh (equ. To 26000t coal)
Household action			Promotion of phosphorus-free washing powder			Household waste treatment plant constructed (23M investment, capacity 600t/d)	

Table S4: Major infrastructure and environmental actions taken by TEDA (continued)

Field of action	**2007**	**2008**	**2009**	**2010**	**2012**	**2013**	**2016**
Infrastructure							
Green area construction	142.8291M invested						
Clean energy							Change of fuel for Binneng Energy 2nd plant
Others		4th thermo-power project started operation		Expansion of 1st and 2nd thermo-power plants of West Zone;		Increased efficiency for Guohua Energy desulfurisation	

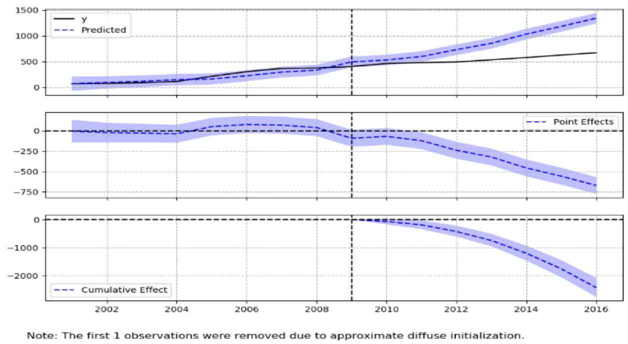
Desulfurisation	Desulfurisation increased workload from 2nd quarter; SO2 reduction support (2.4298M subsidy)	Upgrade of desulfurisation for 5th thermo-power plant phase one and Guohua Energy	Desulfurisation for 2nd, West Zone and 4th thermo-power plants finished			Upgrade of desulfurisation for 2nd thermo-power plant and Binneng 5th thermo-power plant completed;	
Waste utilisation			Wastewater treatment plant phase three started operation; wastewater treatment phase one of Modern Industry Zone completed upgrade			Recycling projects (39.35M investment)	
Wastewater treatment	Chemical wastewater treatment plant phase one, and Coca Cola wastewater treatment plant started operation			Upgrade of 1st wastewater treatment plant of East Zone and waste treatment plant of West Zone	Wastewater treatment plant of Nangang Logistics Zone completed	Emergency wastewater treatment plant of Nangang Zone completed	
Solid wate treatment							Dust removal upgrade of 1st and 2nd furnaces of West Zone 1st thermo-power plant, and Modern Industry Zone thermo-power plant

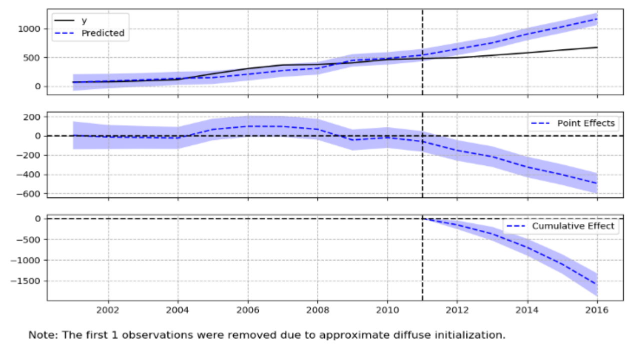
The following contains the figures of Causal Impact and Interrupted Time Series analyses. Due to the fact that the number of figures generated is large, figures are congregated for each method for each EIP as a figure set, and the order of the figures are in accordance with the order of indicators listed in Table 8 in the main body. For Causal Impact, the figures are best understood with Table 23 (BDA), and Table 24 (TEDA) of the main body; for Interrupted Time Series, the figures are best understood with Table 25 (BDA), and Table 26 (TEDA) of the main body.

Figure S1. Causal Impact results for BDA with different tests

Figures of each indicator are laid out in the following order:

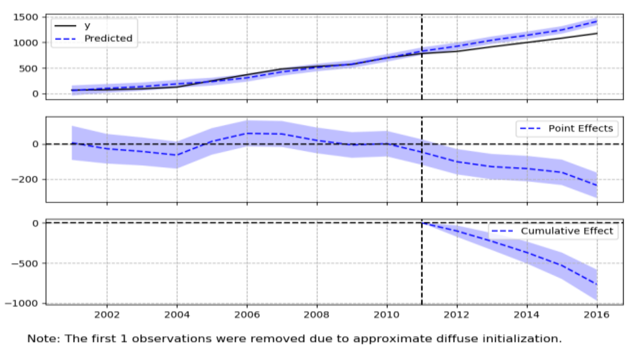
1A (ZSP as covariate, 2009 as effective year)	2A (ZSP as covariate, 2011 as effective year)
1B (Industry/urban as covariate, 2009 as effective year)	2B (Industry/urban as covariate, 2011 as effective year)

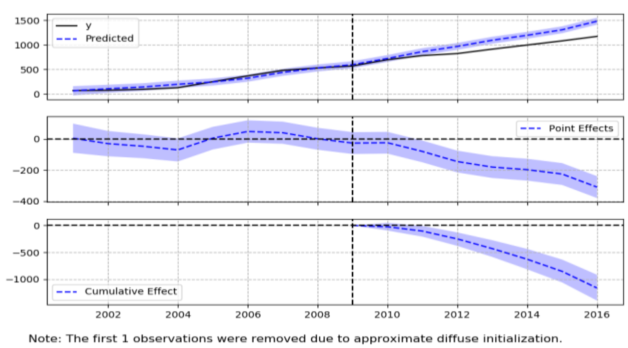




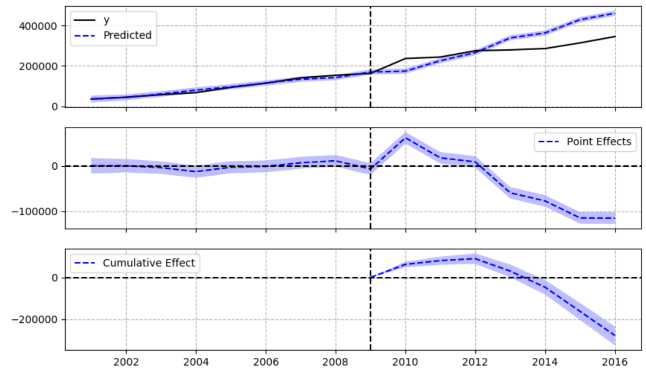
Left figure: Analysis results of economic output (in 100m RMB Yuan) of BDA with ZSP as the covariate. Economic output of BDA was generally increasing after 2009 (solid line in the first panel), its scale was not as great as that of prediction based on the covariate (dotted line in the first panel). This could be interpreted that EIP upgrade did not increase the economic output of BDA as much as its covariate did, which did not undergo EIP upgrade.

Note: Vertical dotted line is the point of treatment, 2009 for BDA. The first panel shows the observations (solid line), fitted values (dotted blue line before 2009), and a counterfactual prediction for the post-treatment period (dotted blue line after 2009). The second panel shows the pointwise difference between observed data and fitted predictions. The third panel shows the cumulative effect of the treatment, adding up the pointwise differences from the second panel. The blue band is the 95% interval of model predictions.

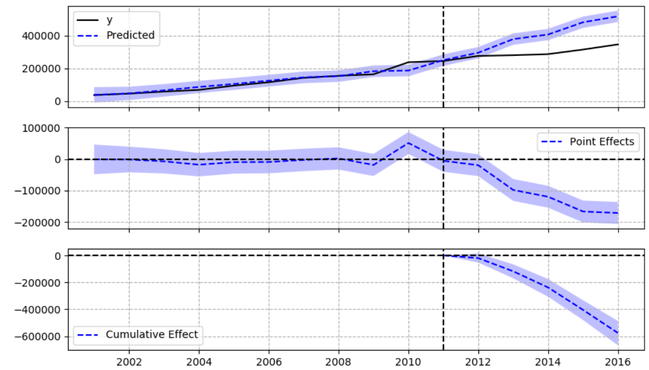




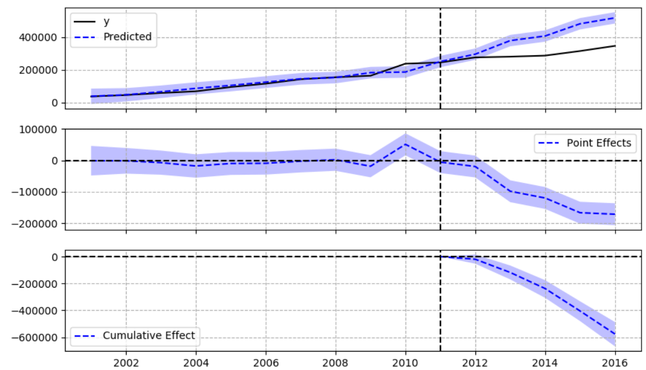
Economic output (100m RMB)



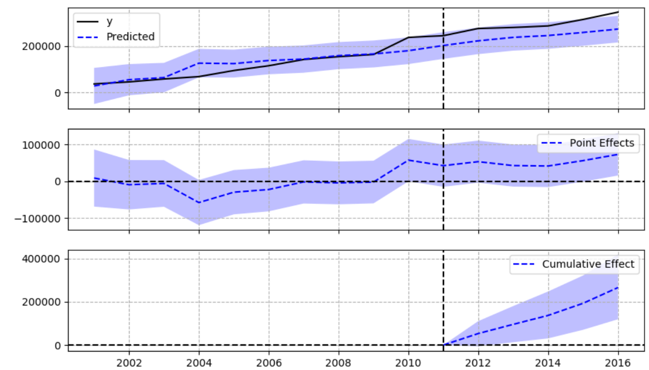
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

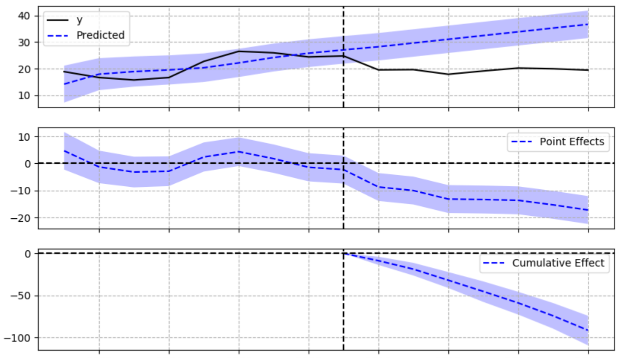


Note: The first 1 observations were removed due to approximate diffuse initialization.

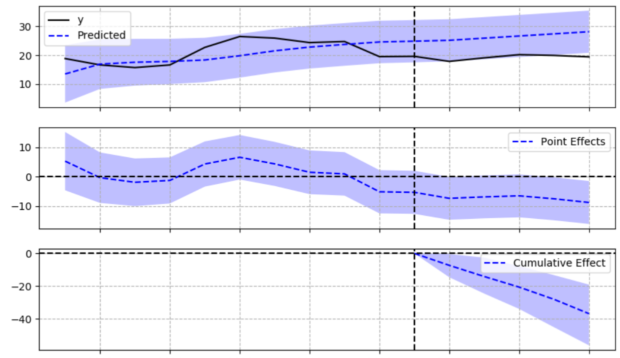


Note: The first 1 observations were removed due to approximate diffuse initialization.

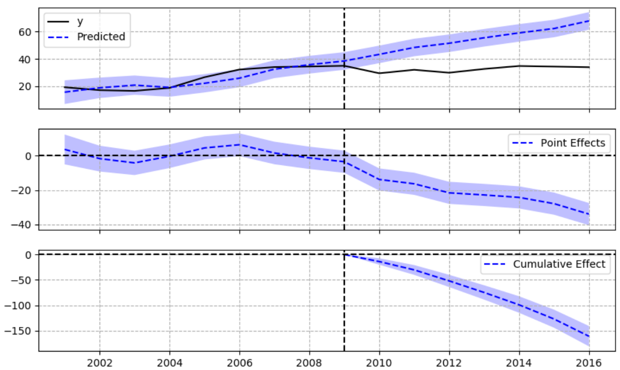
Employee number (number of people)



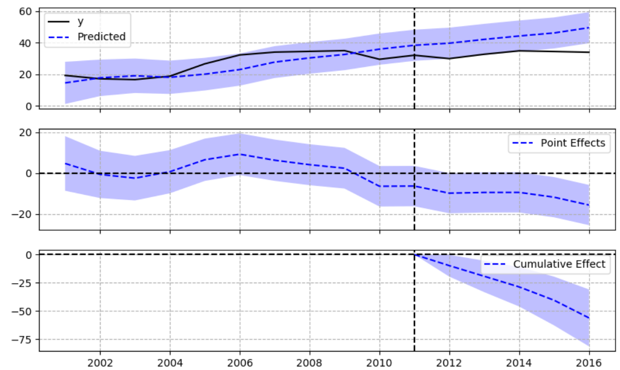
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

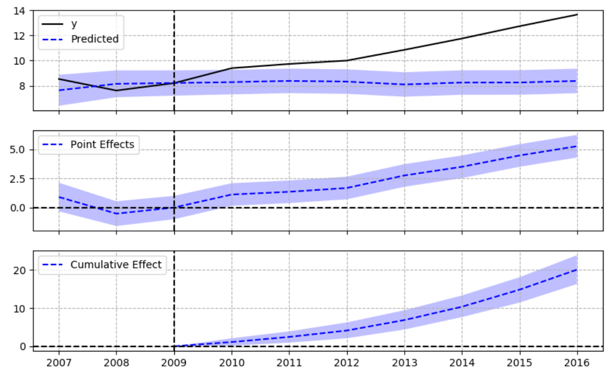


Note: The first 1 observations were removed due to approximate diffuse initialization.

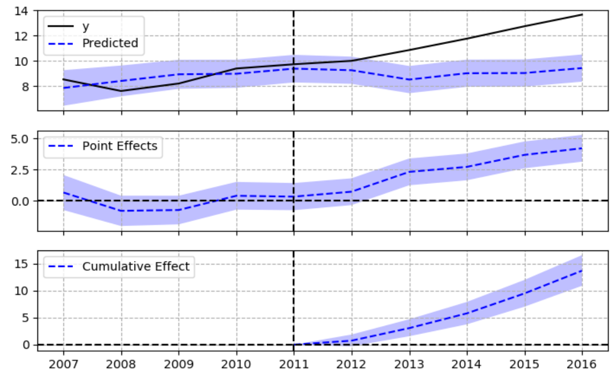


Note: The first 1 observations were removed due to approximate diffuse initialization.

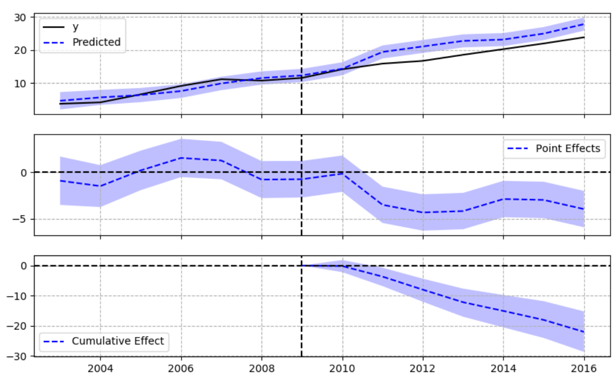
Economic output per employee (10,000 per employee)



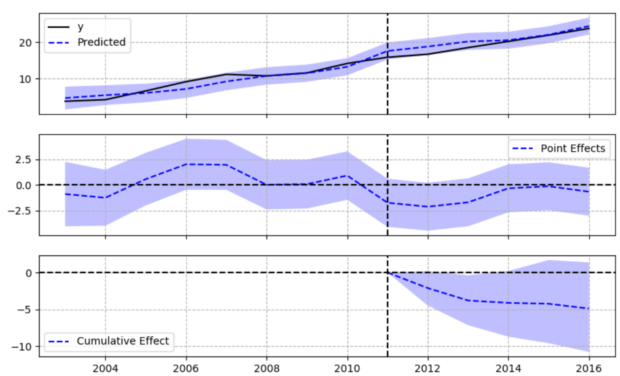
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

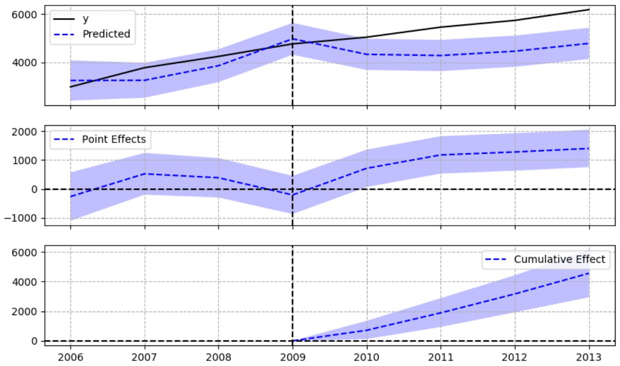


Note: The first 1 observations were removed due to approximate diffuse initialization.

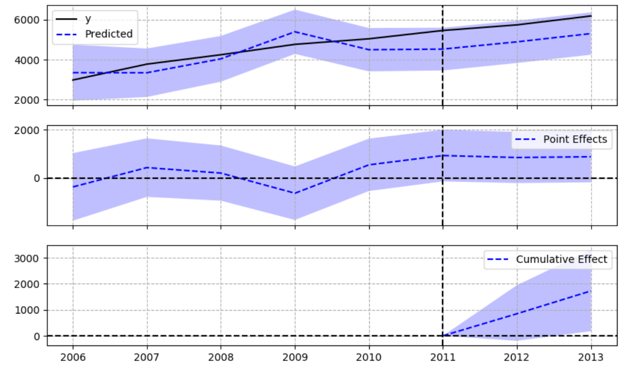


Note: The first 1 observations were removed due to approximate diffuse initialization.

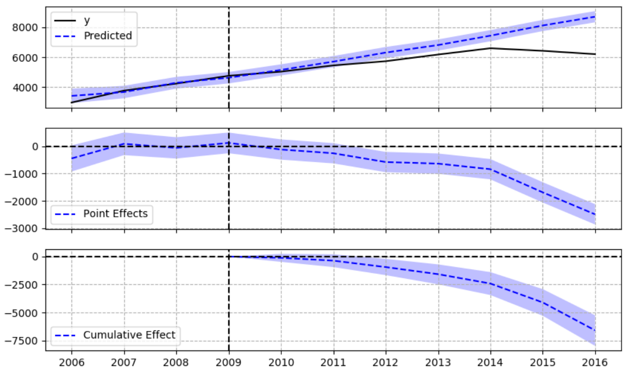
Economic output per unit area (100m RMB per square kilometre)



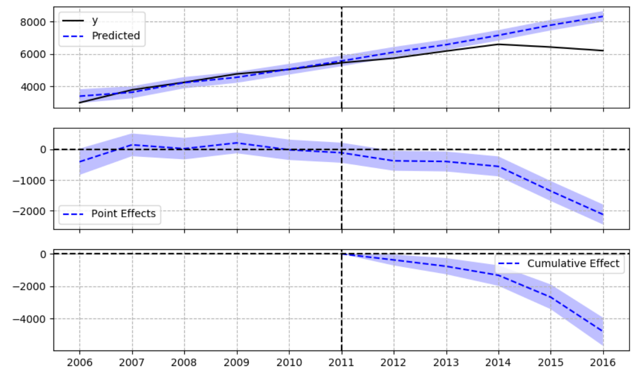
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

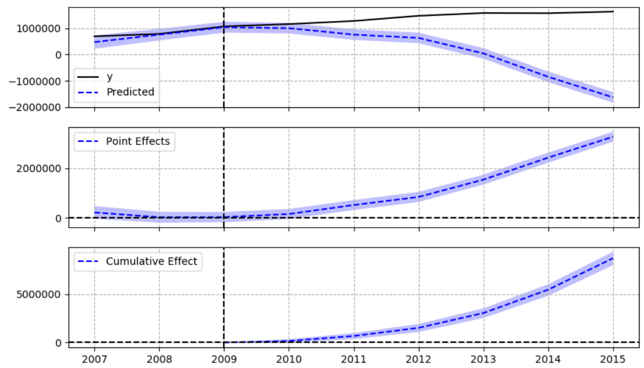


Note: The first 1 observations were removed due to approximate diffuse initialization.

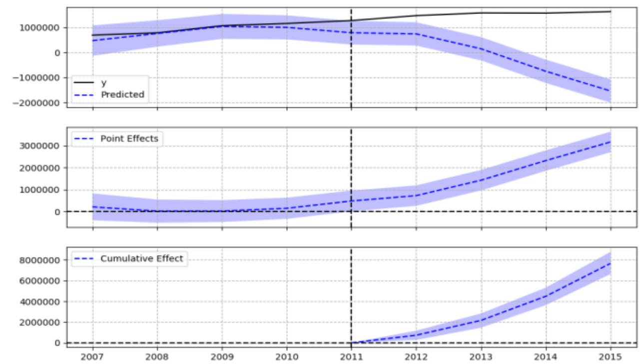


Note: The first 1 observations were removed due to approximate diffuse initialization.

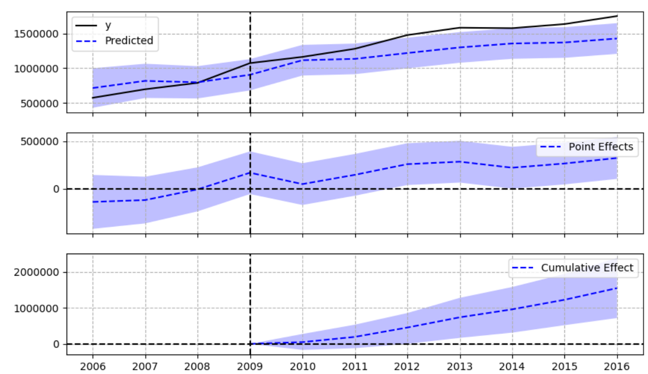
Monthly payment per employee (inflation adjusted) (RMB per month per employee)



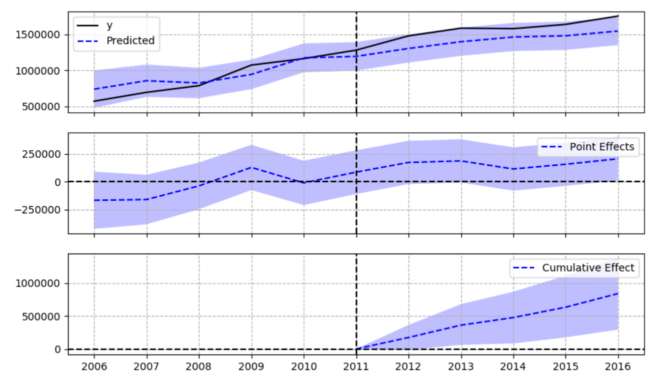
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.



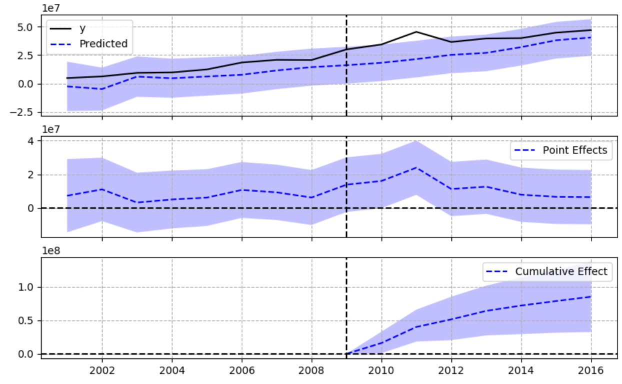
Note: The first 1 observations were removed due to approximate diffuse initialization.



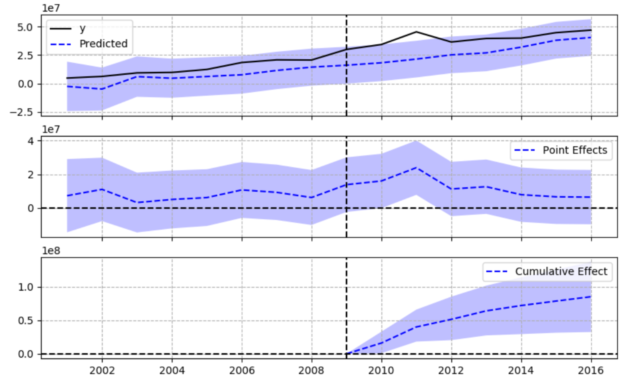
Note: The first 1 observations were removed due to approximate diffuse initialization.

Energy use (tonne of standard coal equivalent per year, tsce per year)

No data	No data

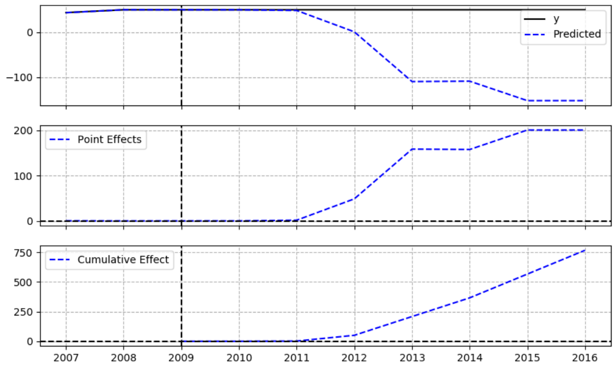


Note: The first 1 observations were removed due to approximate diffuse initialization.

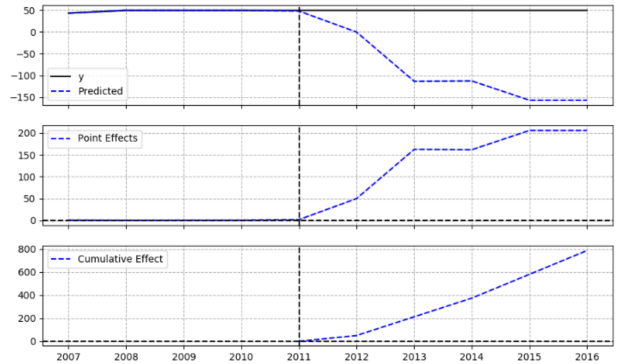


Note: The first 1 observations were removed due to approximate diffuse initialization.

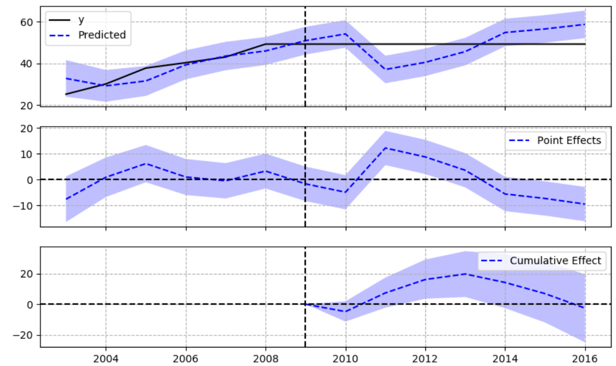
Freshwater use (tonne per year)



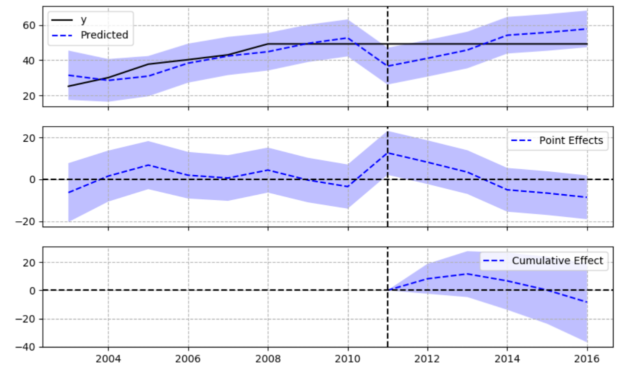
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

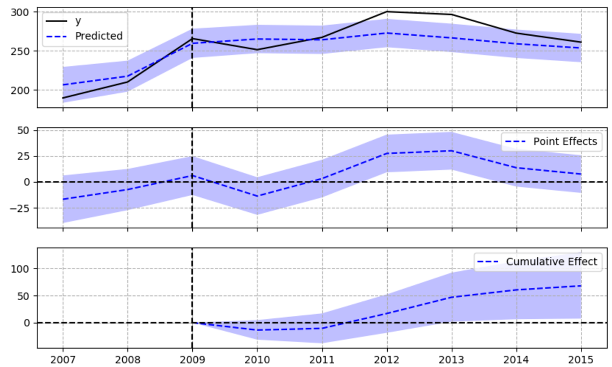


Note: The first 1 observations were removed due to approximate diffuse initialization.

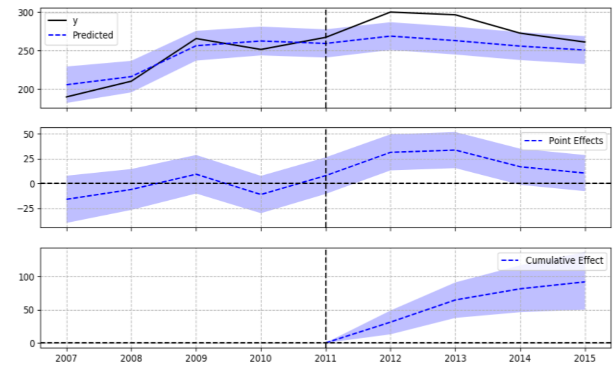


Note: The first 1 observations were removed due to approximate diffuse initialization.

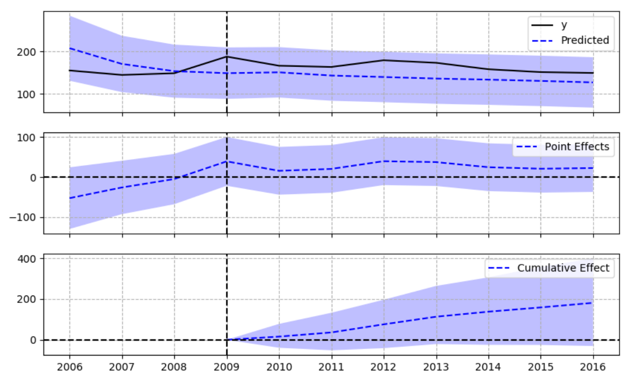
Land use (square kilometre)



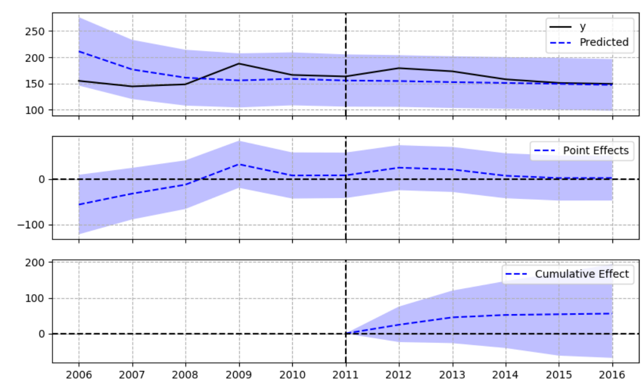
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

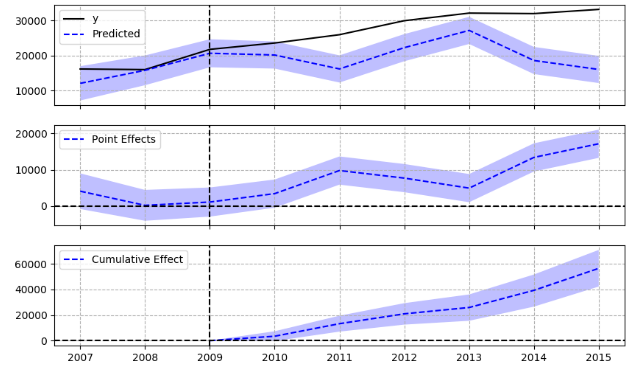


Note: The first 1 observations were removed due to approximate diffuse initialization.

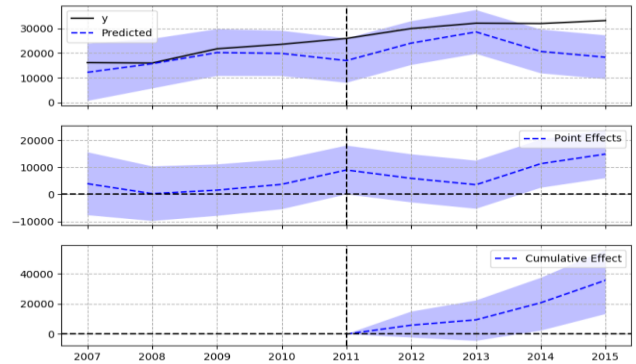


Note: The first 1 observations were removed due to approximate diffuse initialization.

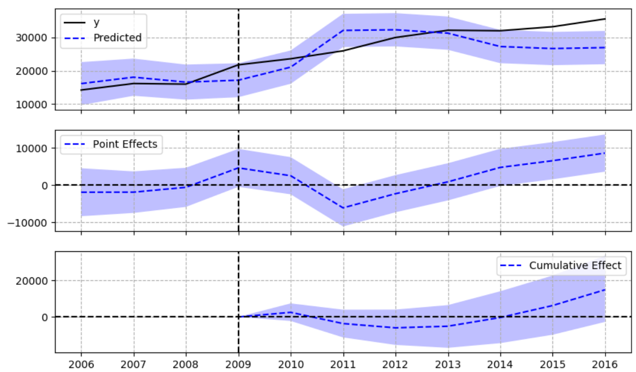
Energy use per unit economic output (tsce per 10m RMB)



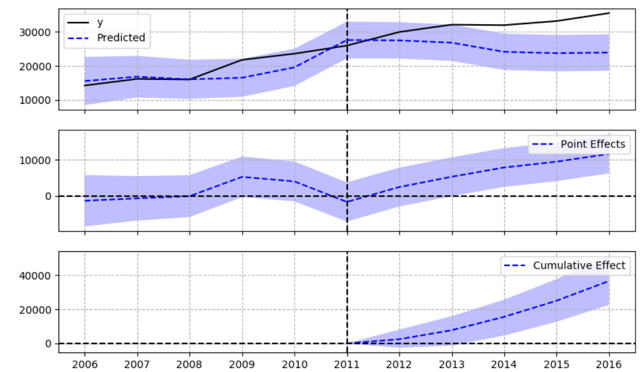
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.



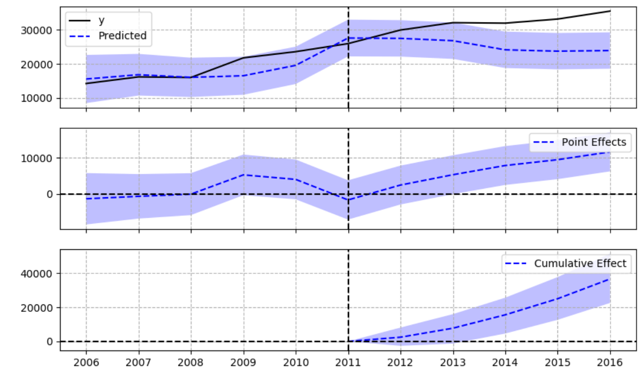
Note: The first 1 observations were removed due to approximate diffuse initialization.



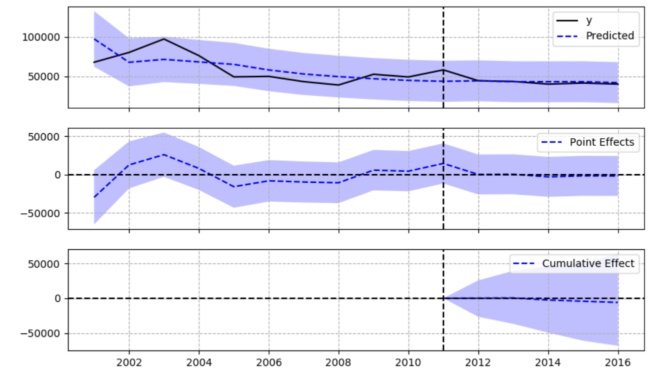
Note: The first 1 observations were removed due to approximate diffuse initialization.

Energy use per unit area (tsce per square kilometre)

No data	No data



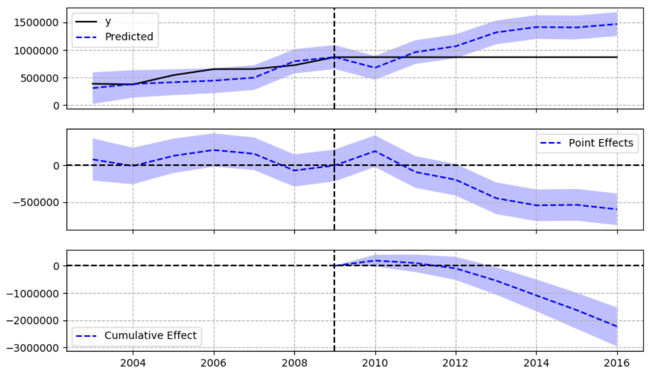
Note: The first 1 observations were removed due to approximate diffuse initialization.



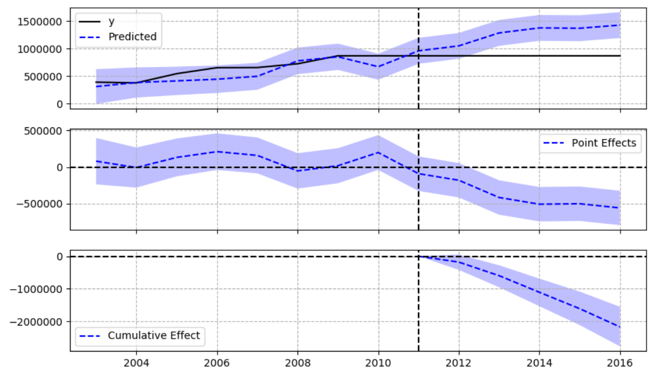
Note: The first 1 observations were removed due to approximate diffuse initialization.

Freshwater use per unit economic output (tonne per 10,000 RMB)

No data	No data



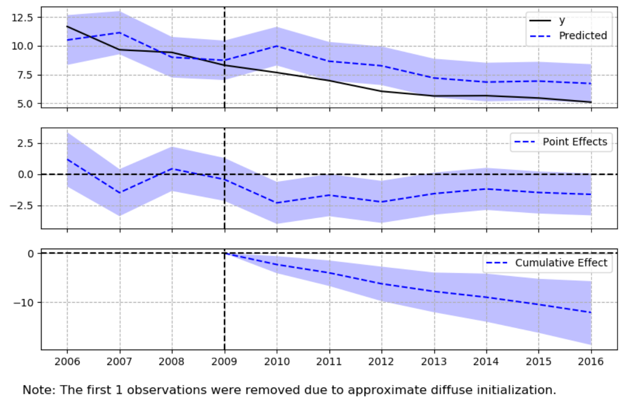
Note: The first 1 observations were removed due to approximate diffuse initialization.

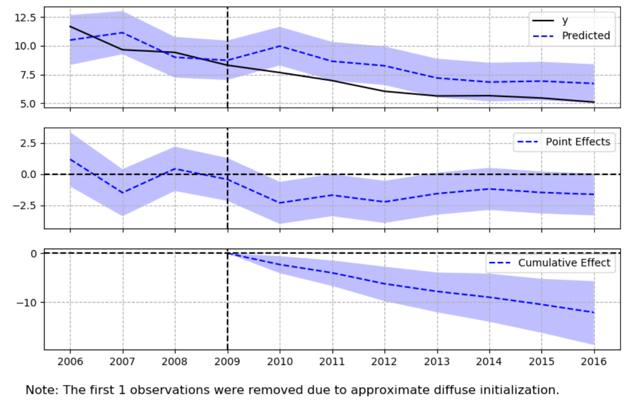


Note: The first 1 observations were removed due to approximate diffuse initialization.

Waste heat use (tsce per year)

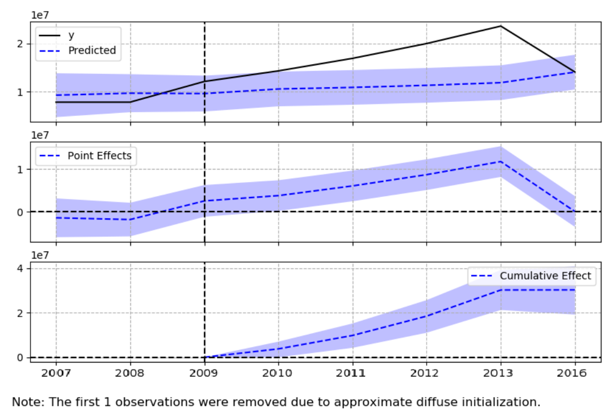
No data	No data

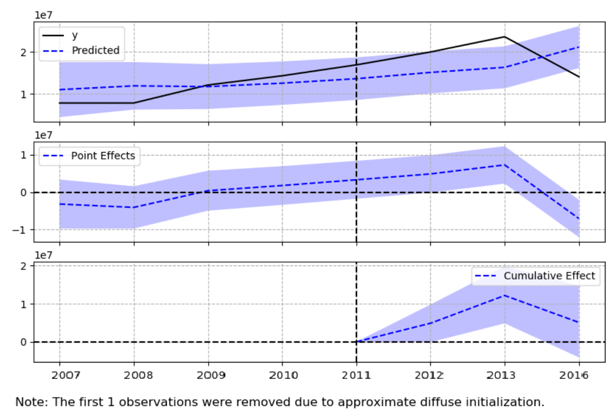




Residual heat reuse ratio (%)

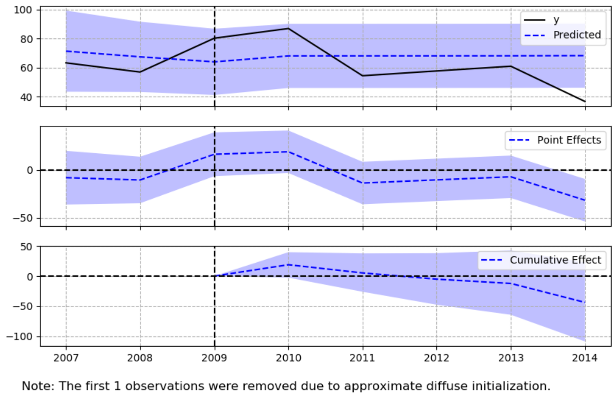
No data	No data

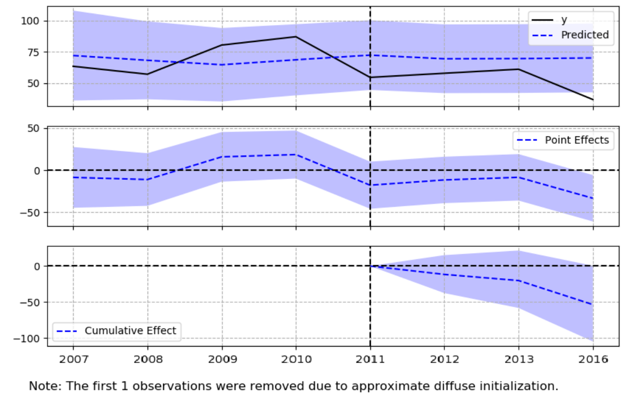




Reclaimed water sales (tonne per year)

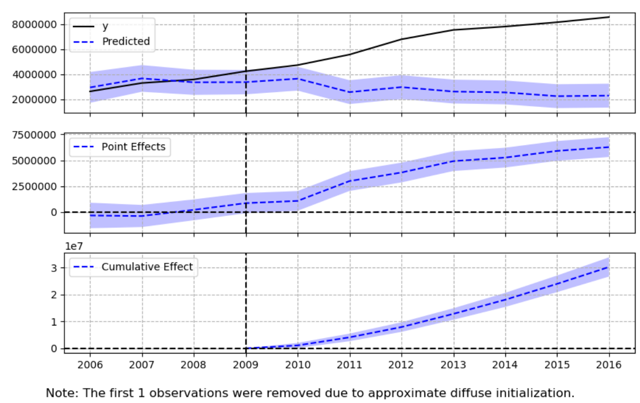
No data	No data

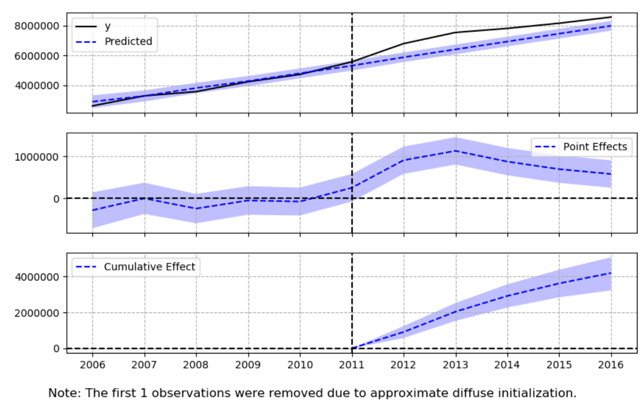




Reclaimed water sales ratio (%)

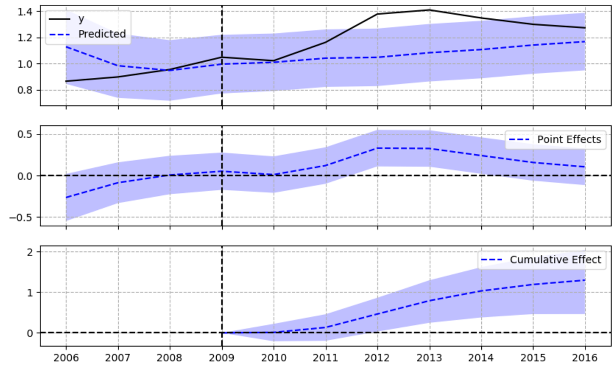
No data	No data



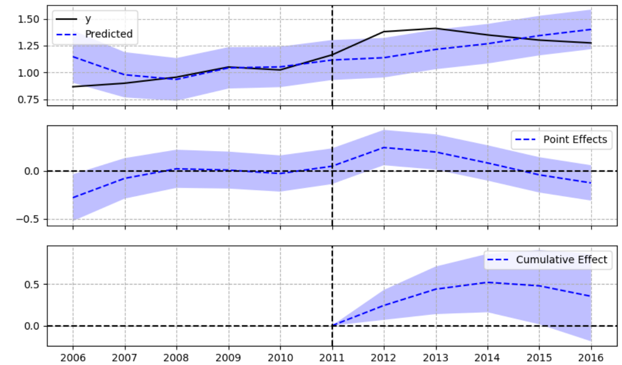


GHG emissions (tonne per year)

No data	No data



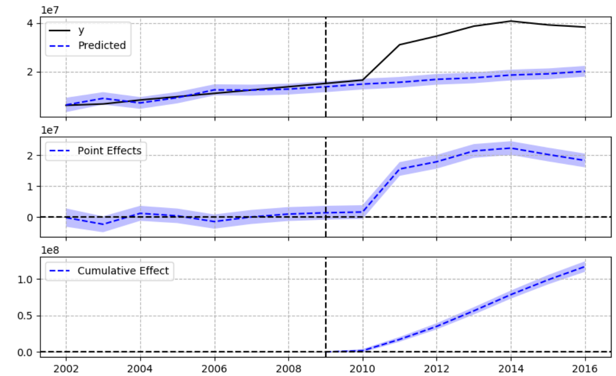
Note: The first 1 observations were removed due to approximate diffuse initialization.



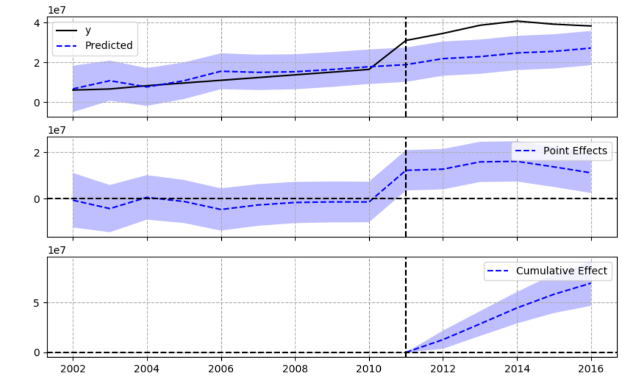
Note: The first 1 observations were removed due to approximate diffuse initialization.

GHG emissions per unit economic output (tonne per 10,000 RMB)

No data	No data



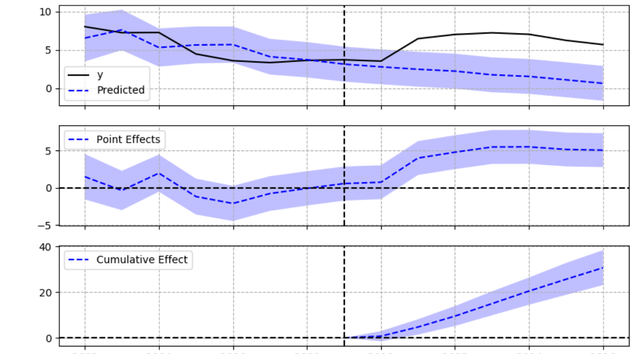
Note: The first 1 observations were removed due to approximate diffuse initialization.



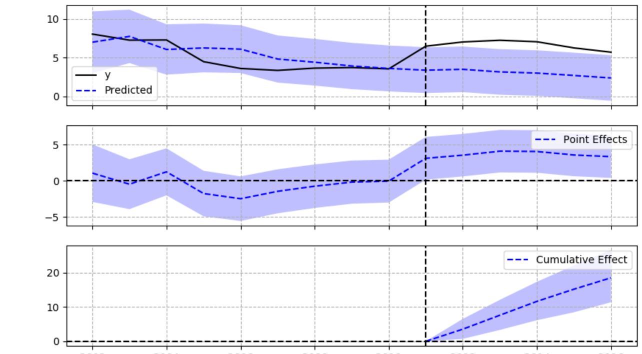
Note: The first 1 observations were removed due to approximate diffuse initialization.

Wastewater discharge (tonne per year)

No data	No data



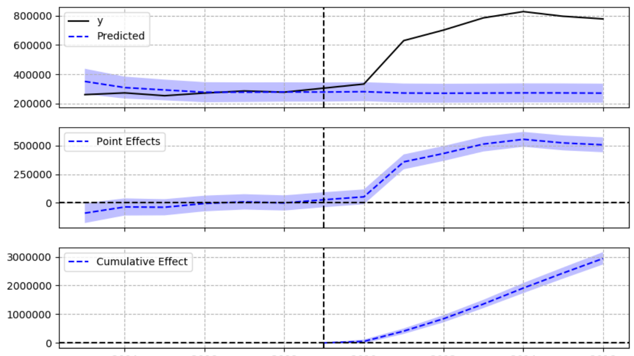
Note: The first 1 observations were removed due to approximate diffuse initialization.



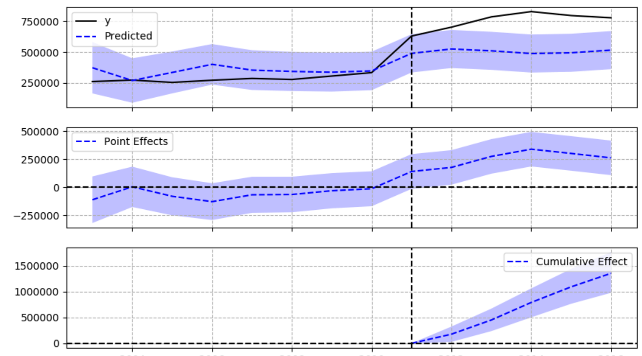
Note: The first 1 observations were removed due to approximate diffuse initialization.

Wastewater discharge per unit economic output (tonne per 10,000 RMB)

No data	No data



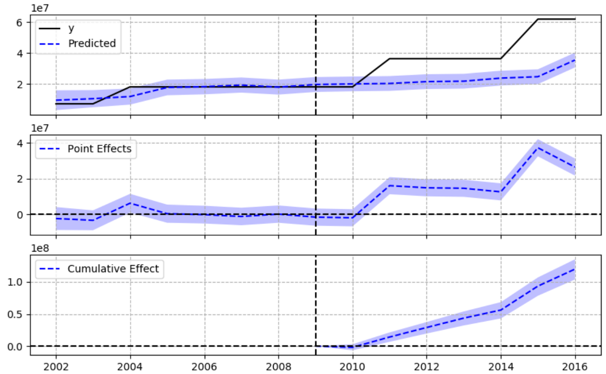
Note: The first 1 observations were removed due to approximate diffuse initialization.



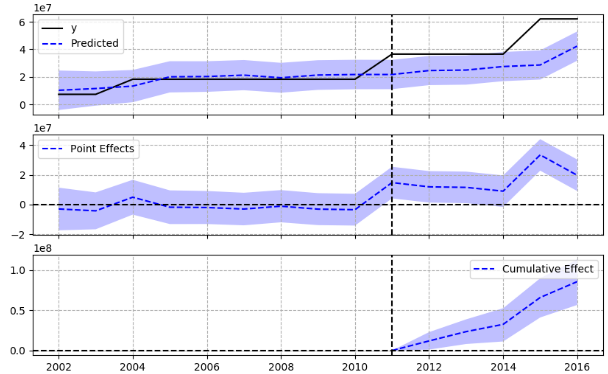
Note: The first 1 observations were removed due to approximate diffuse initialization.

Wastewater discharge per unit area (tonne per square kilometre)

No data	No data



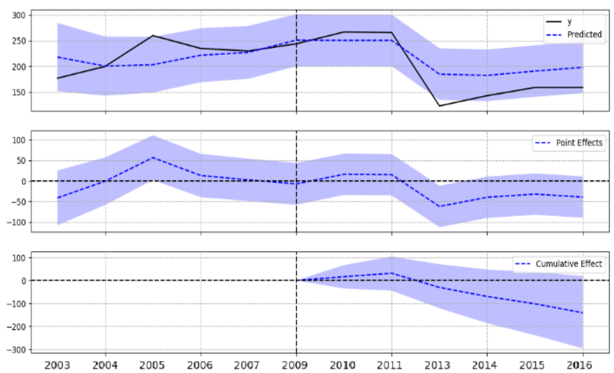
Note: The first 1 observations were removed due to approximate diffuse initialization.



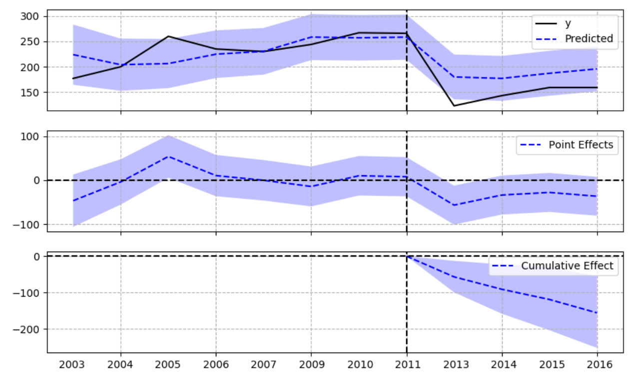
Note: The first 1 observations were removed due to approximate diffuse initialization.

Wastewater treatment capacity (tonne per year)

No data	No data



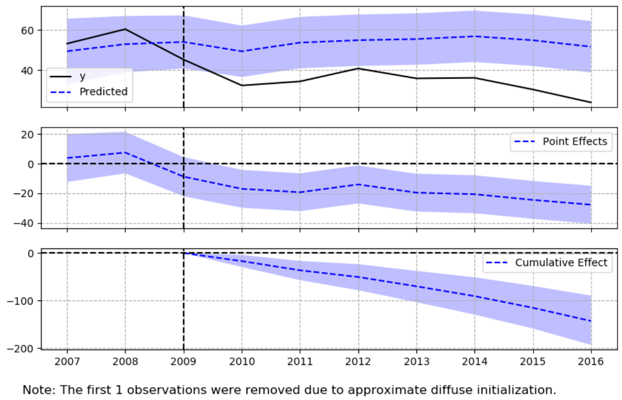
Note: The first 1 observations were removed due to approximate diffuse initialization.

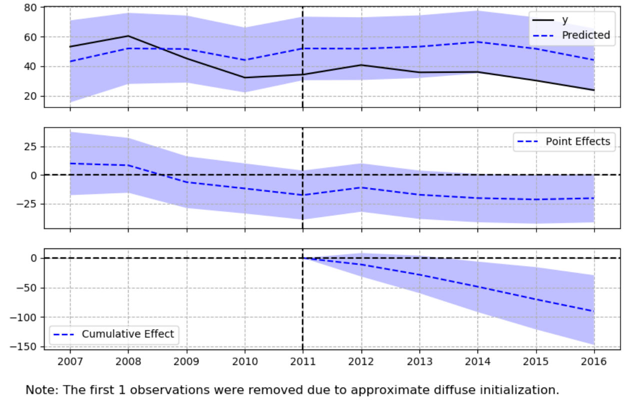


Note: The first 1 observations were removed due to approximate diffuse initialization.

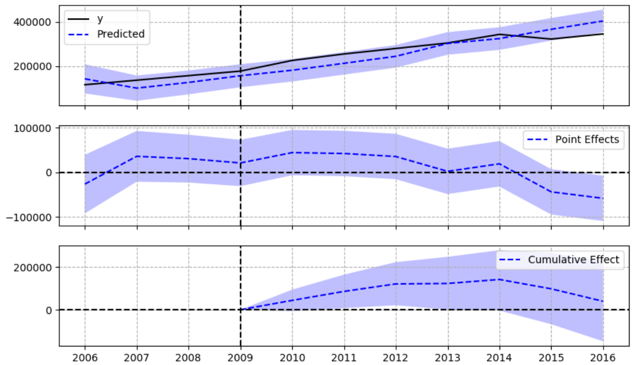
Air quality better than Level II (days per year)

No data	No data

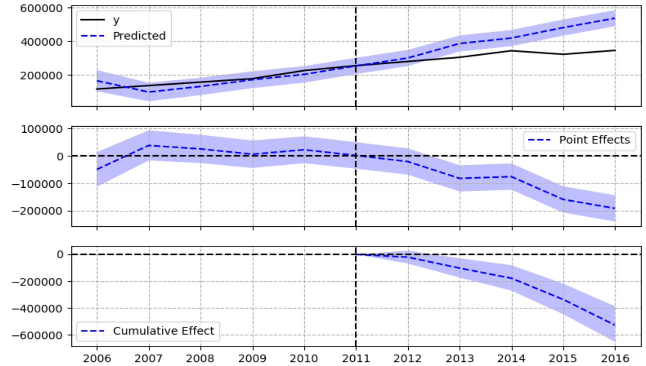




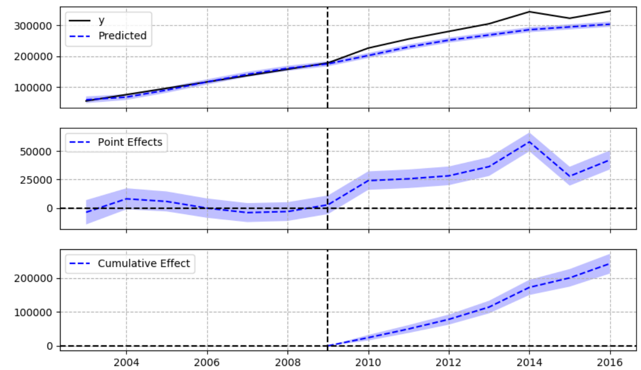
Monthly payment per employee to housing price per m^2 ratio (%)



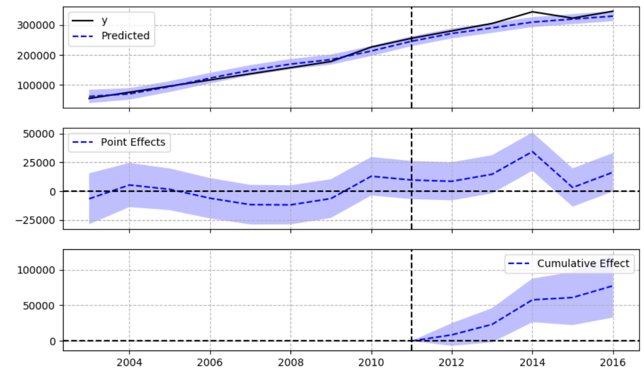
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

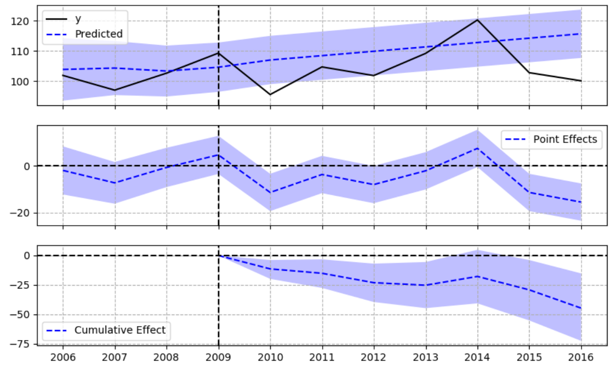


Note: The first 1 observations were removed due to approximate diffuse initialization.

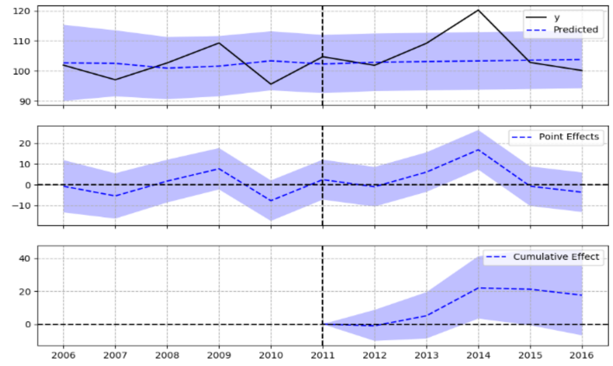


Note: The first 1 observations were removed due to approximate diffuse initialization.

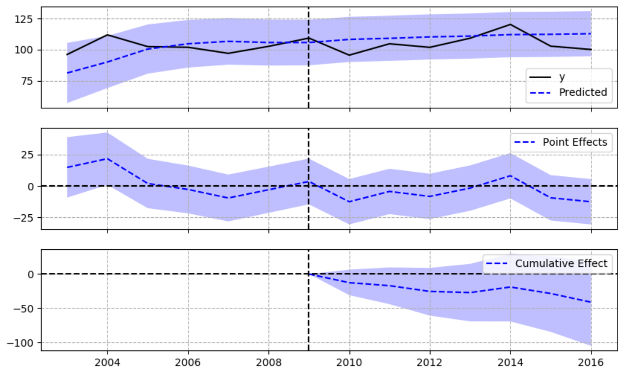
Healthcare coverage (number of people)



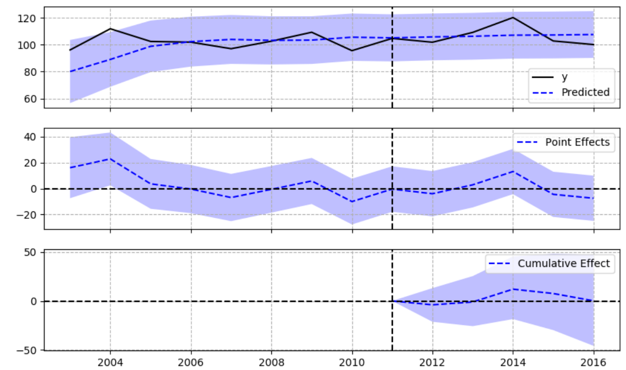
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

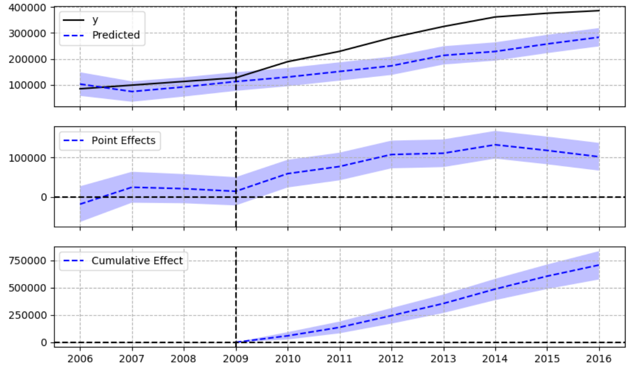


Note: The first 1 observations were removed due to approximate diffuse initialization.

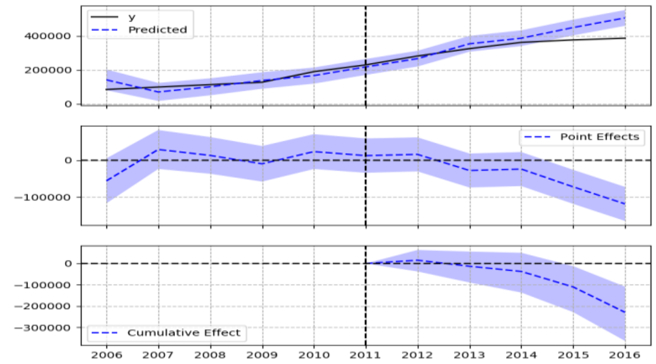


Note: The first 1 observations were removed due to approximate diffuse initialization.

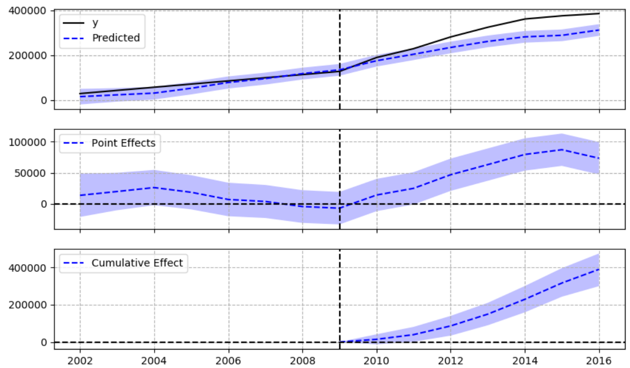
Healthcare coverage rate (%)



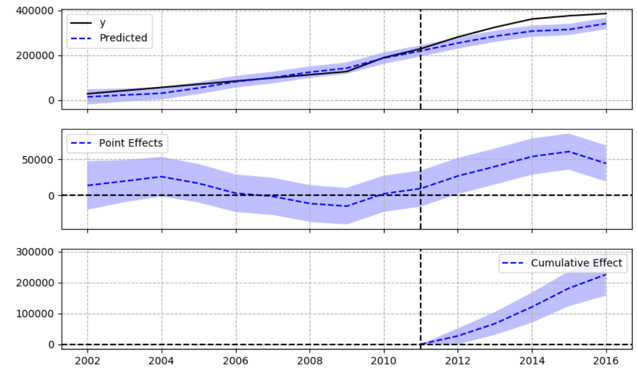
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

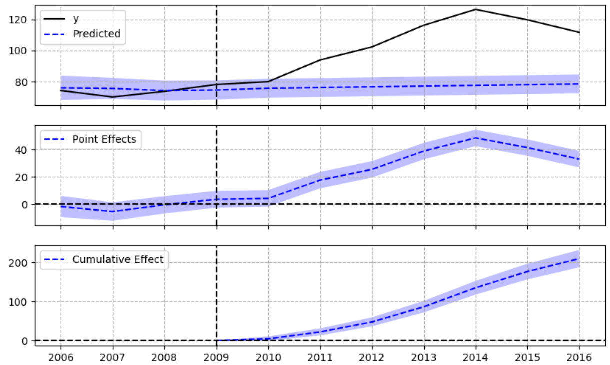


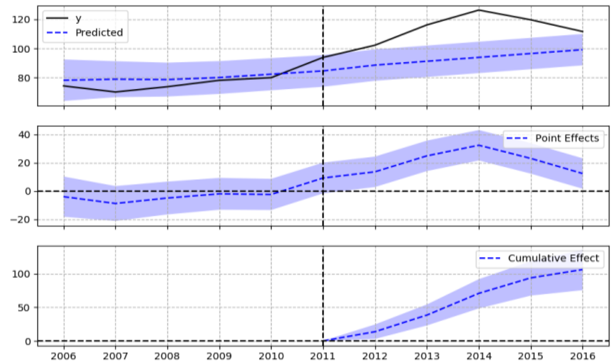
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

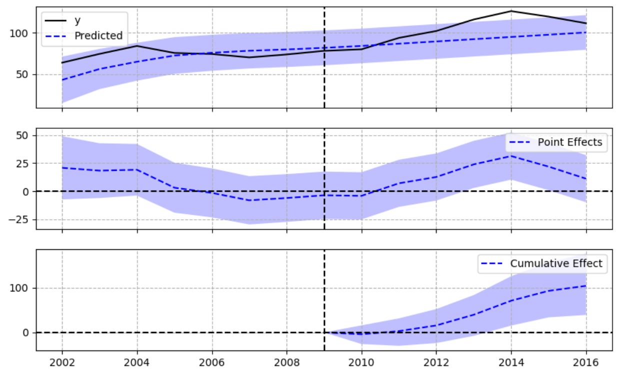
Pension coverage (number of people)

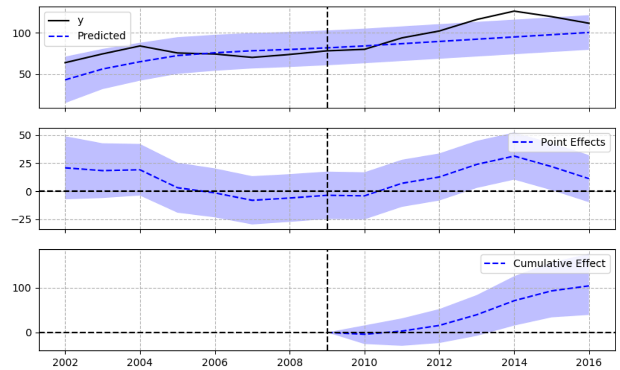




Note: The first 1 observations were removed due to approximate diffuse initialization.

Note: The first 1 observations were removed due to approximate diffuse initialization.



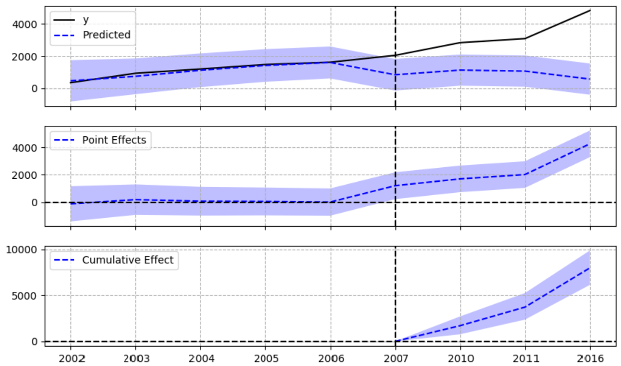


Note: The first 1 observations were removed due to approximate diffuse initialization.

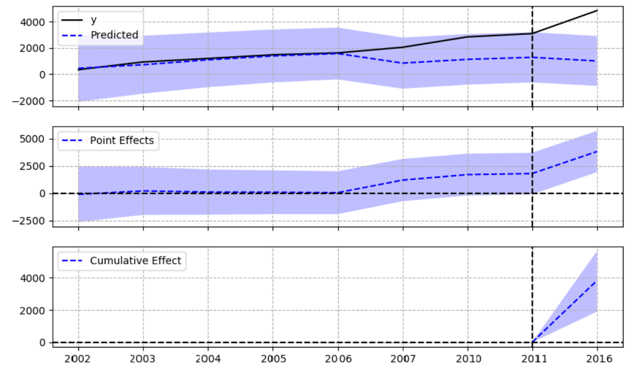
Note: The first 1 observations were removed due to approximate diffuse initialization.

Pension coverage rate (%)

No data	No data



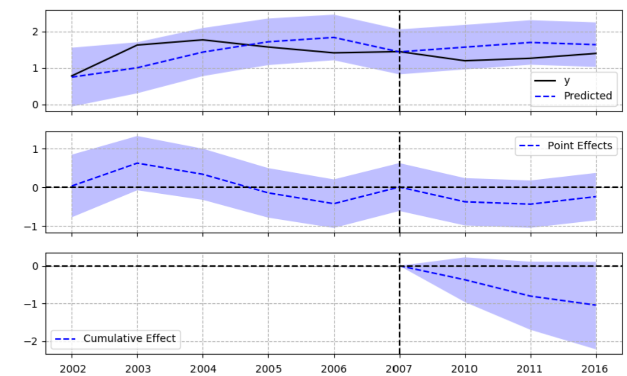
Note: The first 1 observations were removed due to approximate diffuse initialization.



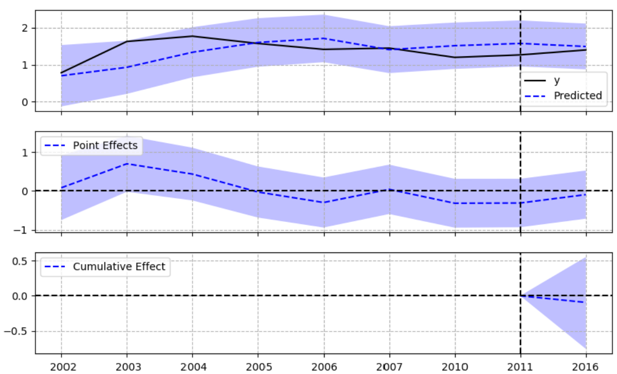
Note: The first 1 observations were removed due to approximate diffuse initialization.

Compulsory education enrolment (number of people)

No data	No data



Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

Compulsory education enrolment rate (%)

Table S5: average absolute effect of EIP upgrade on each indicator for BDA

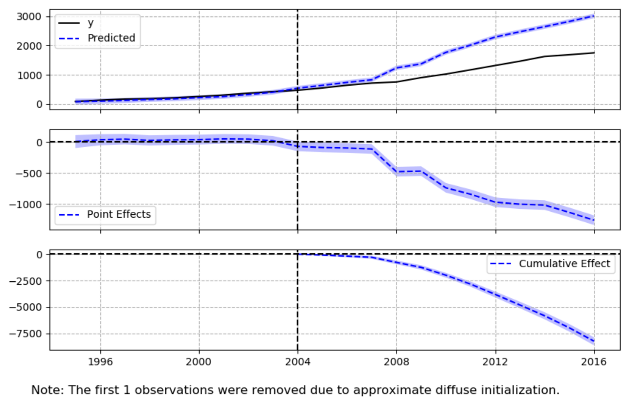
Scenario / Indicators	Scenario A (Another IP in the city as covariate)				Scenario B (Industry/urban of city as covariate)			
	BDA (2009 as the effect year)		BDA (2011 as the effect year)		BDA (2009 as the effect year)		BDA (2011 as the effect year)	
	Absolute effect (mean)	Standard error	Absolute effect (mean)	Standard error	Absolute effect (mean)	Standard error	Absolute effect (mean)	Standard error
Economic output	-3.47E+02	2.45E+01	-3.19E+02	2.85E+01	-1.67E+02	1.75E+01	-1.53E+02	1.97E+01
Employee number	-3.97E+04	3.28E+03	-1.15E+05	9.21E+03	9.04E+04	7.51E+03	5.32E+04	1.53E+04
Economic output per employee	-1.30E+01	1.30E+00	-7.40E+00	1.90E+00	-2.30E+01	1.50E+00	-1.12E+01	2.60E+00
Economic output per unit area	2.90E+00	3.00E-01	2.70E+00	3.00E-01	-3.10E+00	5.00E-01	-1.00E+00	6.00E-01
Monthly payment per employee	1.14E+03	2.04E+02	8.64E+02	3.99E+02	-9.43E+02	9.96E+01	-9.61E+02	8.91E+01
Energy use	1.46E+06	5.91E+04	1.91E+06	1.37E+05	2.21E+05	5.80E+04	1.68E+05	5.53E+04
Freshwater use	no data		no data		1.22E+07	3.82E+06	-1.65E+07	4.87E+06
Land use	1.10E+02	1.00E-01	1.57E+02	4.00E-01	-4.00E-01	1.60E+00	-3.10E+00	2.70E+00
Energy use per unit economic output	1.13E+01	5.20E+00	2.30E+01	5.50E+00	2.59E+01	1.57E+01	1.12E+01	1.34E+01
Energy use per unit area	9.41E+03	1.22E+03	8.90E+03	2.70E+03	2.12E+03	1.31E+03	7.34E+03	1.47E+03
Freshwater use per unit economic output	no data		no data		5.75E-01	6.13E-01	-1.21E-01	6.74E-01
Waste heat use	no data		no data		-3.18E+05	5.19E+04	-4.34E+05	6.19E+04
Residual heat reuse ratio	no data		no data		-1.70E+00	5.00E-01	-4.00E-01	7.00E-01
Reclaimed water sales	no data		no data		6.05E+06	1.11E+06	2.70E+06	7.20E+05
Reclaimed water sales ratio	no data		no data		-8.80E+00	6.70E+00	-1.13E+01	3.90E+00
GHG emissions	no data		no data		4.32E+06	2.63E+05	8.41E+05	9.40E+04

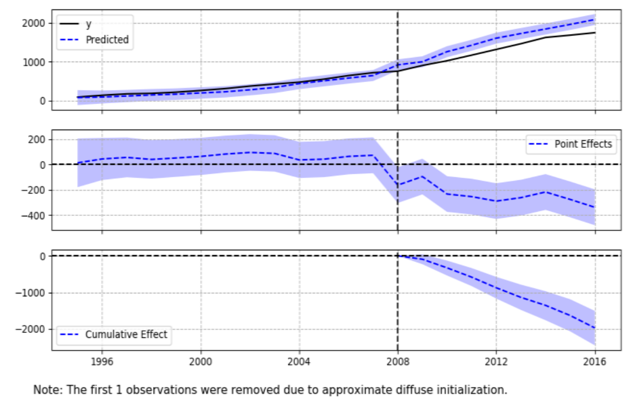
GHG emissions per unit economic output	no data		no data		2.00E-01	1.00E-01	1.00E-01	1.00E-01
Wastewater discharge	no data		no data		1.67E+07	5.23E+05	1.31E+07	2.19E+06
Wastewater discharge per unit economic output	no data		no data		4.40E+00	5.00E-01	3.60E+00	7.00E-01
Wastewater discharge per unit area	no data		no data		4.20E+05	1.56E+04	2.63E+05	3.93E+04
Wastewater treatment capacity	no data		no data		1.71E+07	1.14E+06	1.69E+07	2.71E+06
Air quality	no data		no data		-2.35E+01	1.34E+01	-3.89E+01	1.31E+01
Monthly payment per employee to housing price per m^2 ratio	no data		no data		-2.04E+01	3.80E+00	-1.81E+01	6.00E+00
Healthcare coverage	5.70E+03	1.37E+04	-1.06E+05	1.35E+04	3.47E+04	2.12E+03	1.55E+04	4.56E+03
Healthcare coverage rate	-6.40E+00	2.10E+00	4.70E+00	2.70E+00	-5.90E+00	4.50E+00	0.00E+00	4.80E+00
Pension coverage	1.01E+05	9.46E+03	-4.58E+04	1.30E+04	5.56E+04	6.38E+03	4.83E+04	6.09E+03
Pension coverage rate	3.24E+01	1.80E+00	2.13E+01	3.10E+00	1.48E+01	5.00E+00	2.39E+01	6.30E+00
Compulsory education enrolment	no data		no data		3.82E+03	9.65E+02	3.74E+03	4.96E+02
Compulsory education enrolment rate	no data		no data		-3.00E-01	2.00E-01	-1.00E-01	3.00E-01

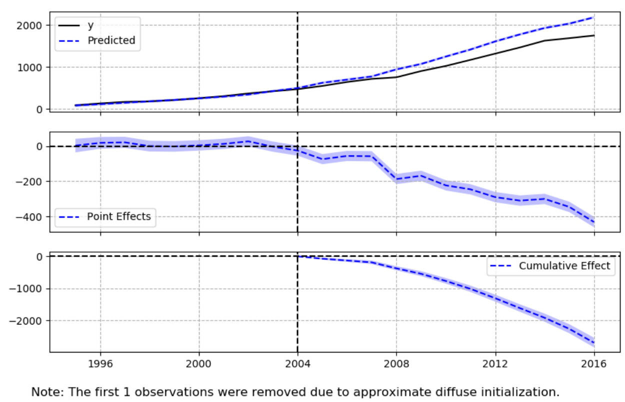
Figure S2. Causal Impact results for TEDA with different tests

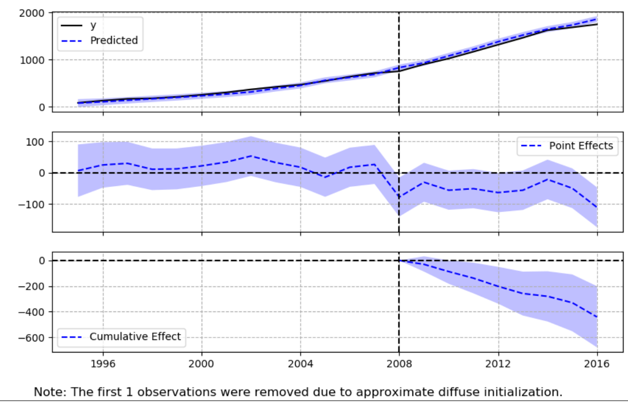
Figures for each indicator are laid out in the following order:

1A (BND as covariate, 2004 as effective year)	2A (BND as covariate, 2008 as effective year)
1B (Industry/urban as covariate, 2004 as effective year)	2B (Industry/urban as covariate, 2008 as effective year)

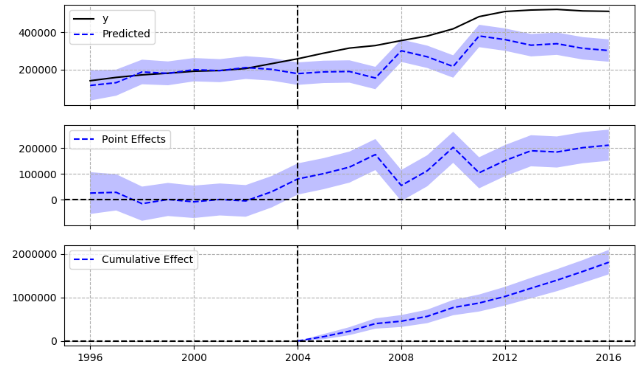




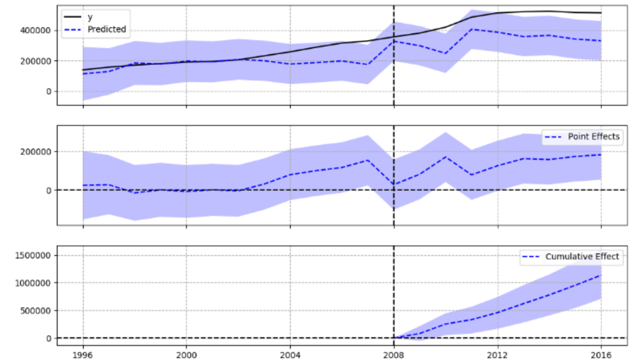




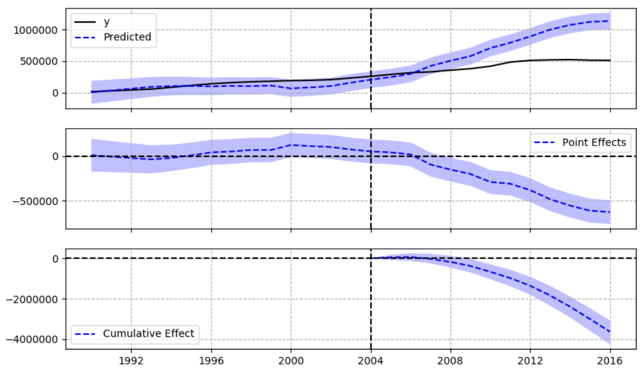
Economic output (100m RMB)



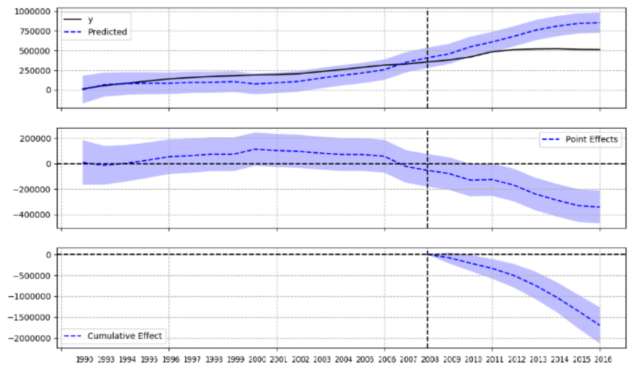
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

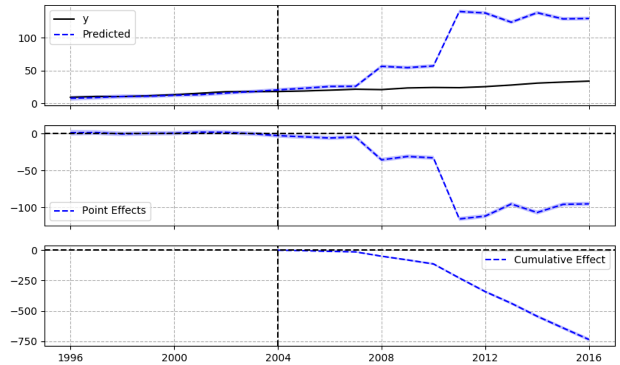


Note: The first 1 observations were removed due to approximate diffuse initialization.

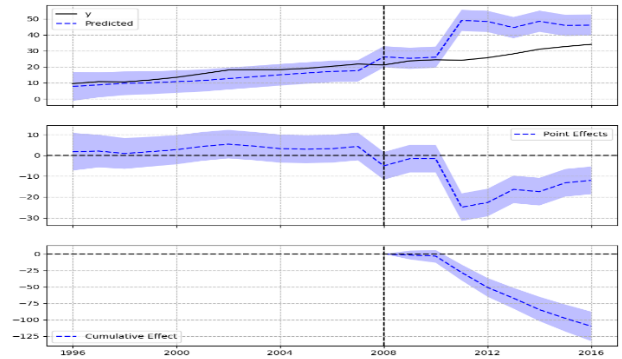


Note: The first 1 observations were removed due to approximate diffuse initialization.

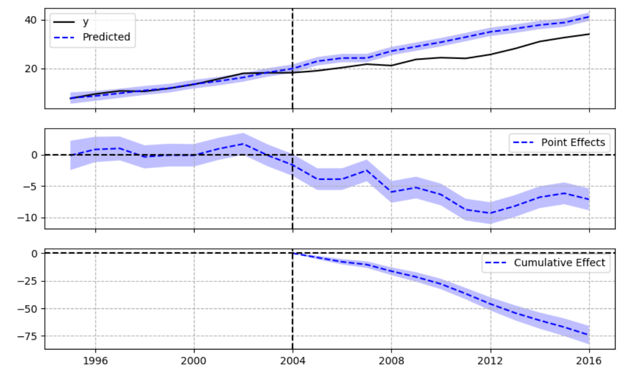
Employee number (number of people)



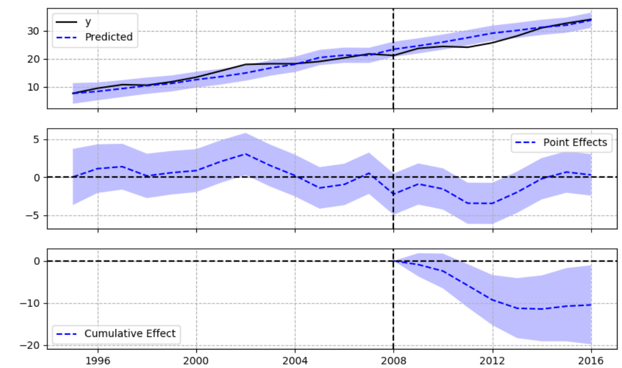
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

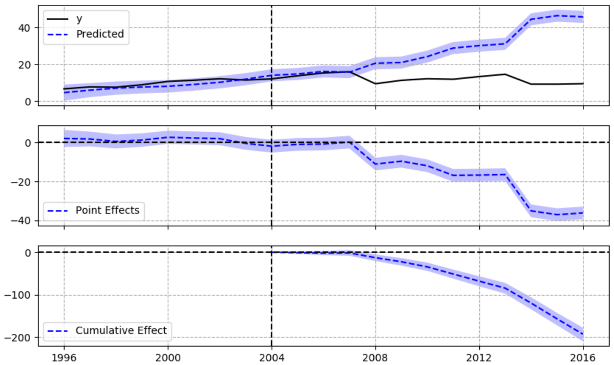


Note: The first 1 observations were removed due to approximate diffuse initialization.

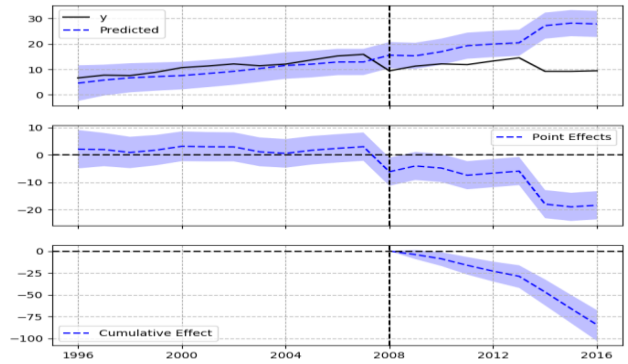


Note: The first 1 observations were removed due to approximate diffuse initialization.

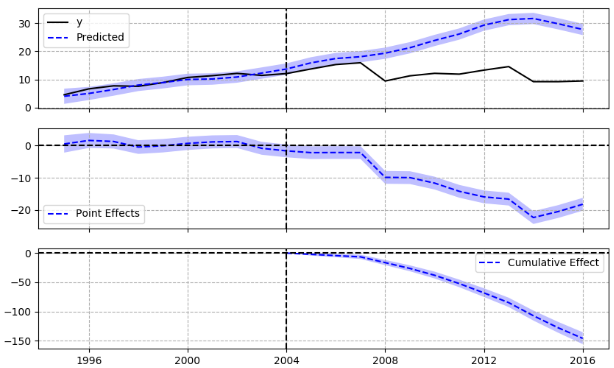
Economic output per employee (10,000 RMB per employee)



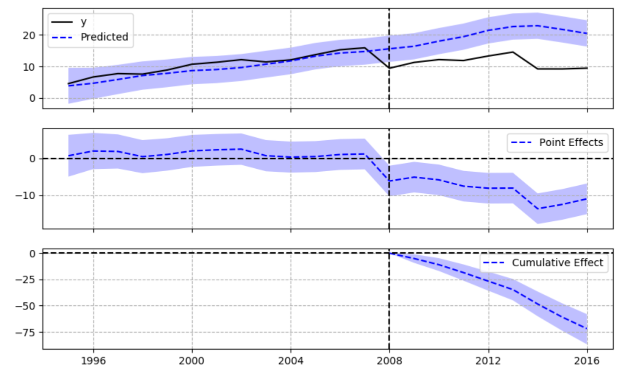
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

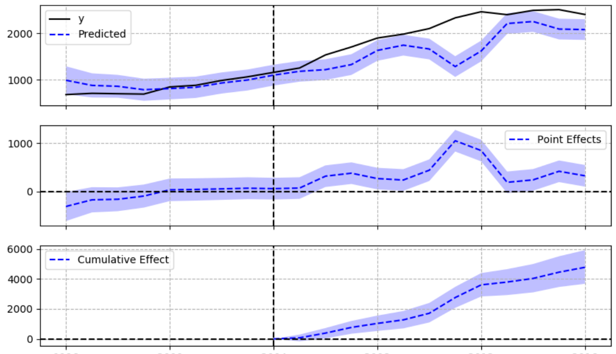


Note: The first 1 observations were removed due to approximate diffuse initialization.

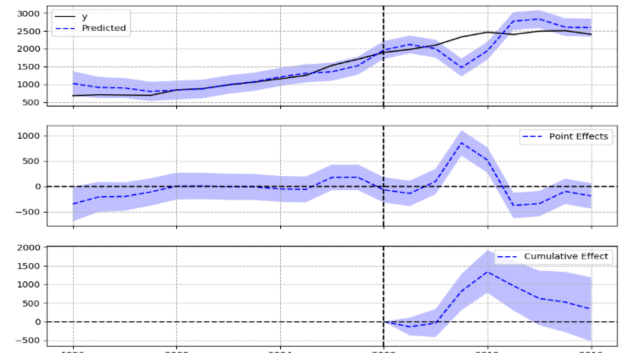


Note: The first 1 observations were removed due to approximate diffuse initialization.

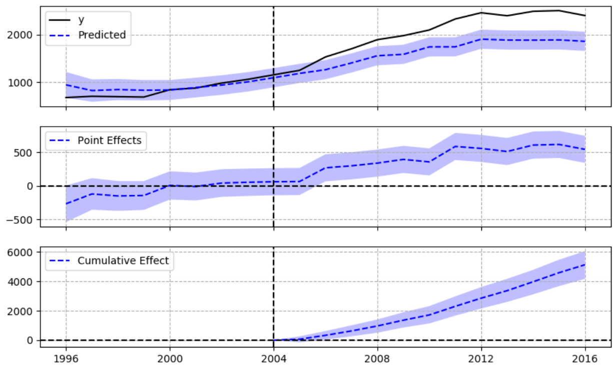
Economic output per unit area (100m RMB per square kilometre)



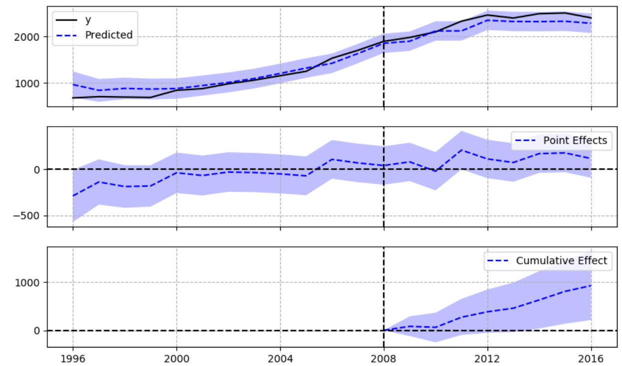
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.



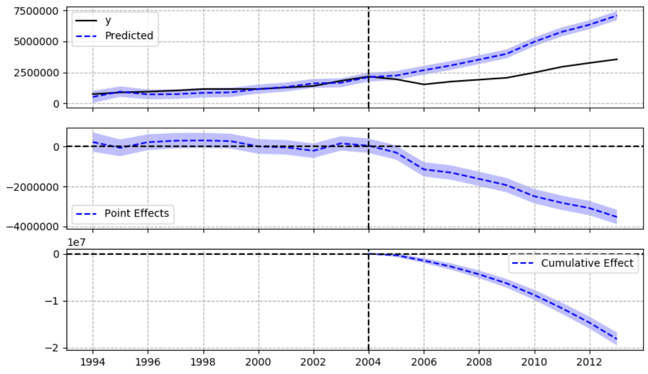
Note: The first 1 observations were removed due to approximate diffuse initialization.



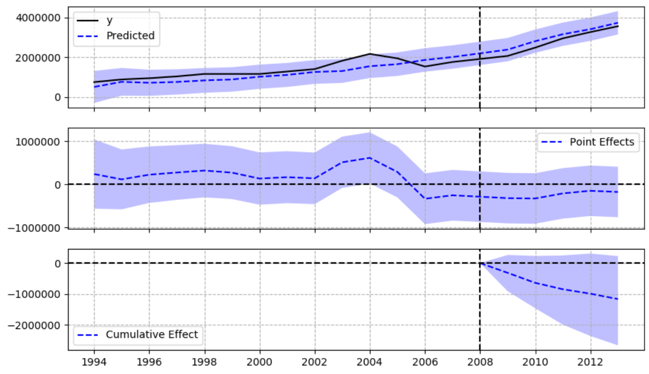
Note: The first 1 observations were removed due to approximate diffuse initialization.

Monthly payment per employee (inflation adjusted) (RMB per month per employee)

No data	No data

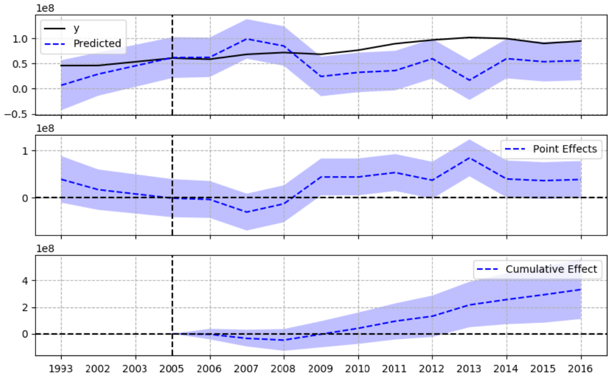


Note: The first 1 observations were removed due to approximate diffuse initialization.

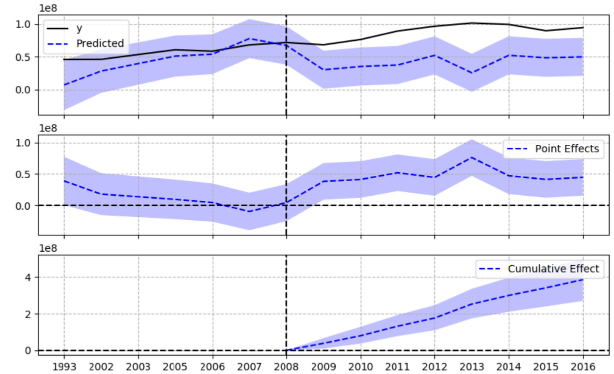


Note: The first 1 observations were removed due to approximate diffuse initialization.

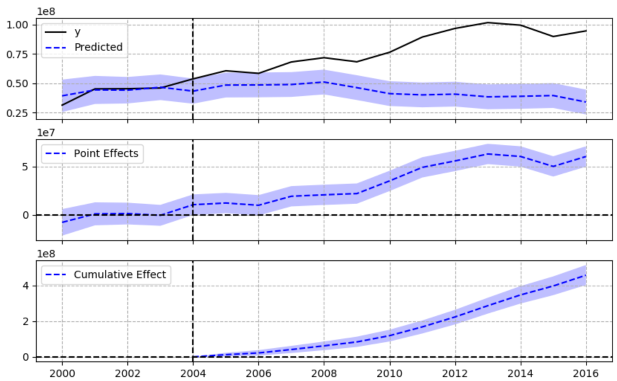
Energy use (tsce per year)



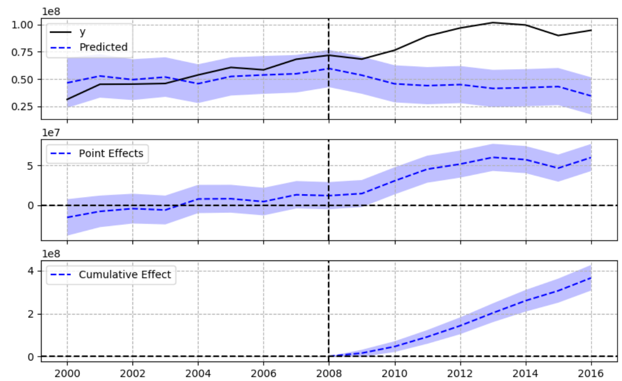
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

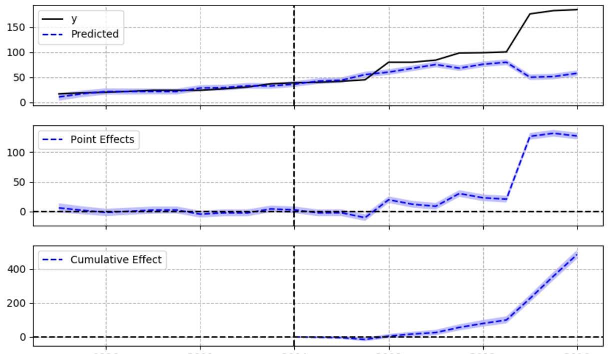


Note: The first 1 observations were removed due to approximate diffuse initialization.

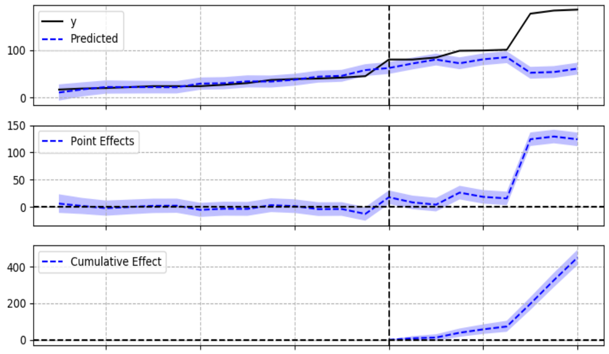


Note: The first 1 observations were removed due to approximate diffuse initialization.

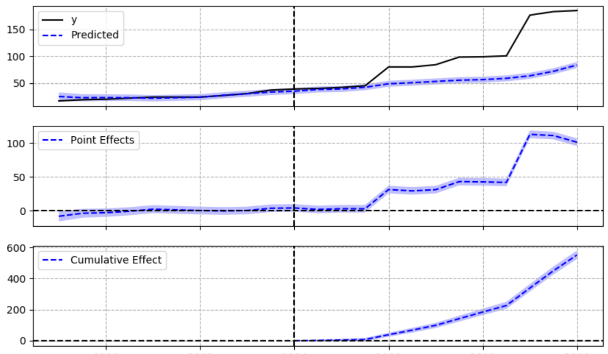
Freshwater use (tonne per year)



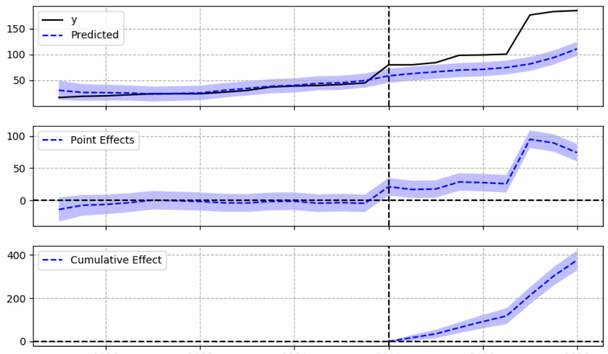
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.



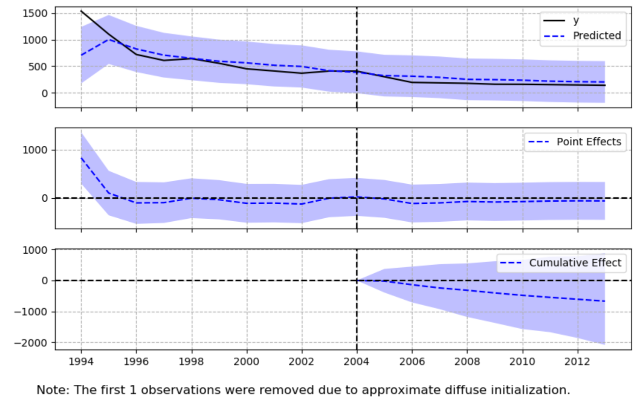
Note: The first 1 observations were removed due to approximate diffuse initialization.

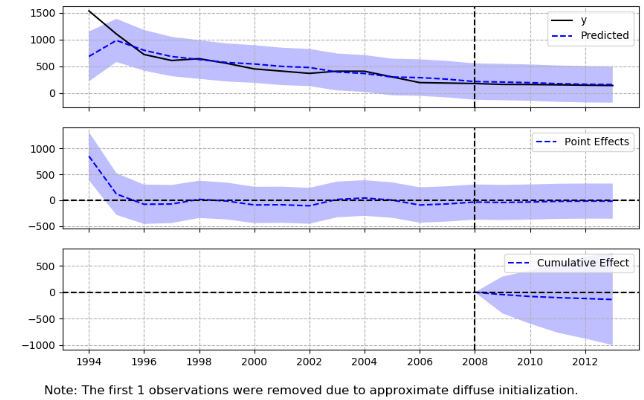


Note: The first 1 observations were removed due to approximate diffuse initialization.

Land use (square kilometre)

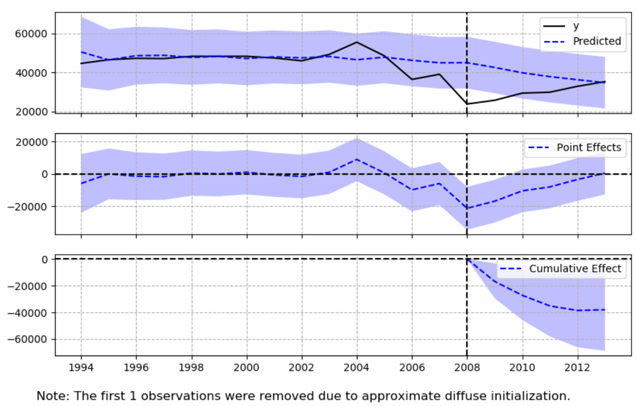
No data	No data

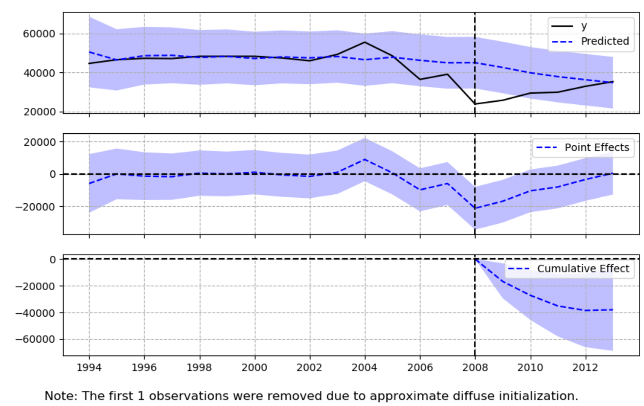




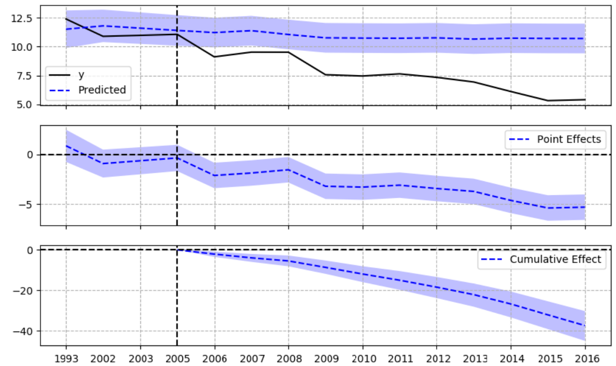
Energy use per unit economic output (tsce per 10m RMB)

No data	No data

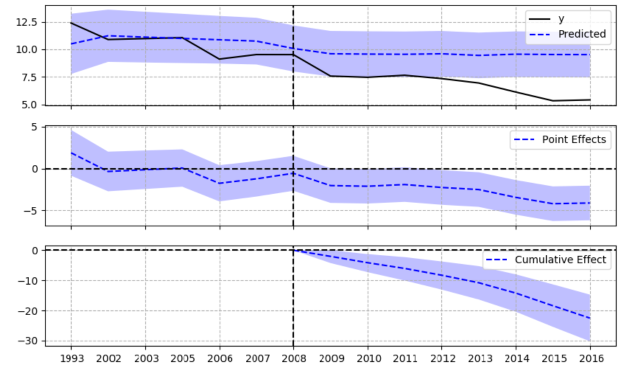




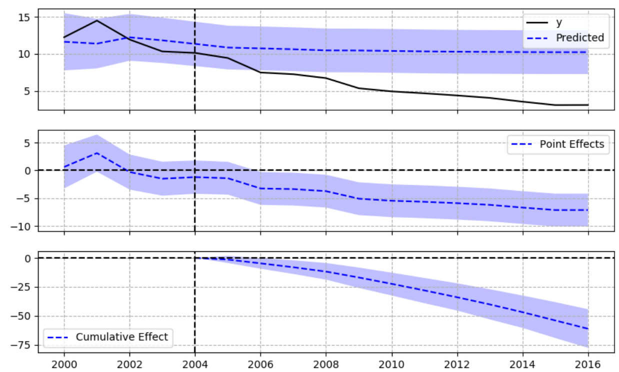
Energy use per unit area (tonne per square kilometre)



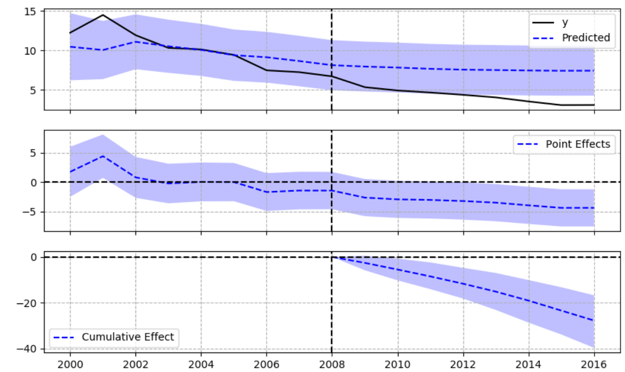
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.



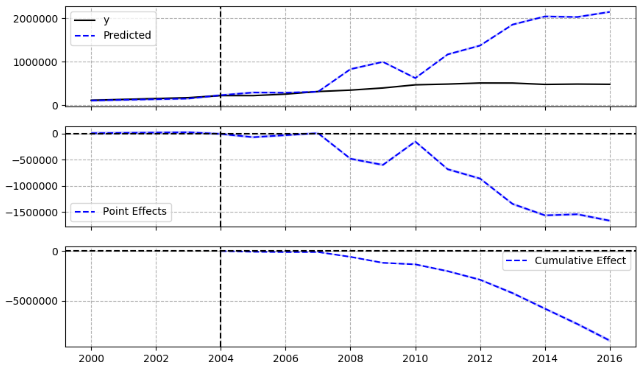
Note: The first 1 observations were removed due to approximate diffuse initialization.



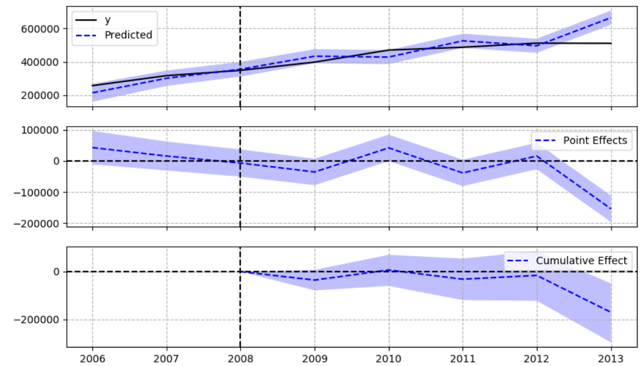
Note: The first 1 observations were removed due to approximate diffuse initialization.

Freshwater use per unit economic output (tonne per 10,000 RMB)

No data	No data



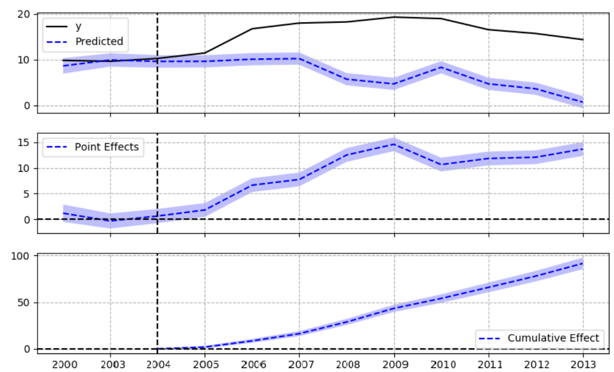
Note: The first 1 observations were removed due to approximate diffuse initialization.



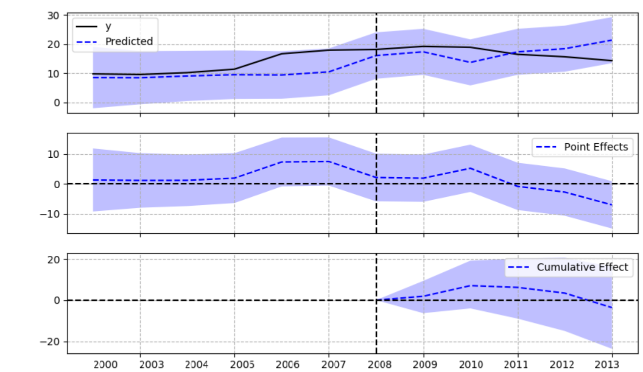
Note: The first 1 observations were removed due to approximate diffuse initialization.

Waste heat use (tsce per year)

No data	No data



Note: The first 1 observations were removed due to approximate diffuse initialization.

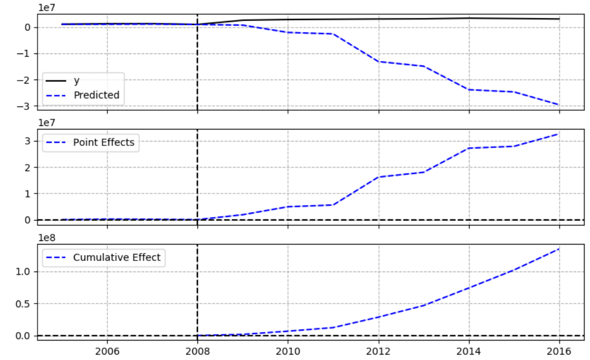


Note: The first 1 observations were removed due to approximate diffuse initialization.

Residual heat reuse ratio (%)

No data	No data

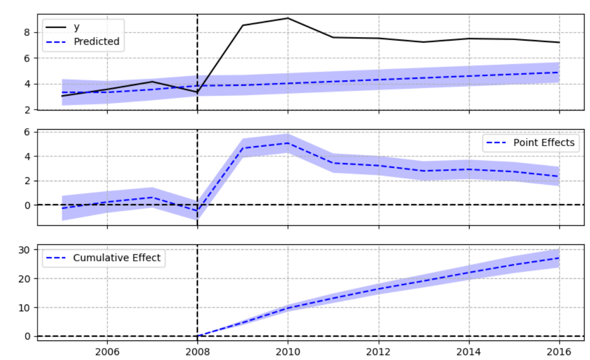
Data too few



Note: The first 1 observations were removed due to approximate diffuse initialization.

Reclaimed water sales (tonne per year)

No data	No data
Data too few	

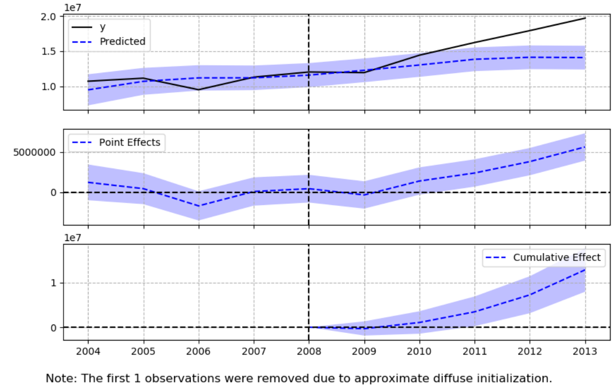


Note: The first 1 observations were removed due to approximate diffuse initialization.

Reclaimed water sales ratio (%)

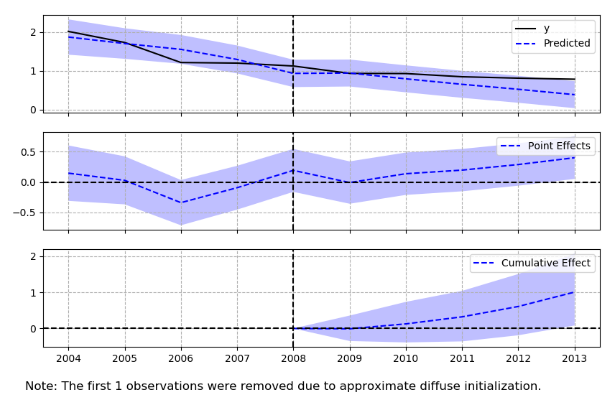
No data	No data

Data too few



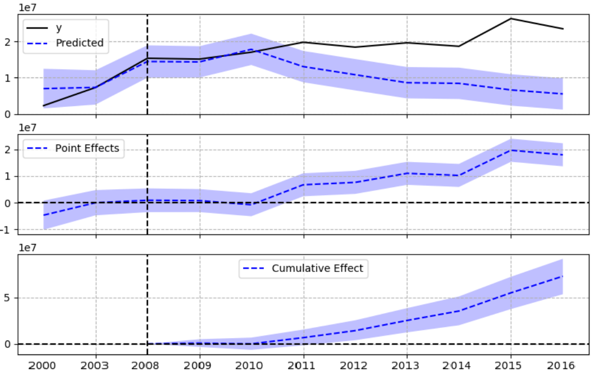
GHG emissions (tonne CO_2-equivalent per year)

No data	No data
Data too few	

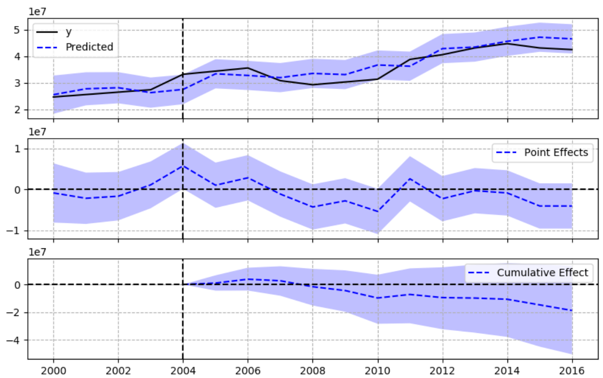


GHG emissions per unit economic output (tonne CO_2-equivalent per 10,000 RMB)

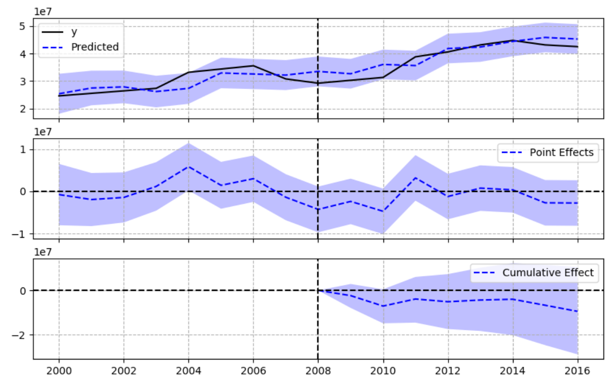
Data too few



Note: The first 1 observations were removed due to approximate diffuse initialization.



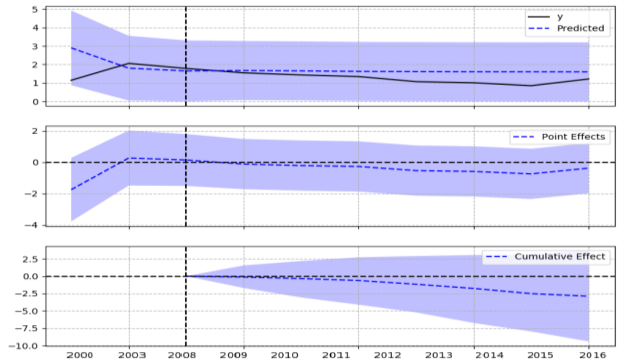
Note: The first 1 observations were removed due to approximate diffuse initialization.



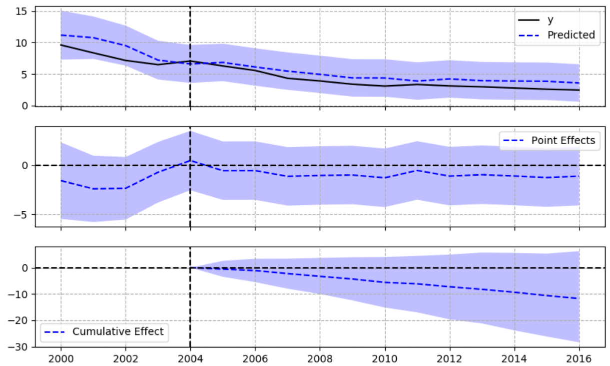
Note: The first 1 observations were removed due to approximate diffuse initialization.

Wastewater discharge (tonne per year)

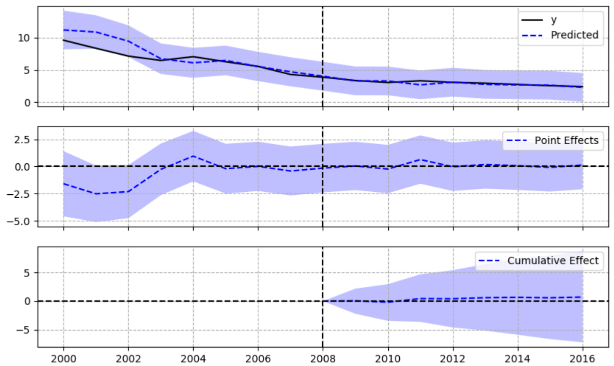
Data too few



Note: The first 1 observations were removed due to approximate diffuse initialization.



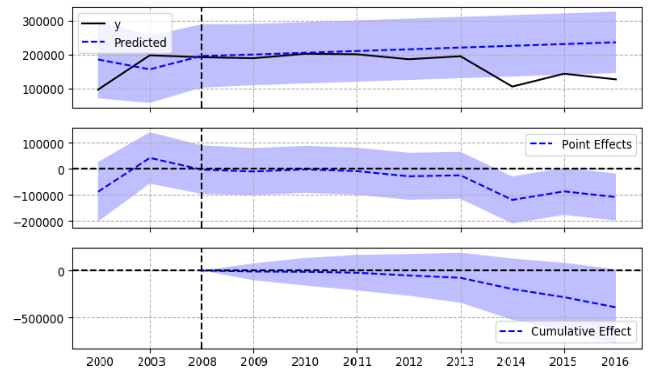
Note: The first 1 observations were removed due to approximate diffuse initialization.



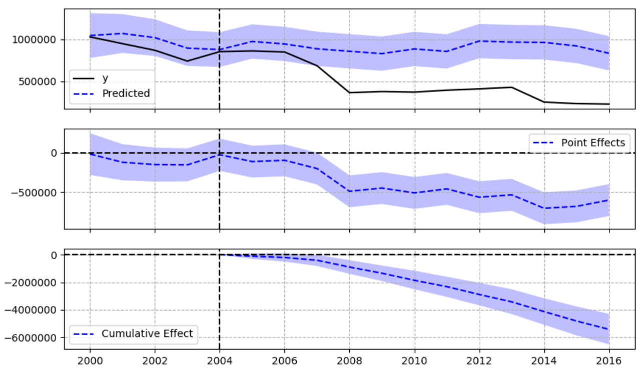
Note: The first 1 observations were removed due to approximate diffuse initialization.

Wastewater discharge per unit economic output (tonne per 10,000 RMB)

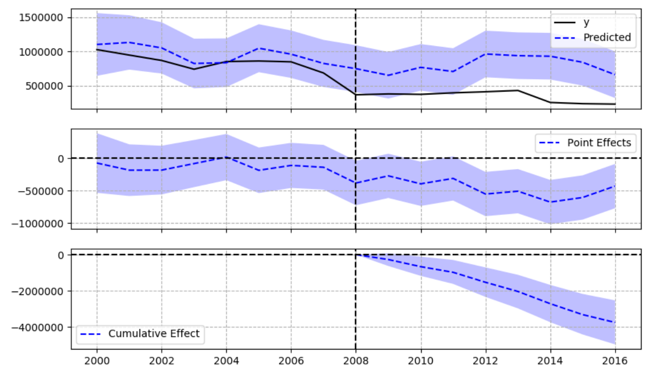
Data too few



Note: The first 1 observations were removed due to approximate diffuse initialization.



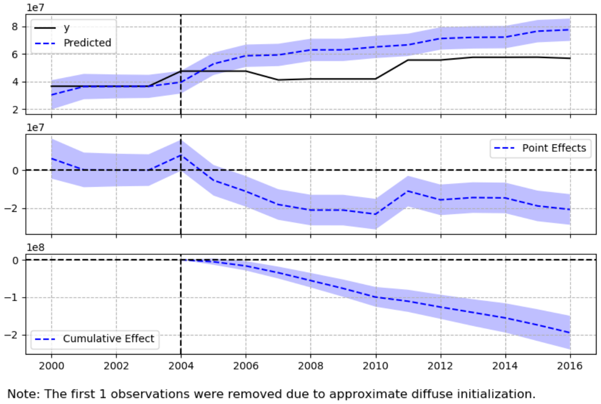
Note: The first 1 observations were removed due to approximate diffuse initialization.

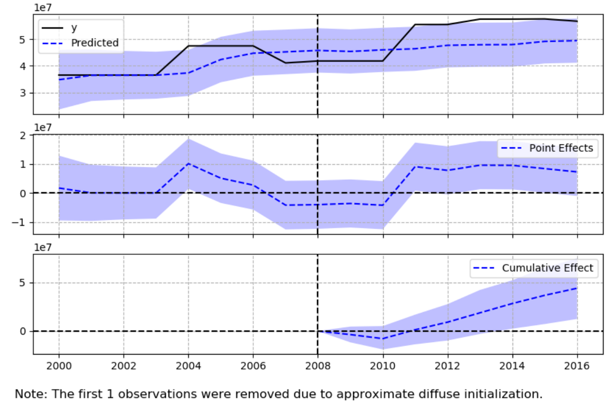


Note: The first 1 observations were removed due to approximate diffuse initialization.

Wastewater discharge per unit area (tonne per square kilometre)

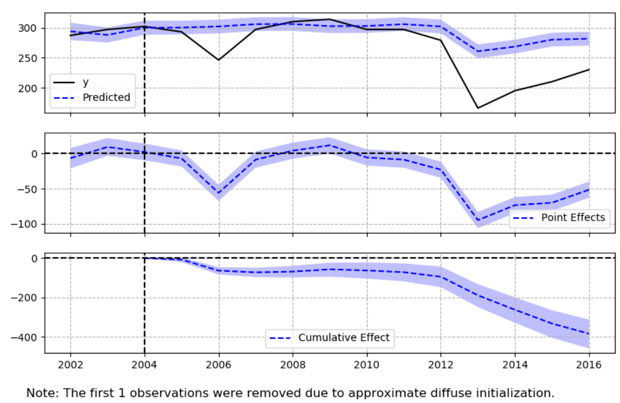
No data	No data

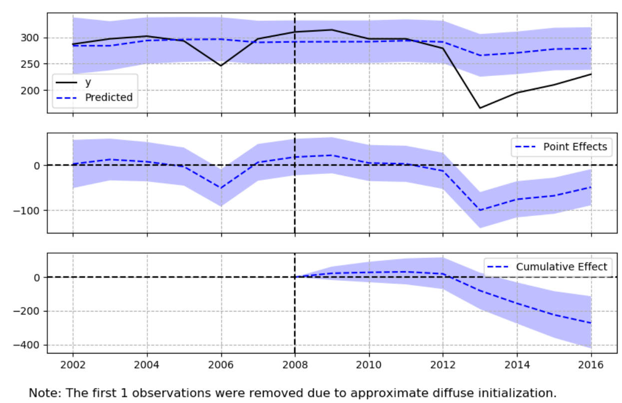




Wastewater treatment capacity (tonne per year)

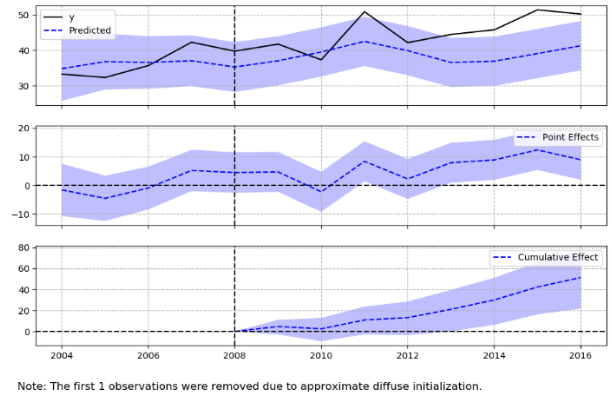
No data	No data



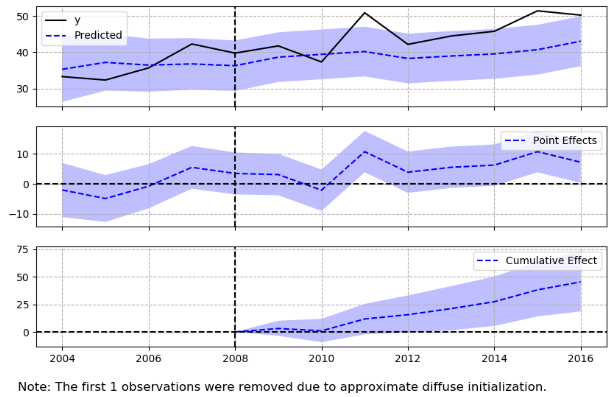


Air quality better than Level II (days per year)

Data too few

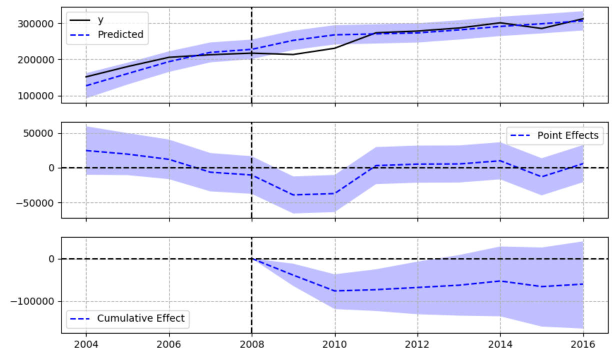


Data too few



Monthly payment per employee to housing price per m^2 ratio (%)

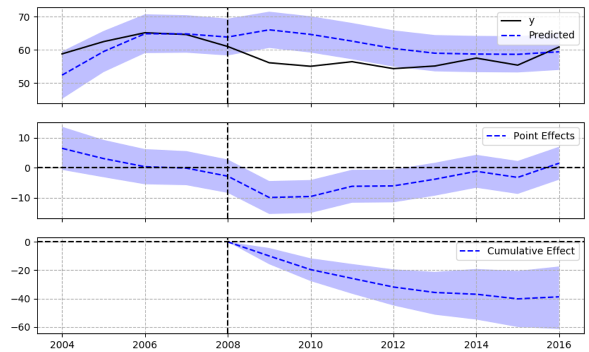
No data	No data
Data too few	



Note: The first 1 observations were removed due to approximate diffuse initialization.

Healthcare coverage (number of people)

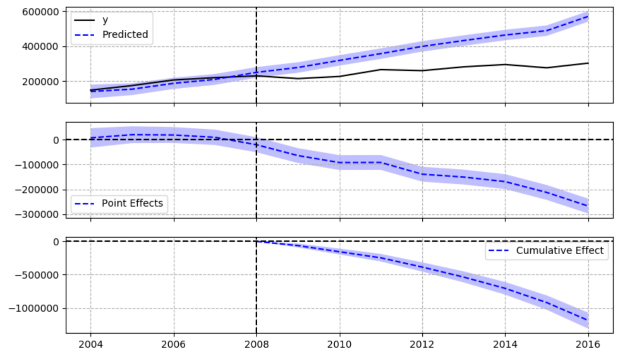
No data	No data
Data too few	



Note: The first 1 observations were removed due to approximate diffuse initialization.

Healthcare coverage rate (%)

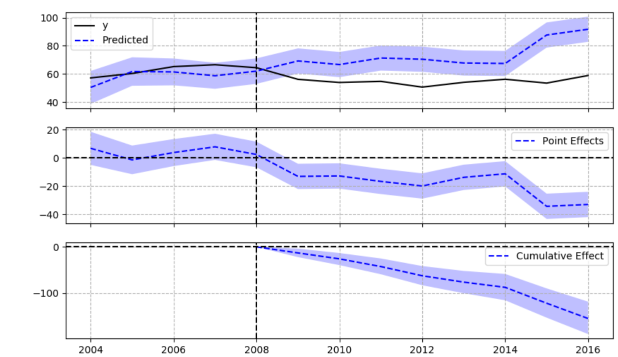
No data	No data
Data too few	



Note: The first 1 observations were removed due to approximate diffuse initialization.

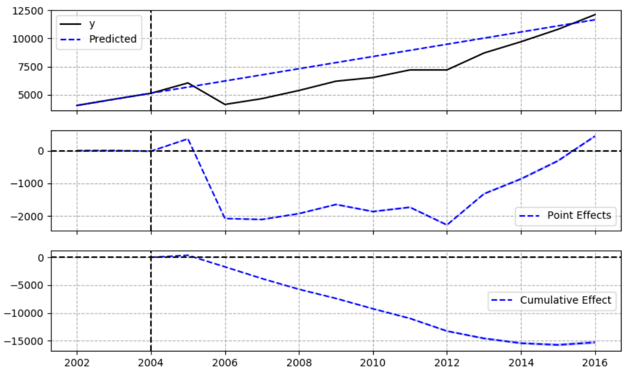
Pension coverage (number of people)

No data	No data
Data too few	

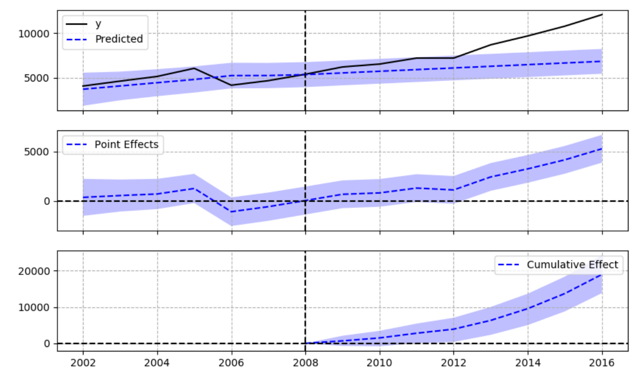


Note: The first 1 observations were removed due to approximate diffuse initialization.

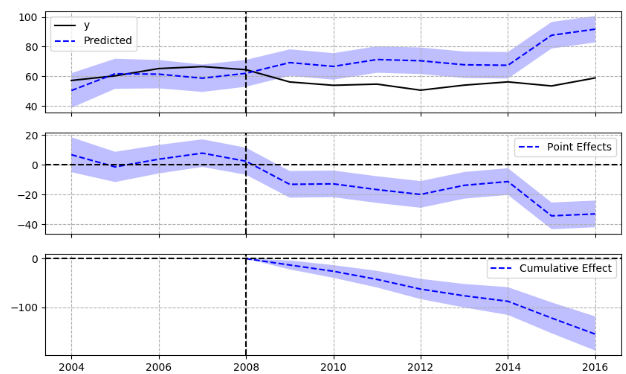
Pension coverage rate (%)



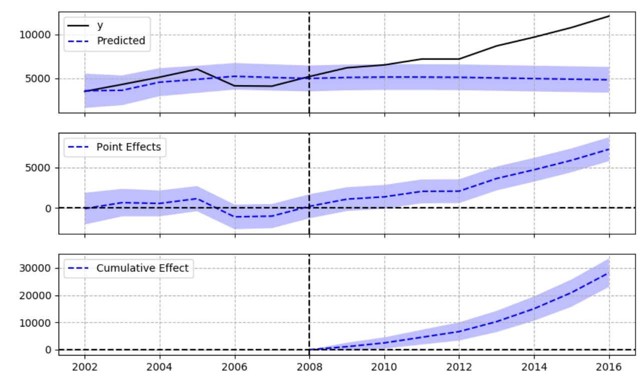
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

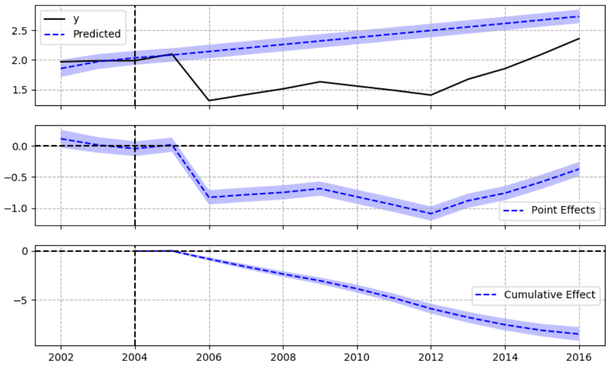


Note: The first 1 observations were removed due to approximate diffuse initialization.

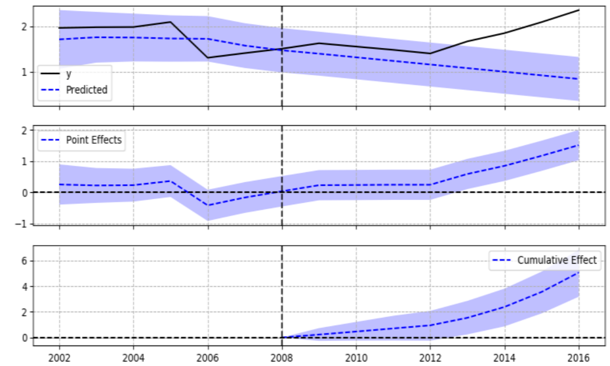


Note: The first 1 observations were removed due to approximate diffuse initialization.

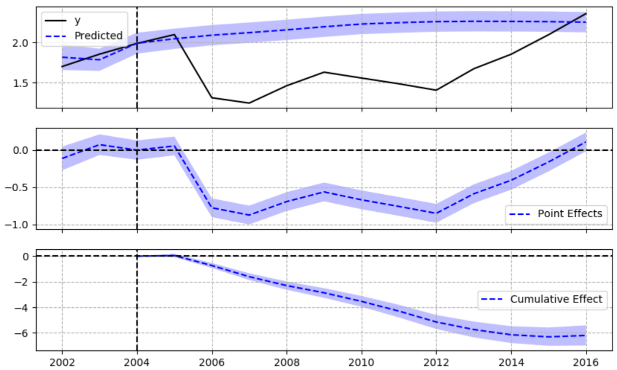
Compulsory education enrolment (number of people)



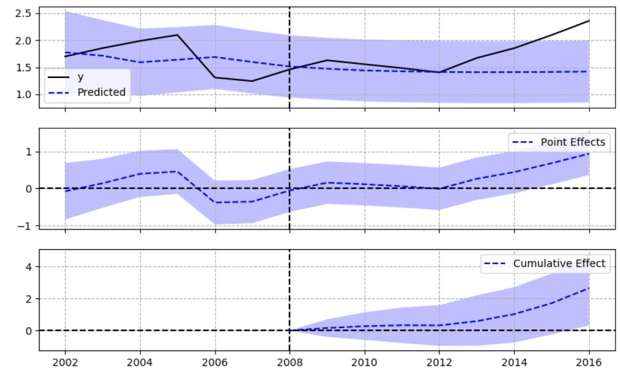
Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.



Note: The first 1 observations were removed due to approximate diffuse initialization.

Compulsory education enrolment rate (%)

Table S6: average absolute effect of EIP upgrade on each indicator for TEDA

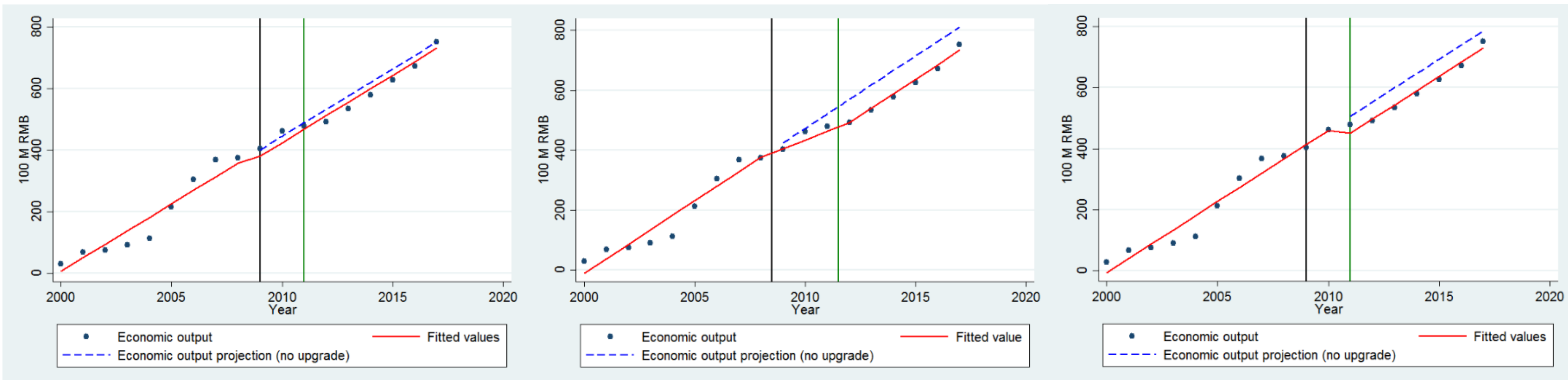
Scenario / Indicators	Scenario A (Another IP in the city as covariate)				Scenario B (Industry/urban of city as covariate)			
	TEDA (2004 as effect year)		TEDA (2008 as effect year)		TEDA (2004 as effect year)		TEDA (2008 as effect year)	
	Absolute effect (mean)	Standard error	Absolute effect (mean)	Standard error	Absolute effect (mean)	Standard error	Absolute effect (mean)	Standard error
Economic output	-686.1	16.1	-246.4	30.6	-173.6	8.6	-1.39E+01	1.54E+01
Employee number	150849.8	11946.1	141873.5	28211.9	-324031.9	23200.1	-215406.4	24911.1
Economic output per employee	-61.3	0.6	-13.7	1.4	-2.8	0.5	1.4	0.6
Economic output per unit area	-16.1	0.7	-10.5	1.1	-20.3	0.4	-13.1	1.1
Monthly payment per employee	398.1	47.7	4.22E+01	5.48E+01	476.2	41.9	3.97E+01	5.19E+01
Energy use	no data		no data		-2.02E+06	7.79E+04	-2.33E+05	1.47E+05
Freshwater use	30071144.7	10512843.9	48178685	7208324.7	38177651.5	2384333	45793410.5	3810369.3
Land use	40.4	1.1	56.4	2.7	46	1.2	46.9	2.8
Energy use per unit economic output	no data		no data		-7.43E+01	8.39E+01	-2.75E+01	8.89E+01
Energy use per unit area	no data		no data		-1.10E+04	1.28E+03	-7.61E+03	3.19E+03
Freshwater use per unit economic output	-3.4	0.3	-2.8	0.5	-5.1	0.7	-3.5	0.7
Waste heat use	no data		no data		-749548.2	6453.3	-34005.9	12535.6
Residual heat reuse ratio	no data		no data		10.2	0.3	-4	1.6
Reclaimed water sales	no data		no data		data too few		16788030.3	62541.9

Reclaimed water sales ratio	no data		no data		data too few		3.4	0.2
GHG emissions	no data		no data		data too few		2571641.2	495655.8
GHG emissions per unit economic output	no data		no data		data too few		0.2	0.1
Wastewater discharge	data too few		9119600	1145251.5	-1.57E+06	1.36E+06	-1.19E+06	1.20E+06
Wastewater discharge per unit economic output	data too few		-4.00E-01	5.00E-01	-1.00E+00	7.00E-01	1.00E-01	5.00E-01
Wastewater discharge per unit area	data too few		-49203	25411.4	-451204.4	46971.8	-468809.5	77413.6
Wastewater treatment capacity	no data		no data		-16259812	1912240.7	5502628.3	1927783.1
Air quality	no data		no data		-32	3.1	-34.1	9.9
Monthly payment per employee to housing price per m^2 ratio	data too few		6.4	1.8	data too few		5.7	1.8
Healthcare coverage	no data		no data		data too few		-7.53E+03	6.53E+03
Healthcare coverage rate	no data		no data		data too few		-4.8	1.4
Pension coverage	no data		no data		data too few		-148294.6	7646.8
Pension coverage rate	no data		no data		data too few		-19.3	2.2
Compulsory education enrolment	-1275.3	11.8	2373.2	325.6	1486	152.1	3525	332.3
Compulsory education enrolment rate	-0.7	0	0.6	0.1	-0.5	0	0.3	0.1

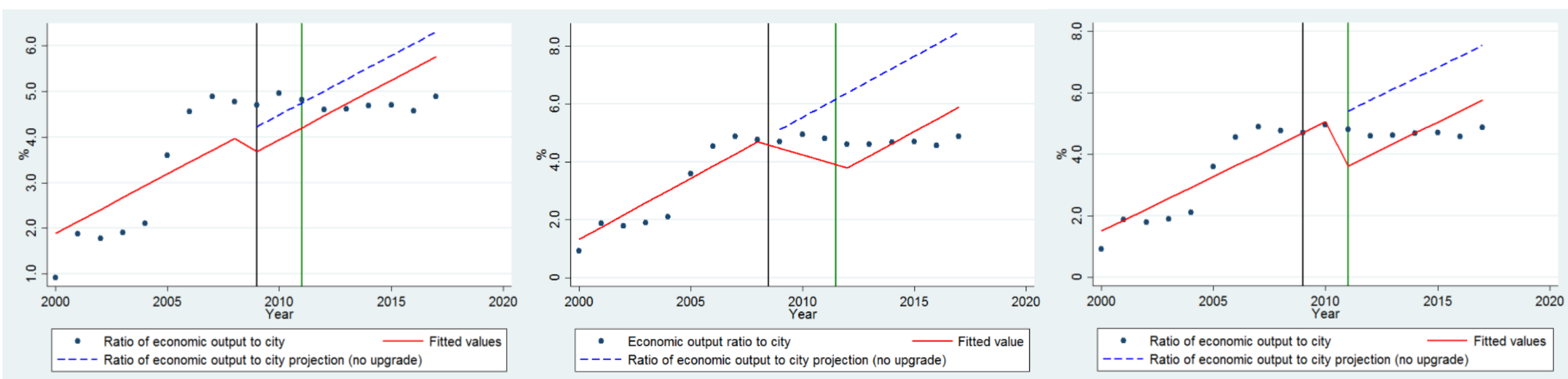
Figure S3. Interrupted Time Series analysis results for BDA with different tests

Figures are laid out in the following order:

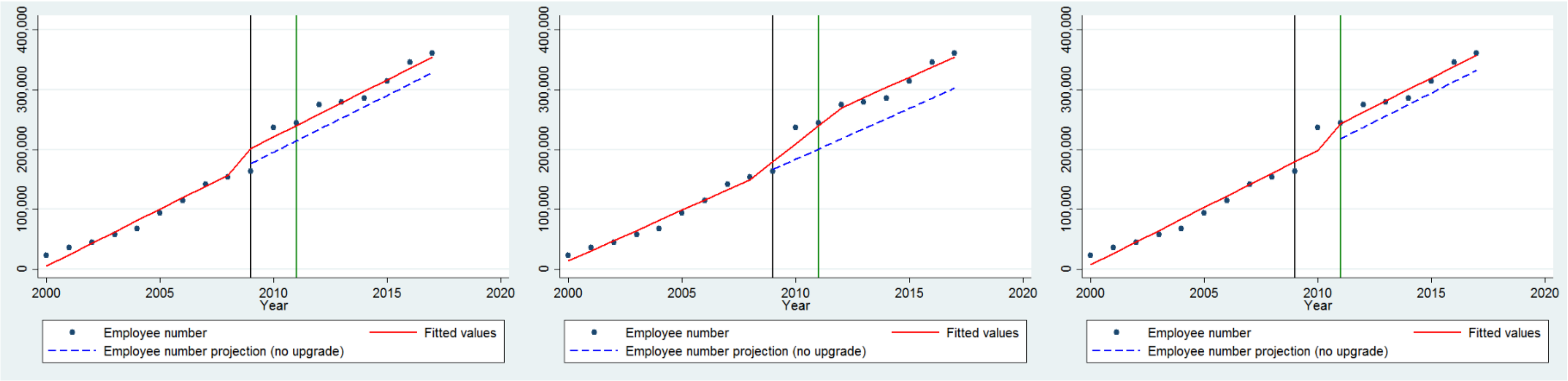
2009 as effective year | 2009-2011 as effective period | 2011 as effective year



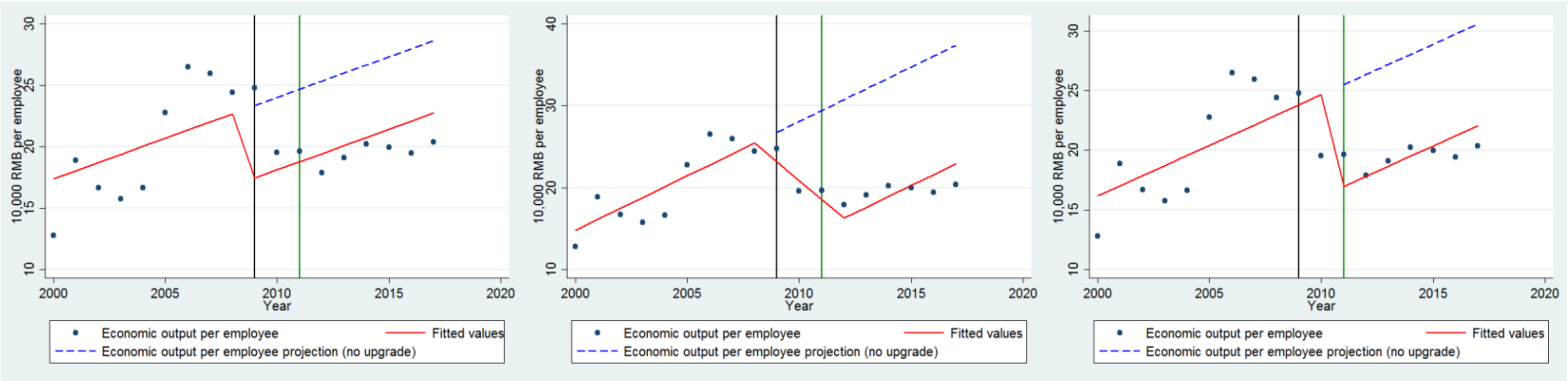
Economic output



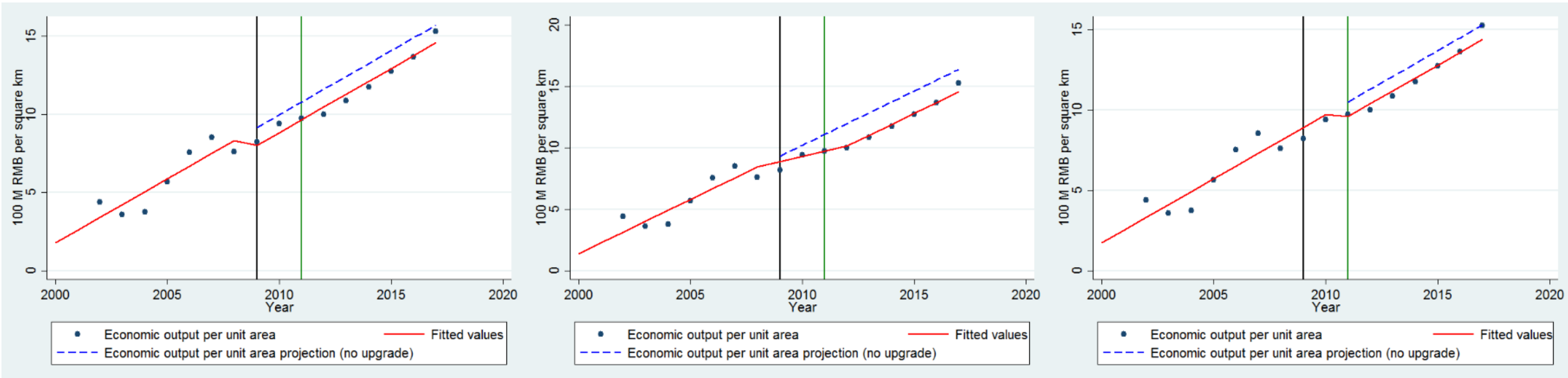
Ratio of economic output to economic output of city



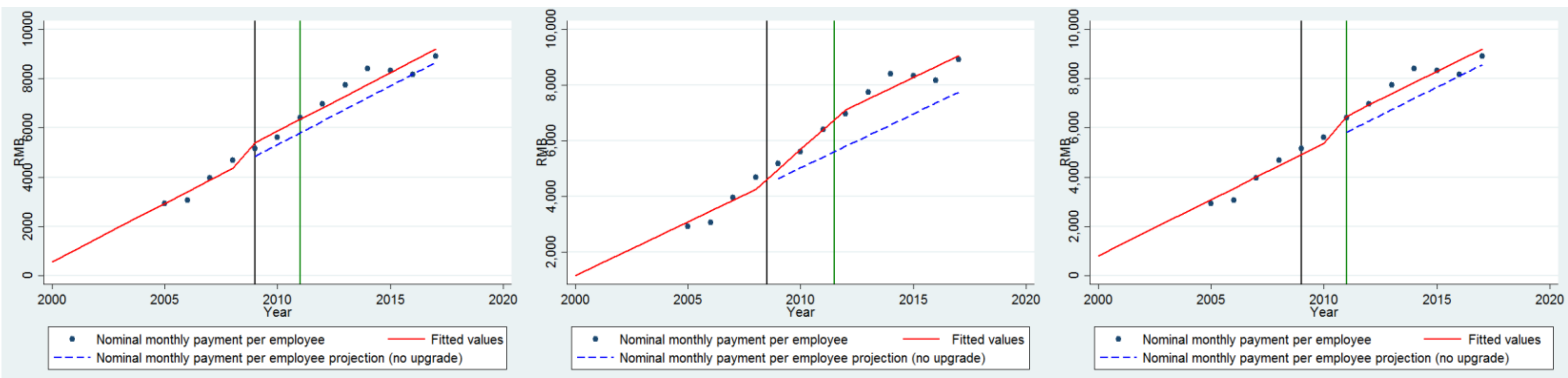
Employee number



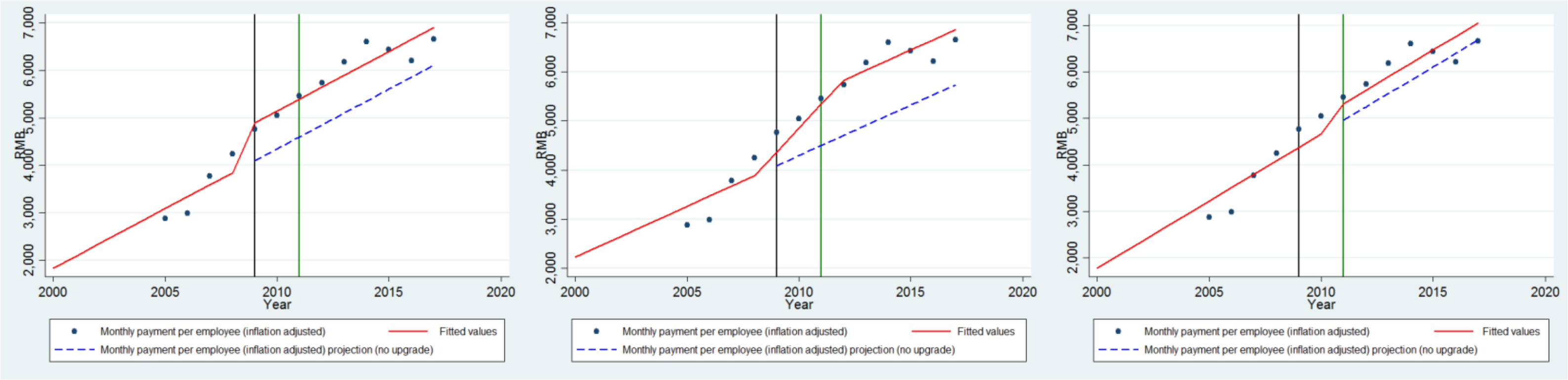
Economic output per employee



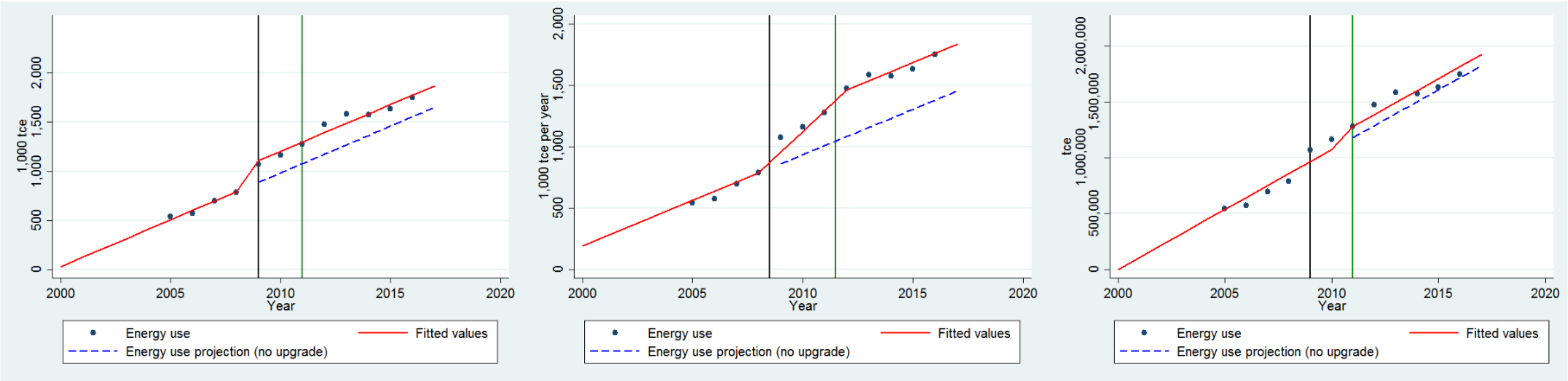
Economic output per unit area



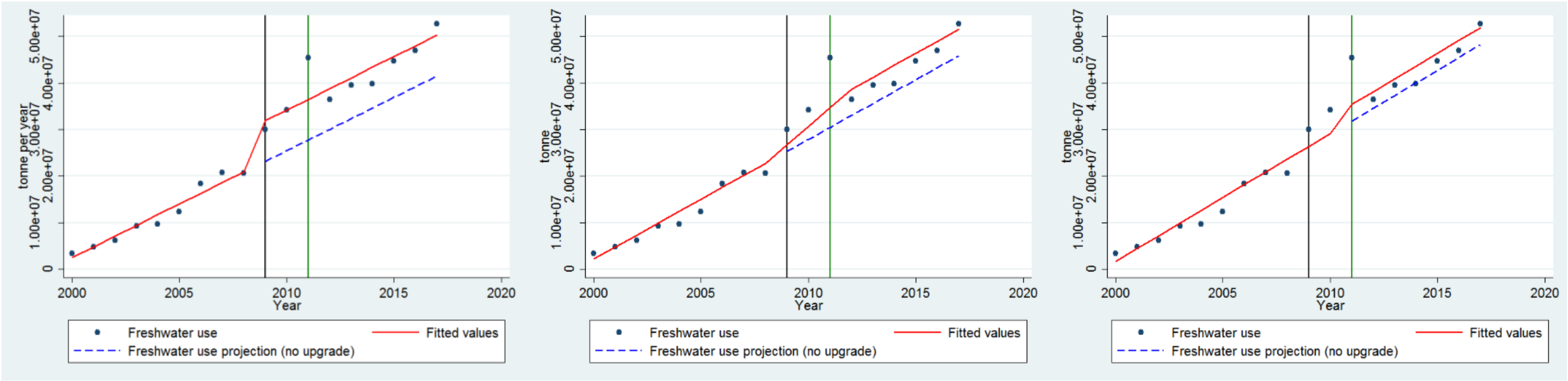
Nominal monthly payment per employee



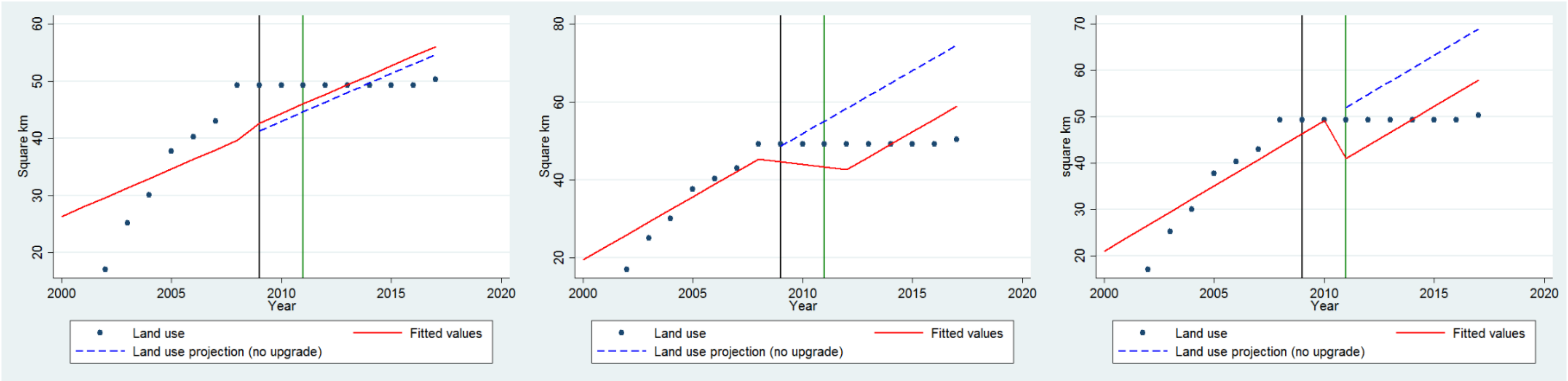
Monthly payment per employee (inflation adjusted)



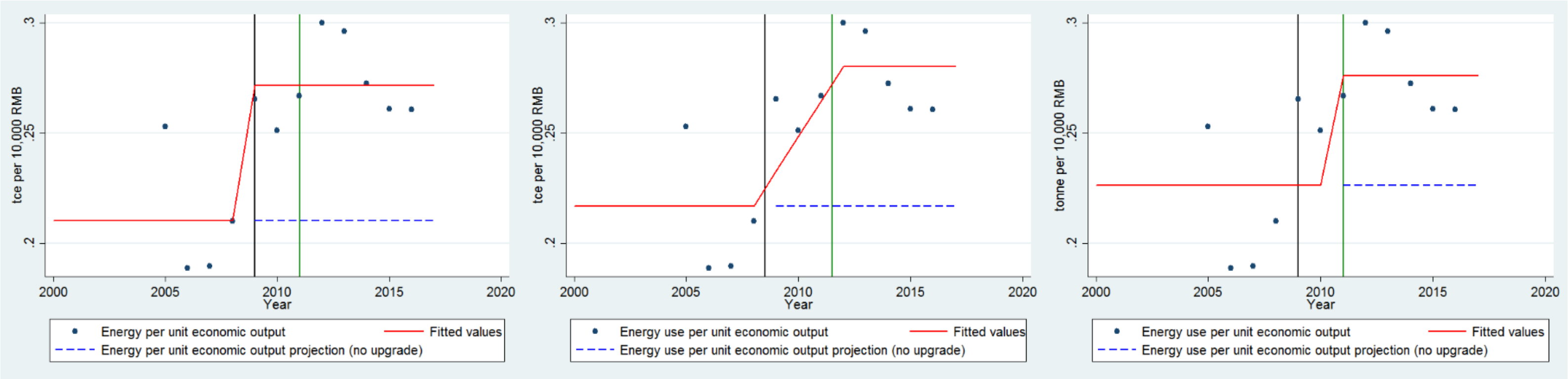
Energy use



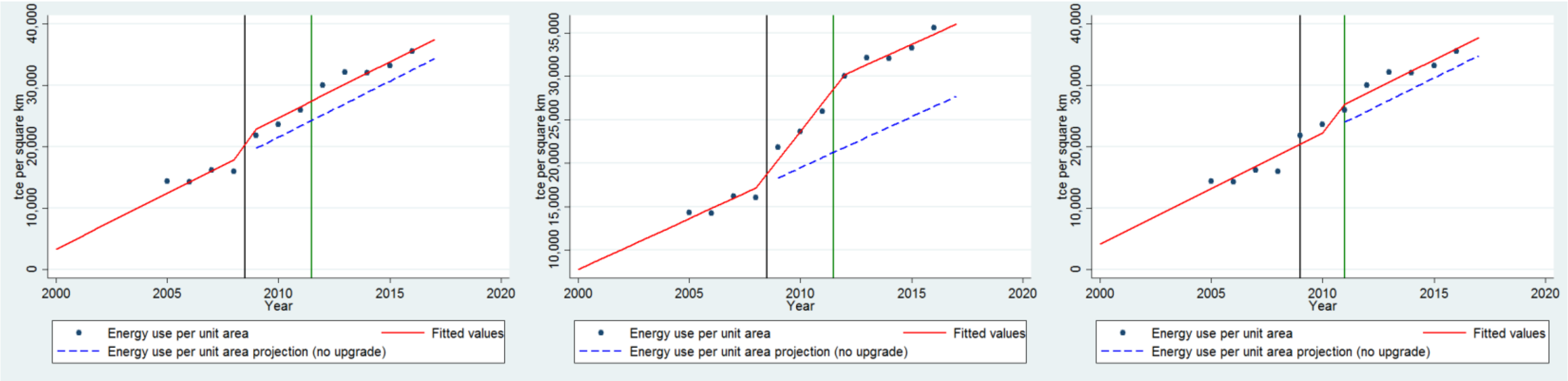
Freshwater use



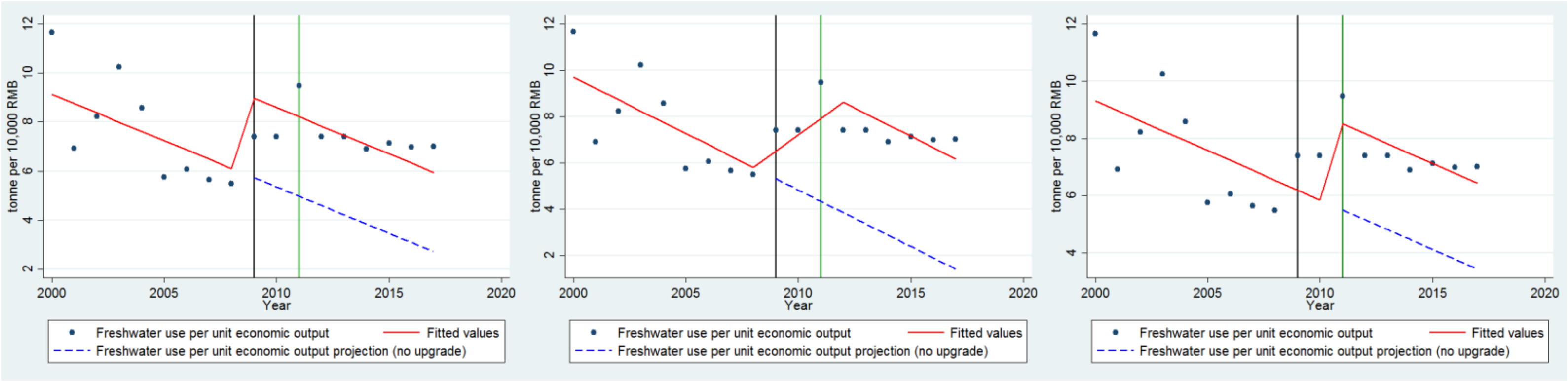
Land use



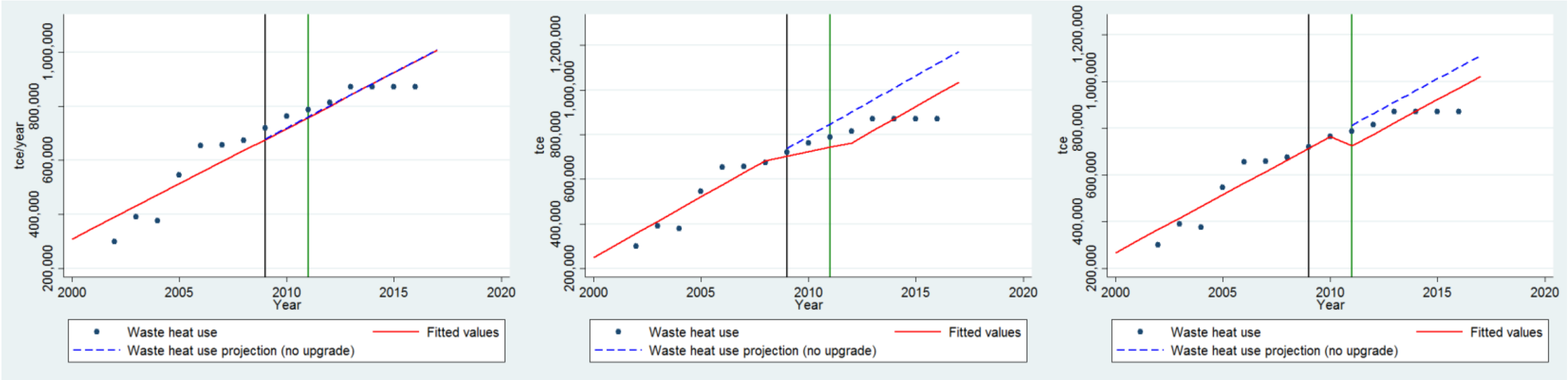
Energy use per unit economic output



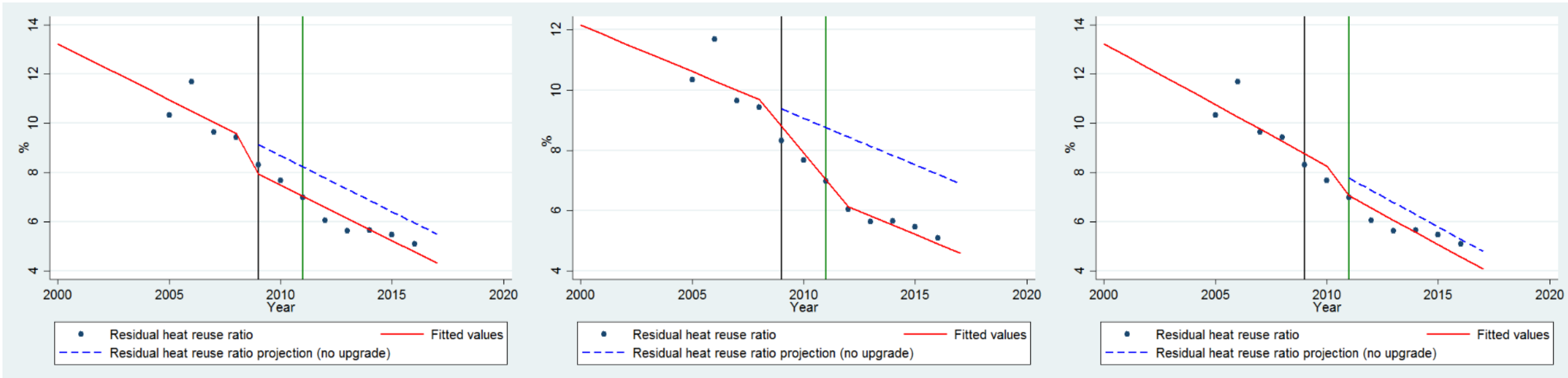
Energy use per unit area



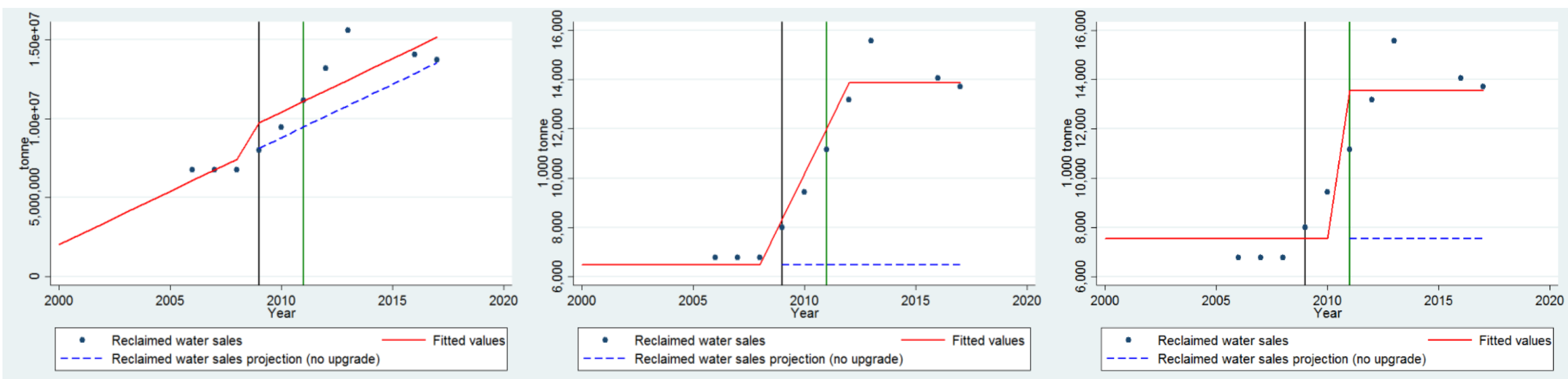
Freshwater use per unit economic output



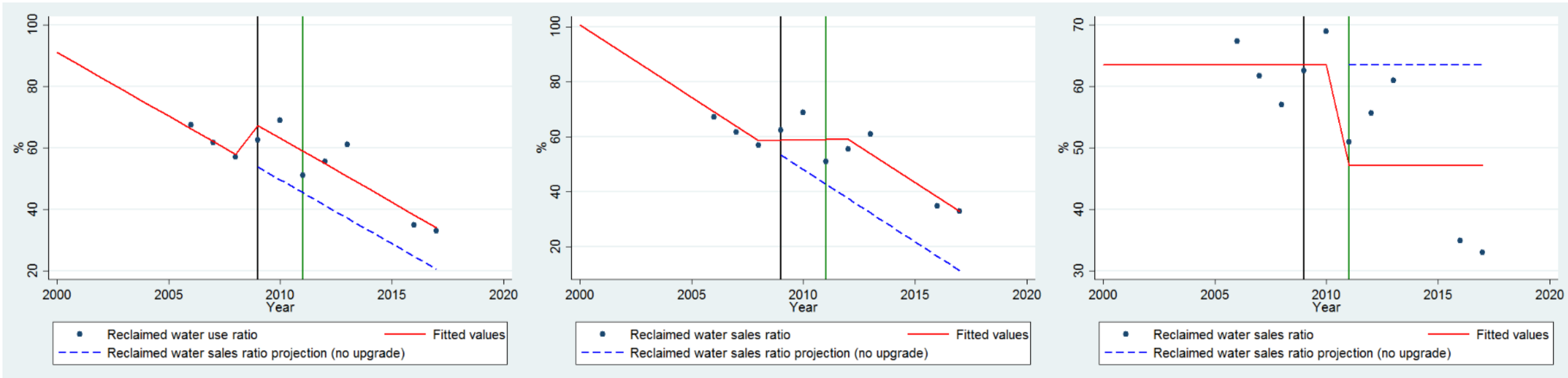
Waste heat use



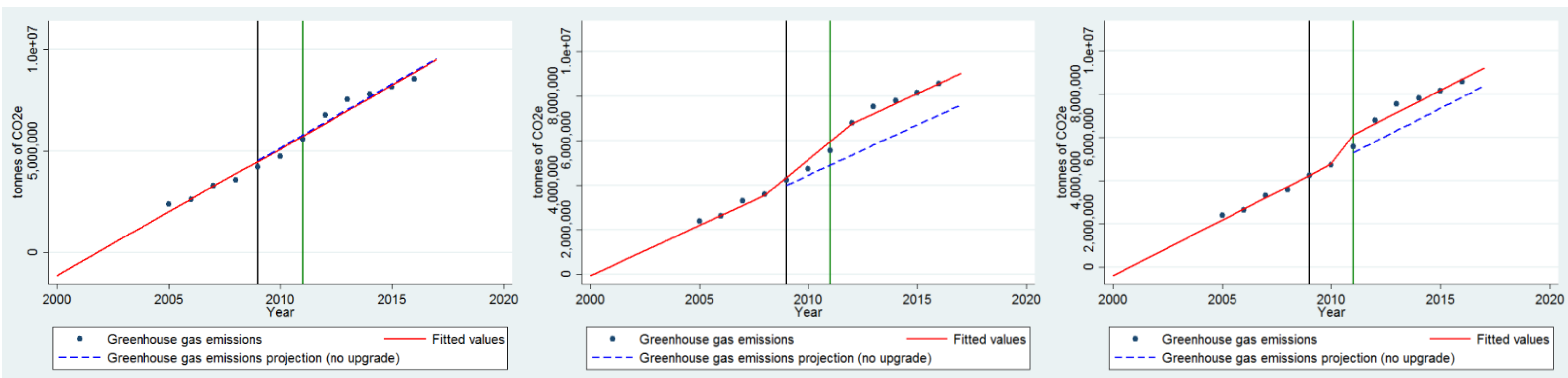
Residual heat reuse ratio



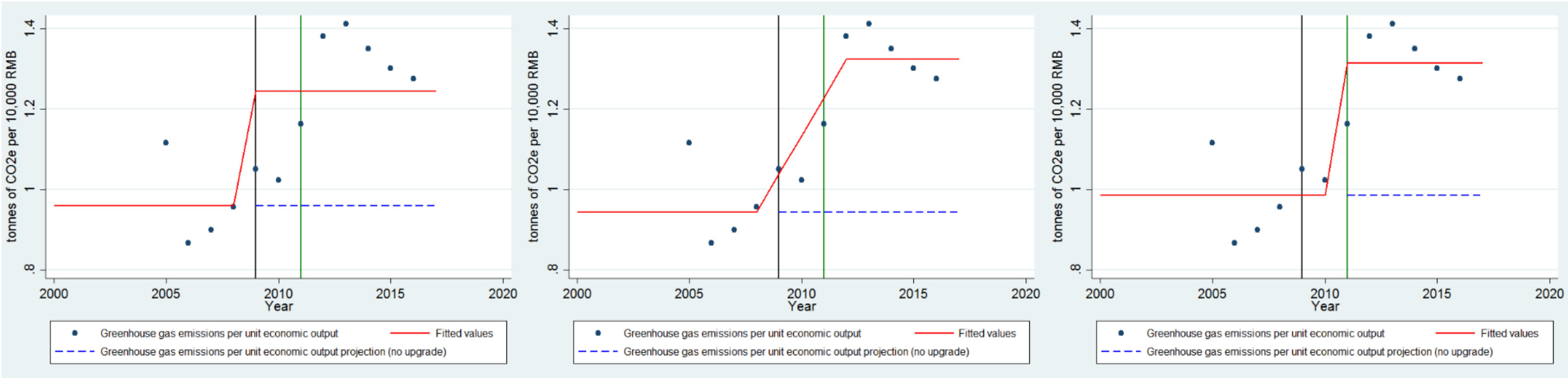
Reclaimed water sales



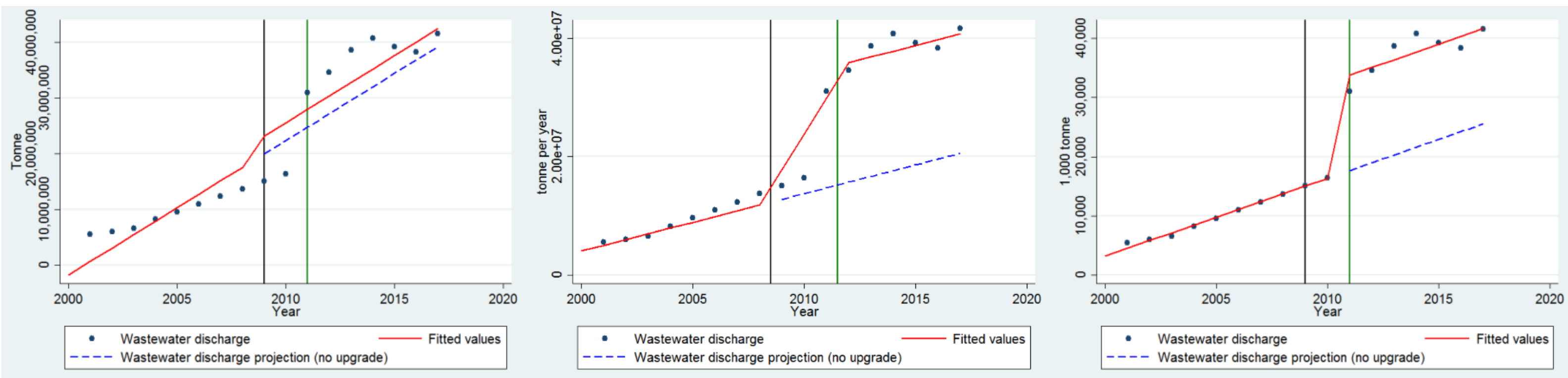
Reclaimed water sales ratio



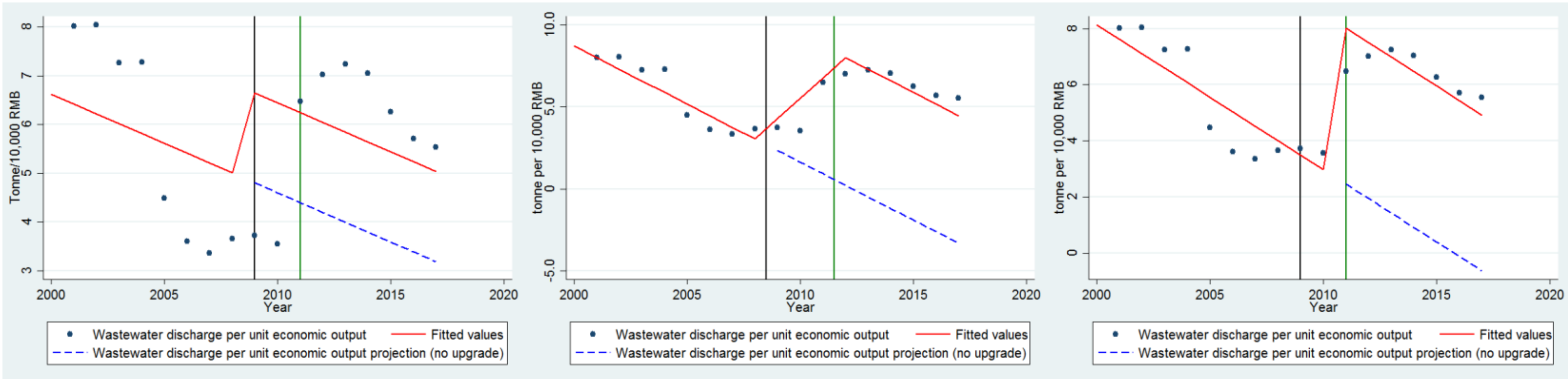
GHG emissions



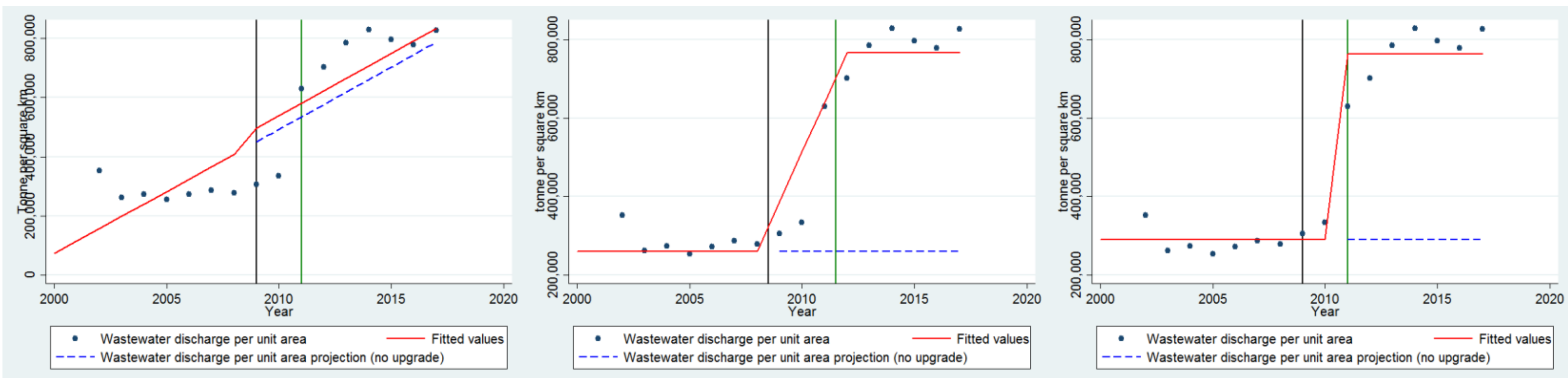
GHG emissions per unit economic output



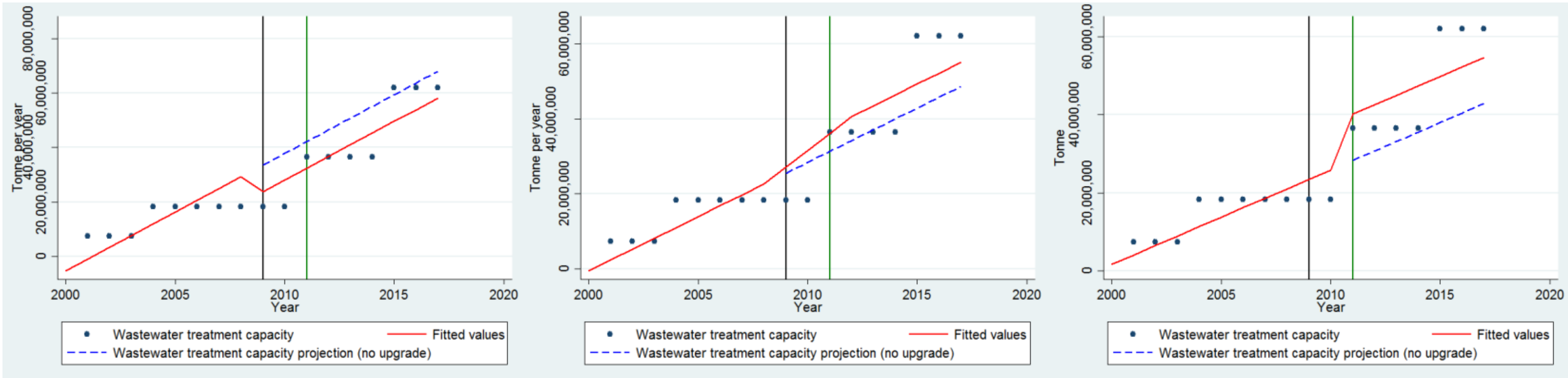
Wastewater discharge



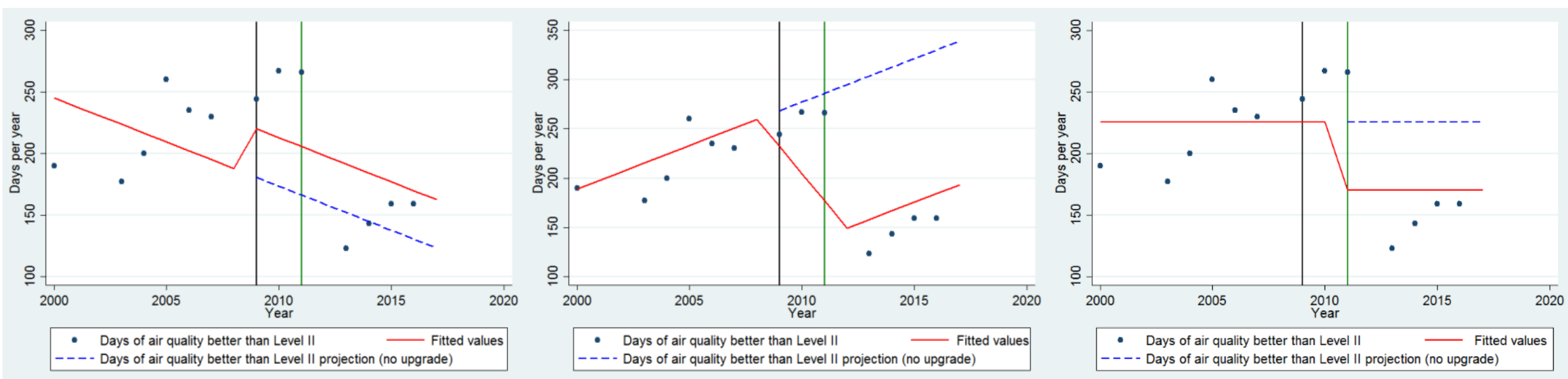
Wastewater discharge per unit output



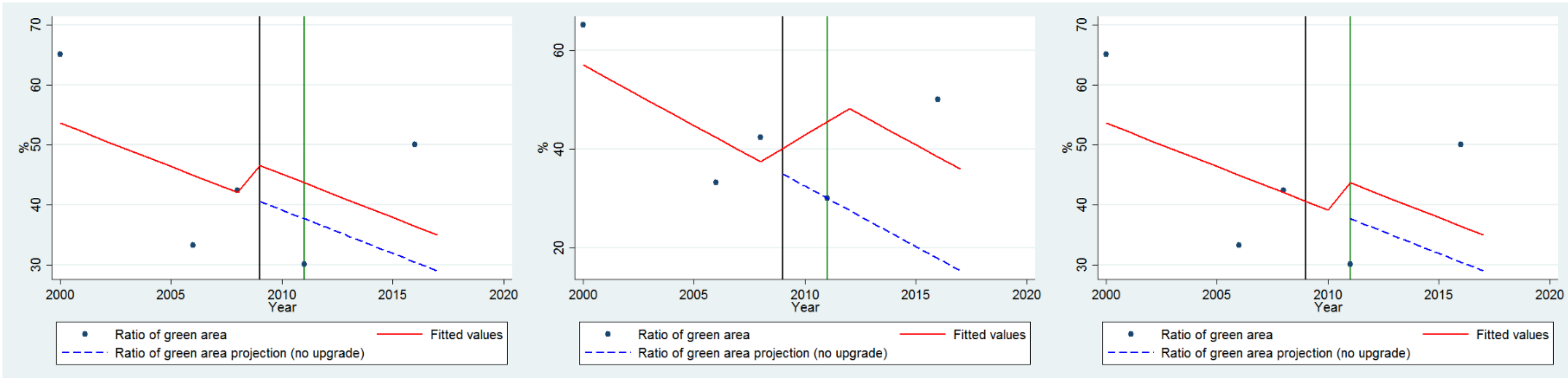
Wastewater discharge per unit area



Wastewater treatment capacity

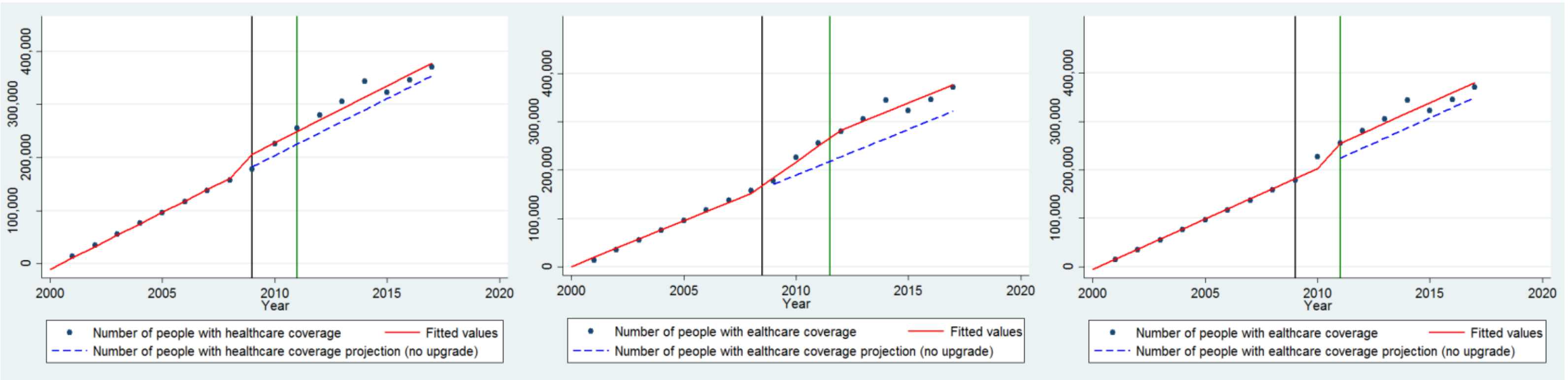


Air quality better than Level II

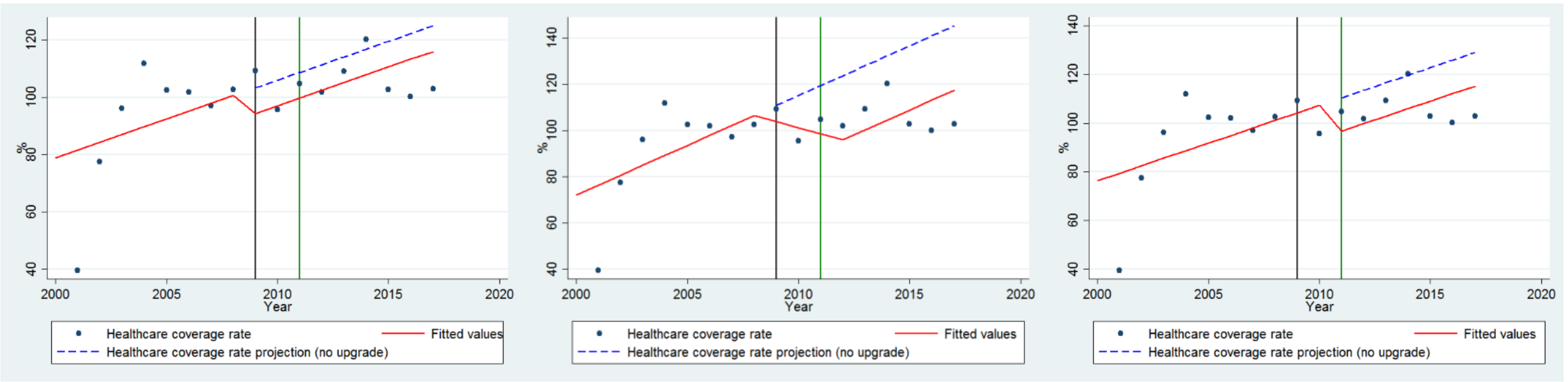


Ratio of green area

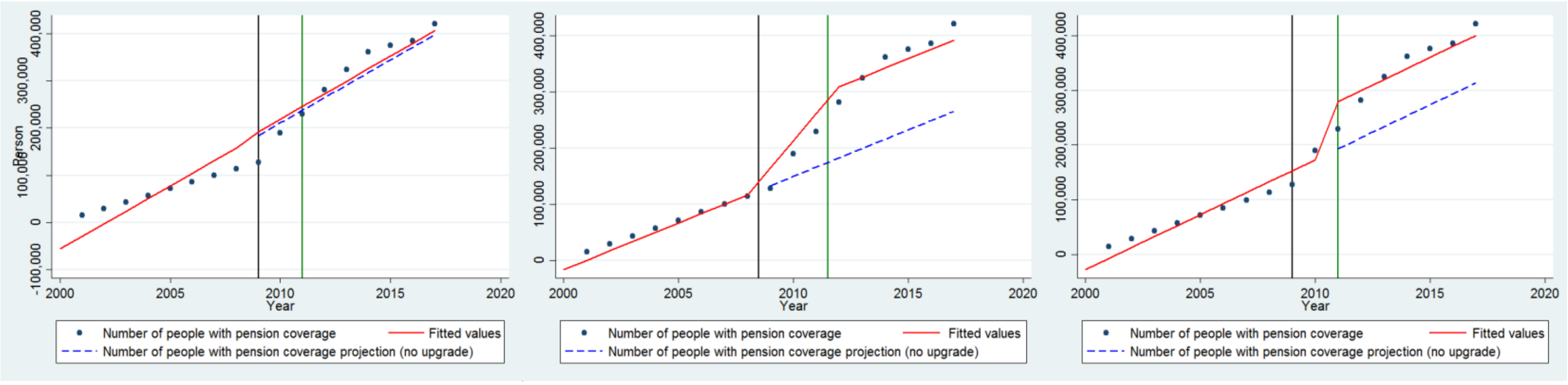
Monthly payment per employee to housing price per m^2 ratio



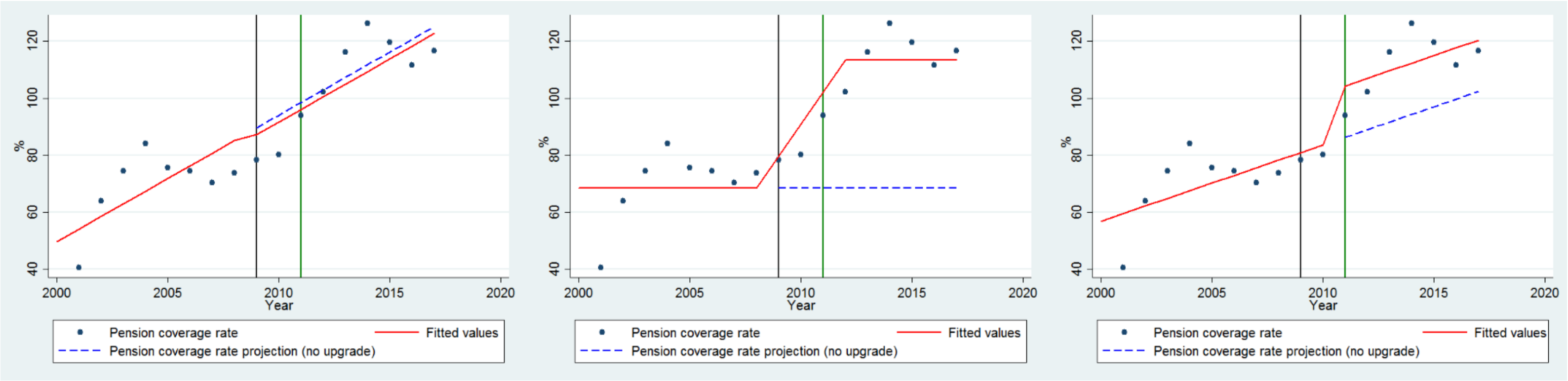
Healthcare coverage



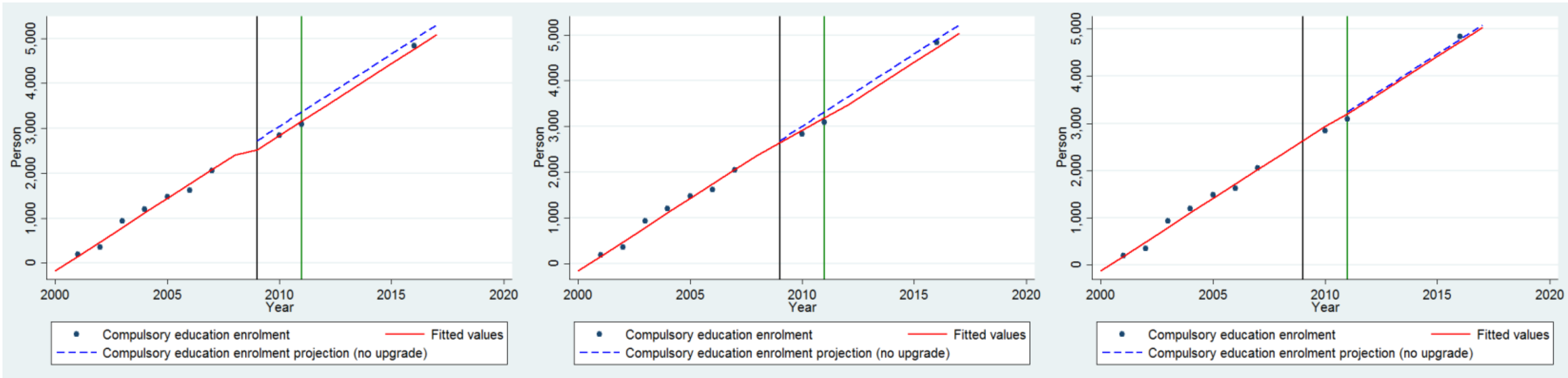
Healthcare coverage rate



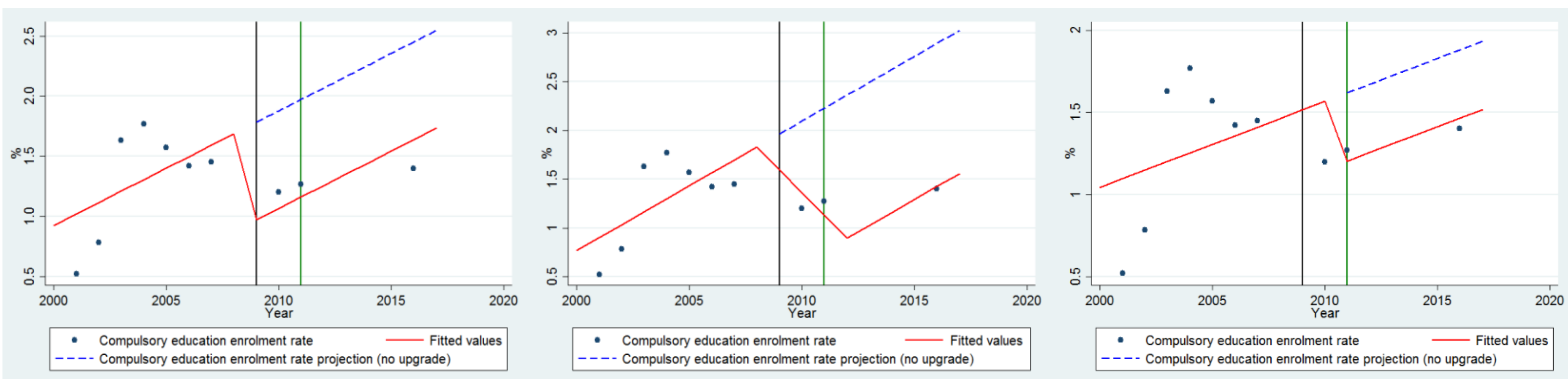
Pension coverage



Pension coverage rate



Compulsory education enrolment

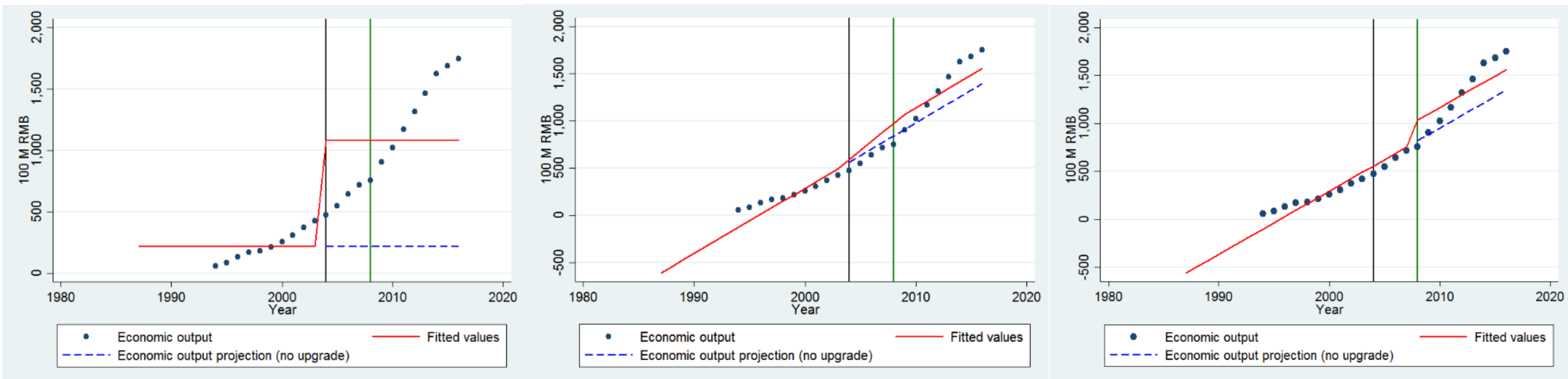


Compulsory education enrolment rate

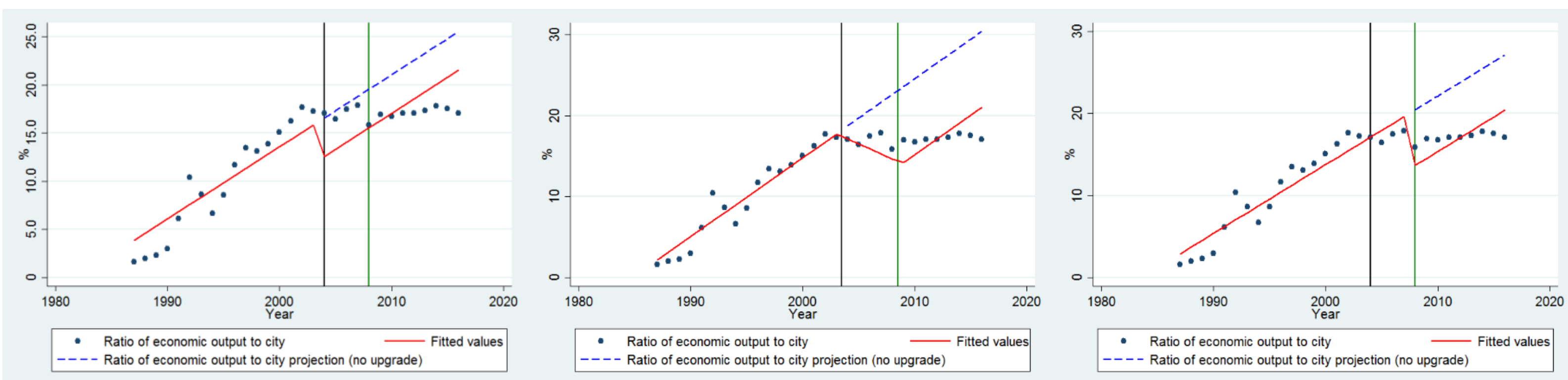
Figure S4. Interrupted Time Series analysis results for TEDA with different tests

Figures are laid out in the following order:

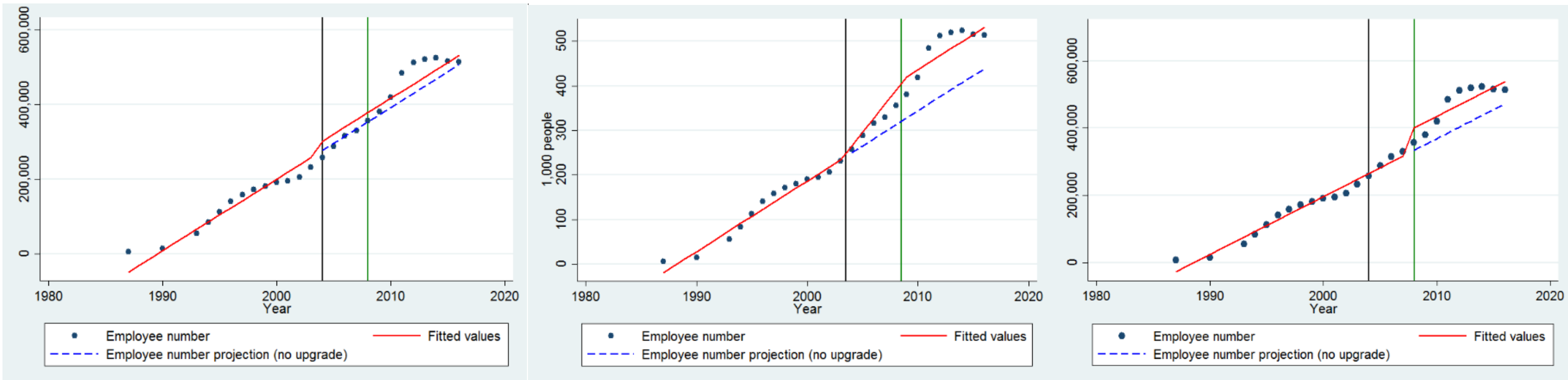
2004 as effective year | 2004-2008 as effective period | 2008 as effective year



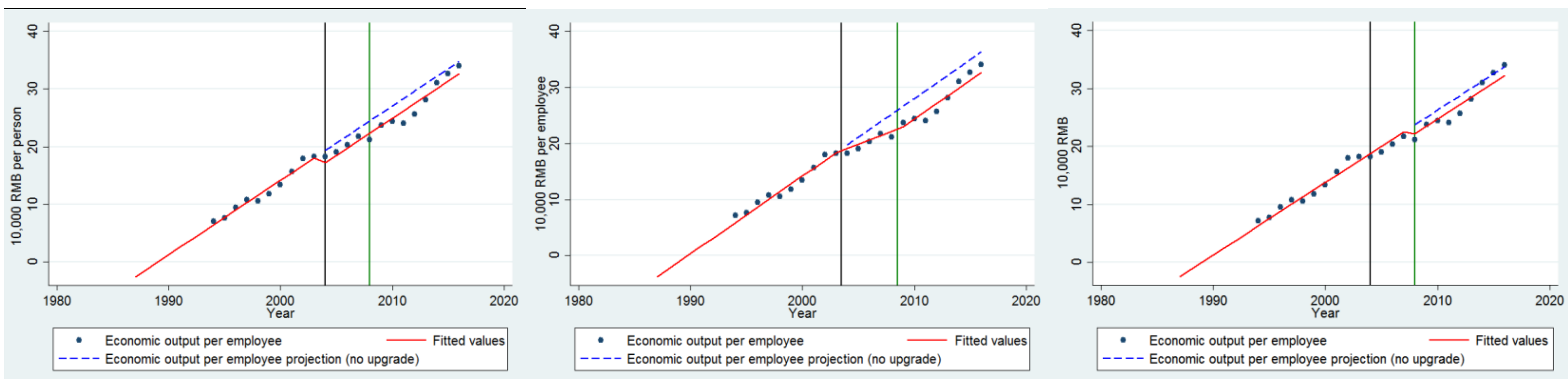
Economic output



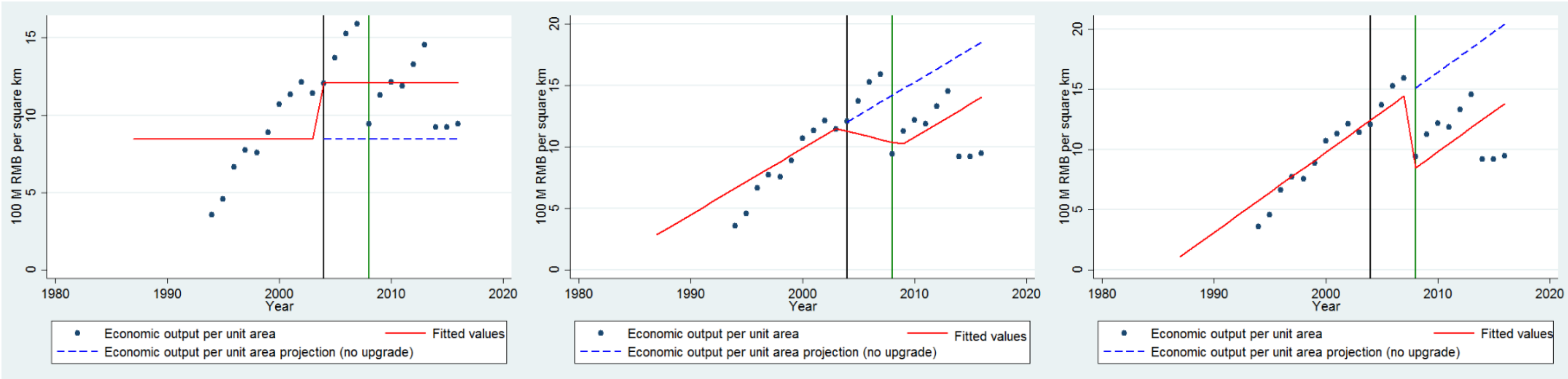
Ratio of economic output to economic output of city



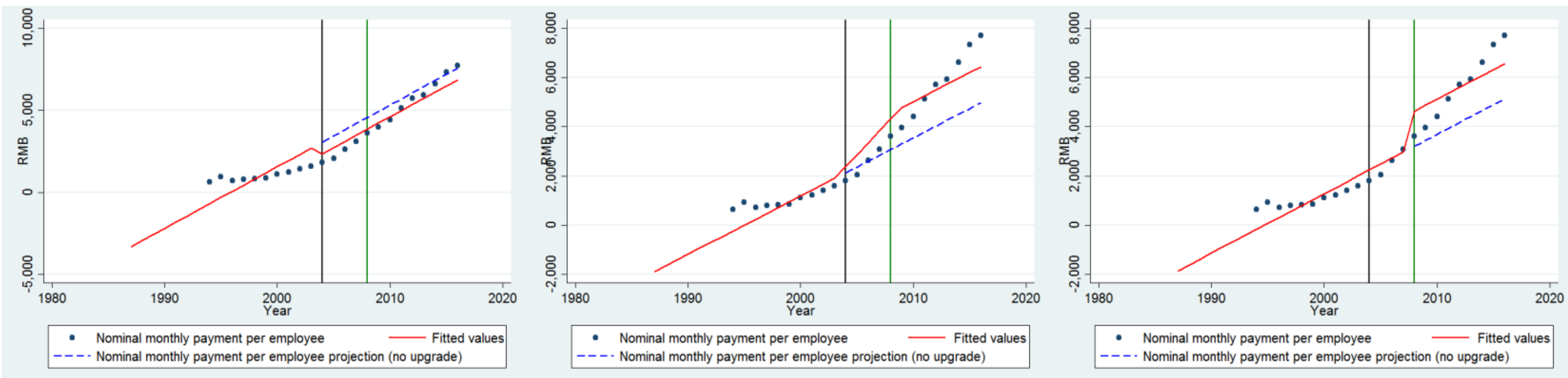
Employee number



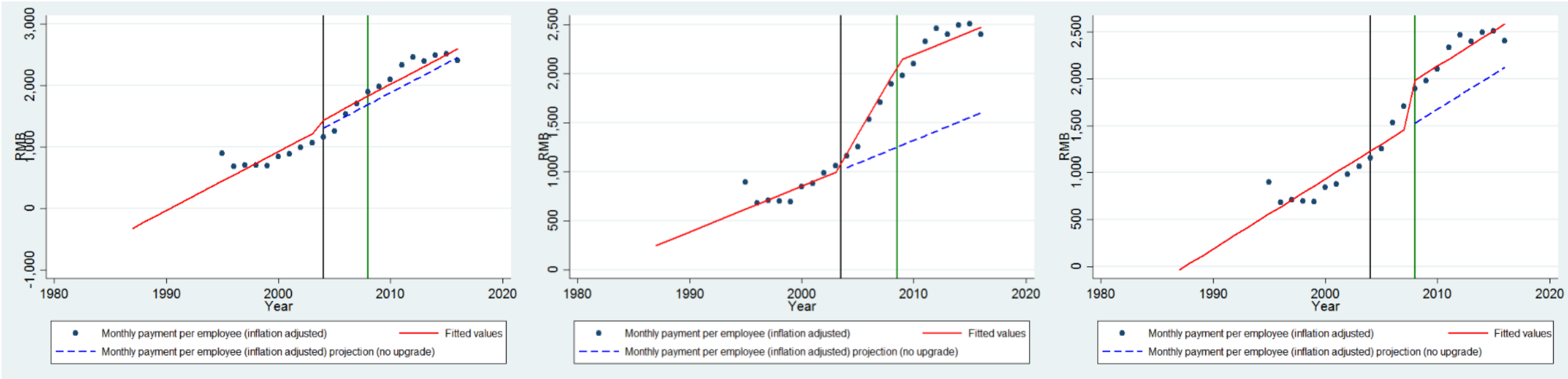
Economic output per employee



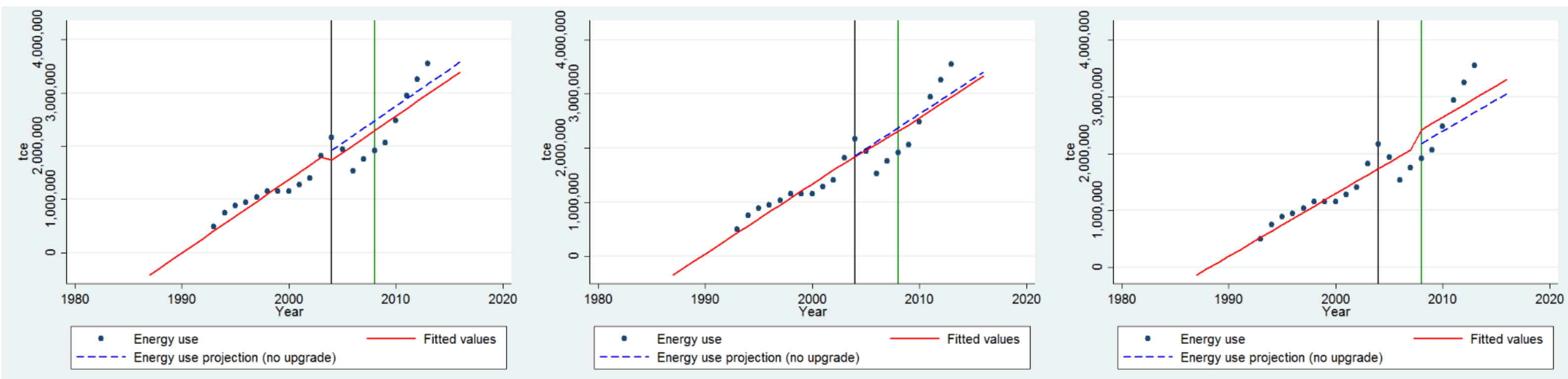
Economic output per unit area



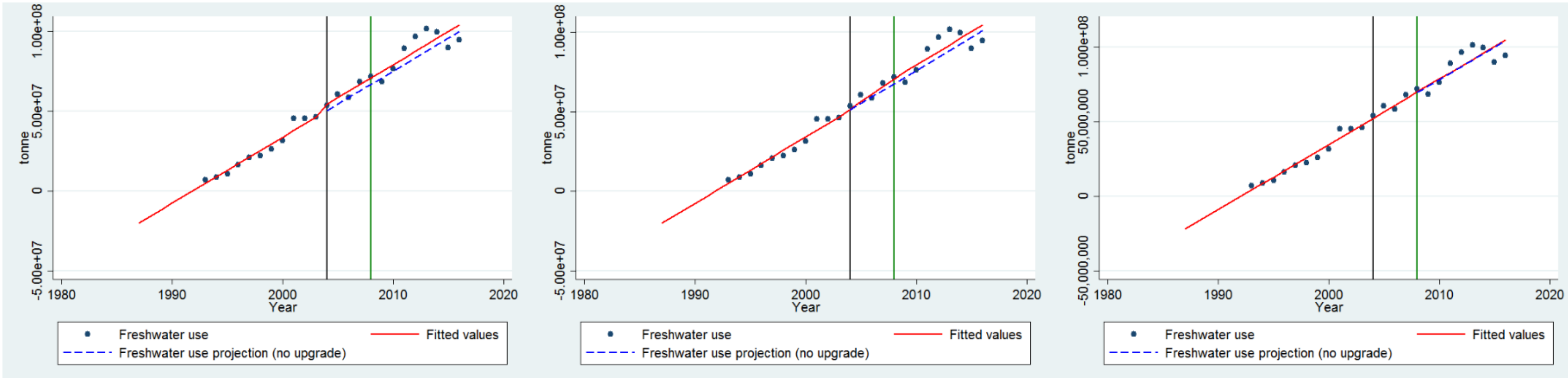
Nominal monthly payment per employee



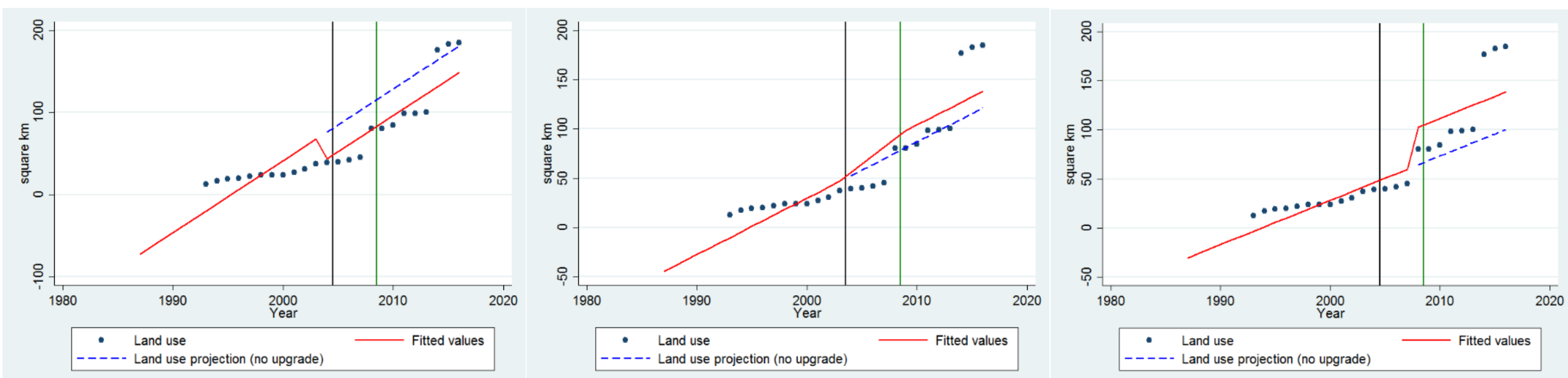
Monthly payment per employee (inflation adjusted)



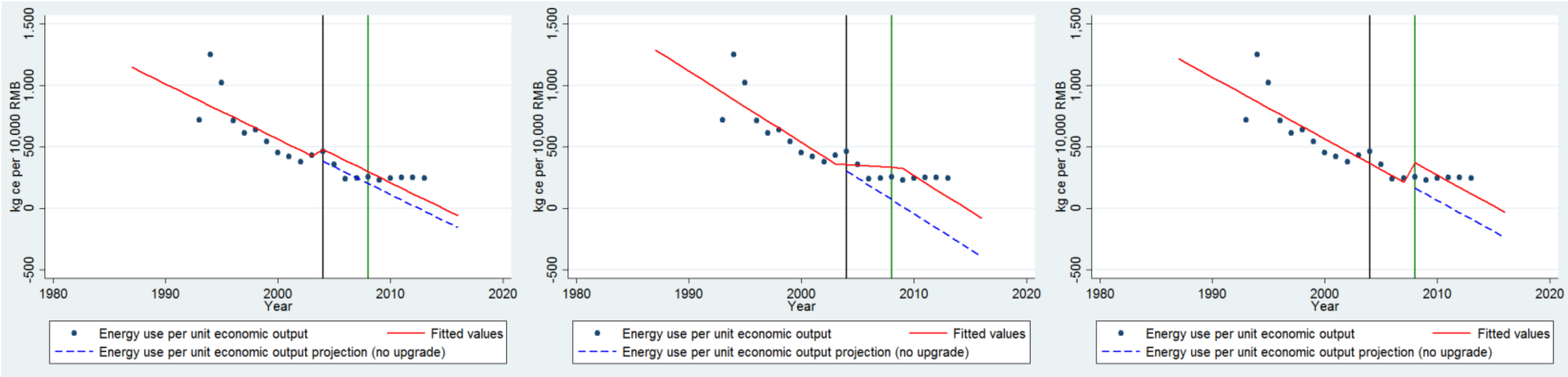
Energy use



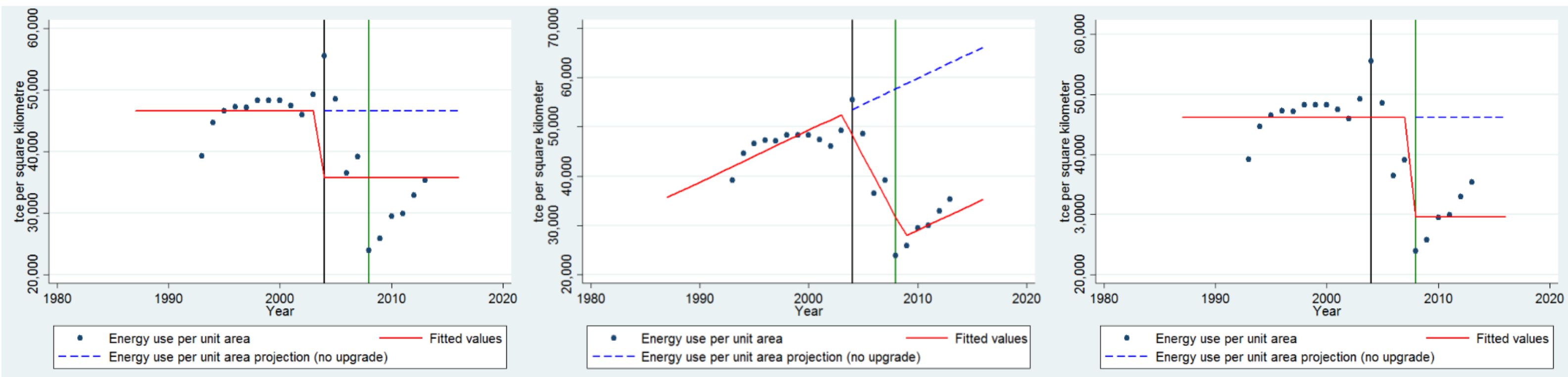
Freshwater use



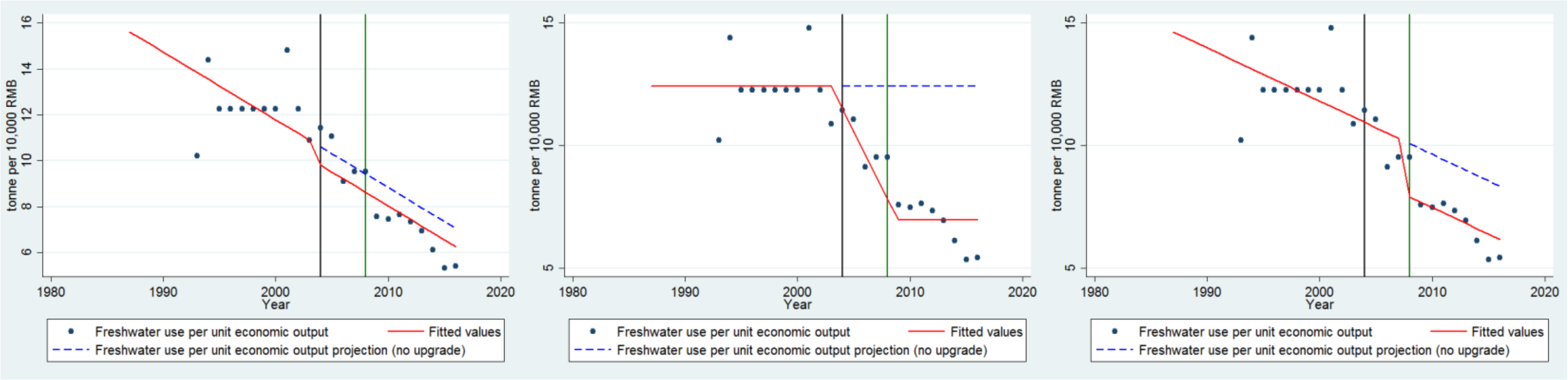
Land use



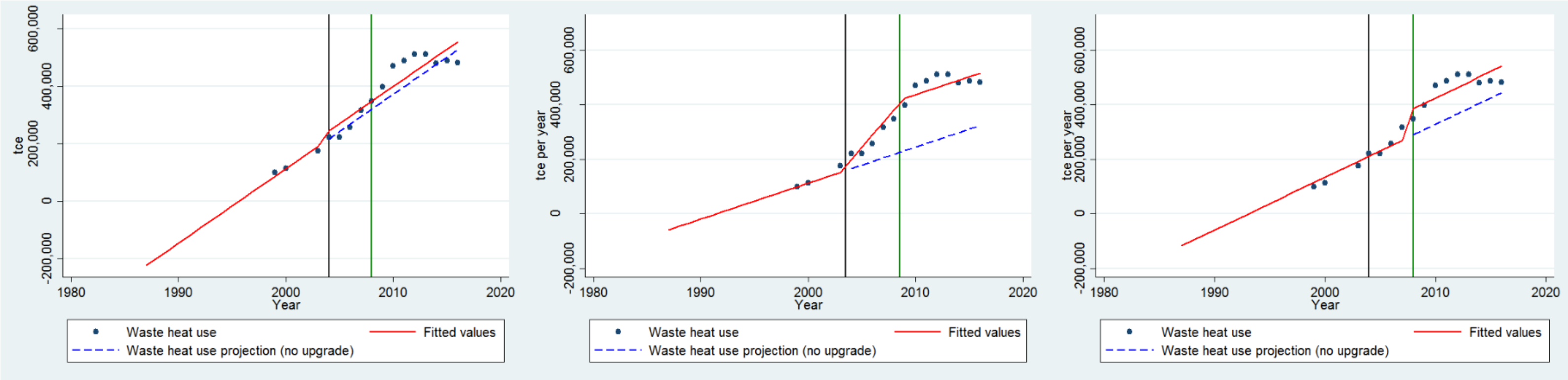
Energy use per unit economic output



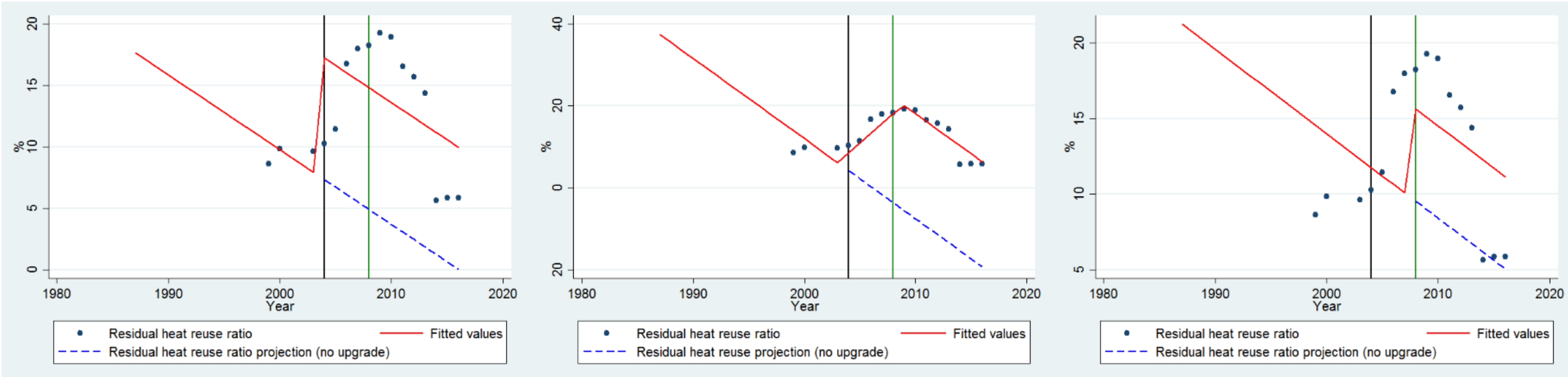
Energy use per unit area



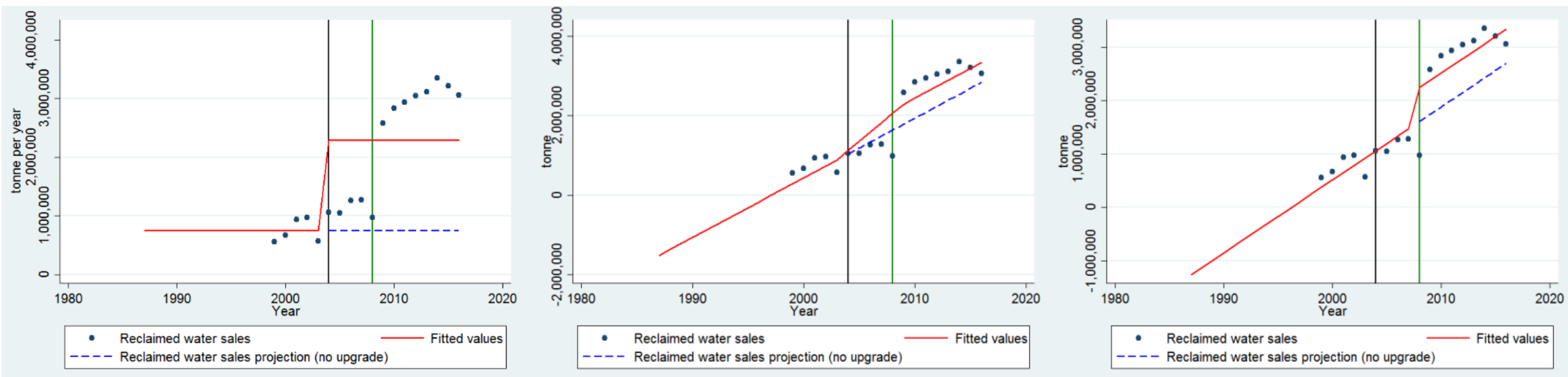
Freshwater use per unit economic output



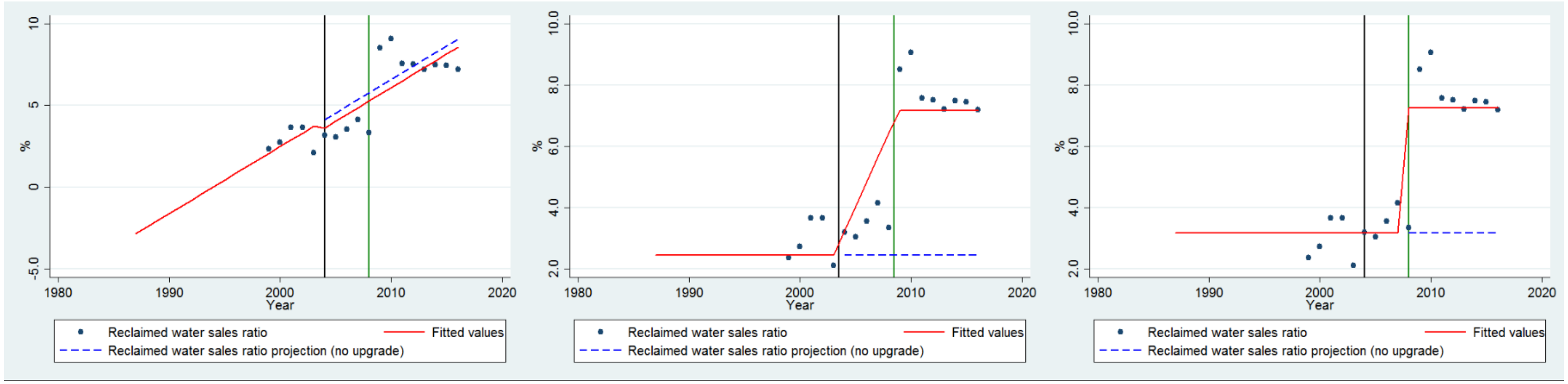
Waste heat use



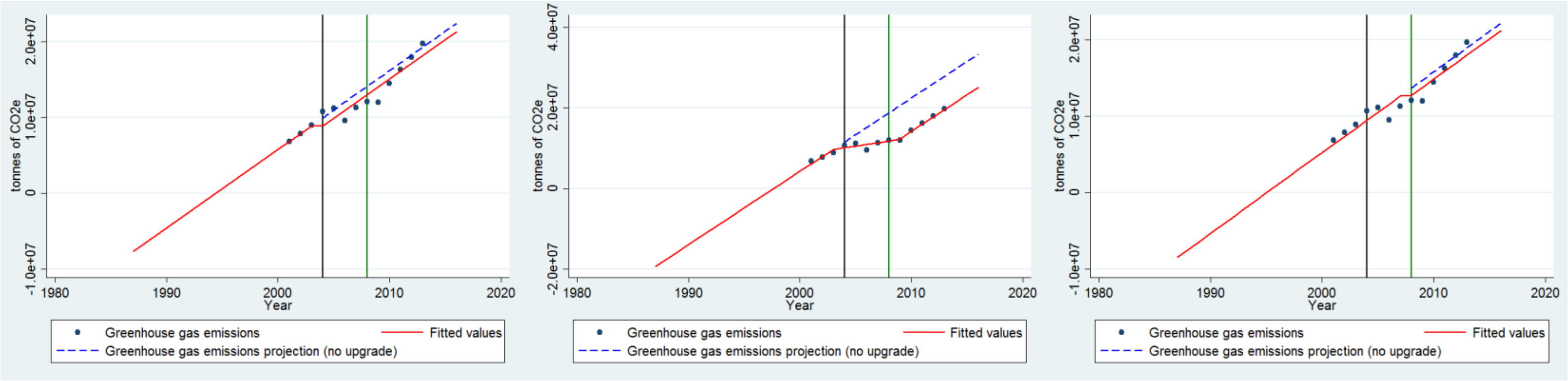
Residual heat reuse ratio



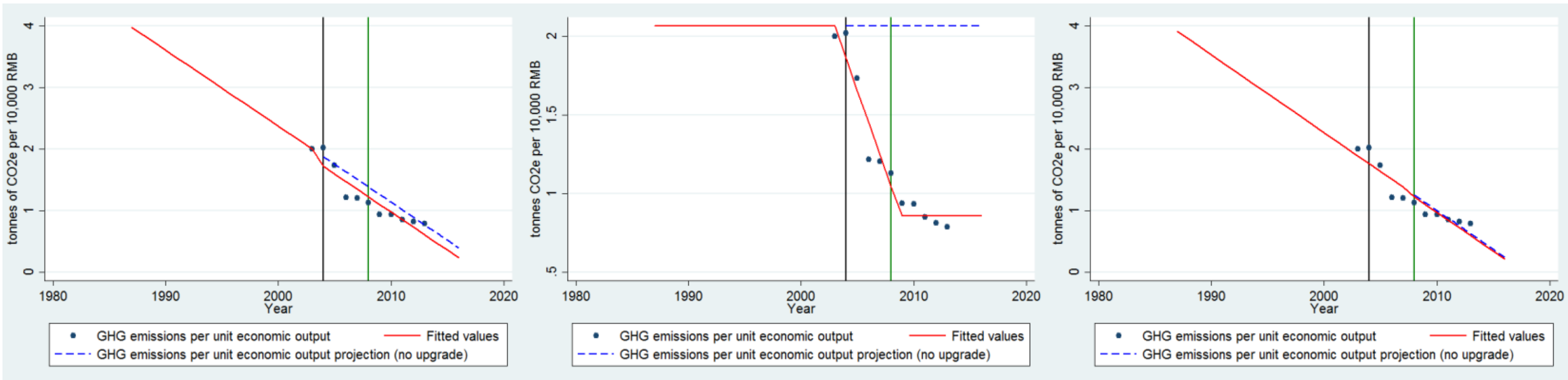
Reclaimed water sales



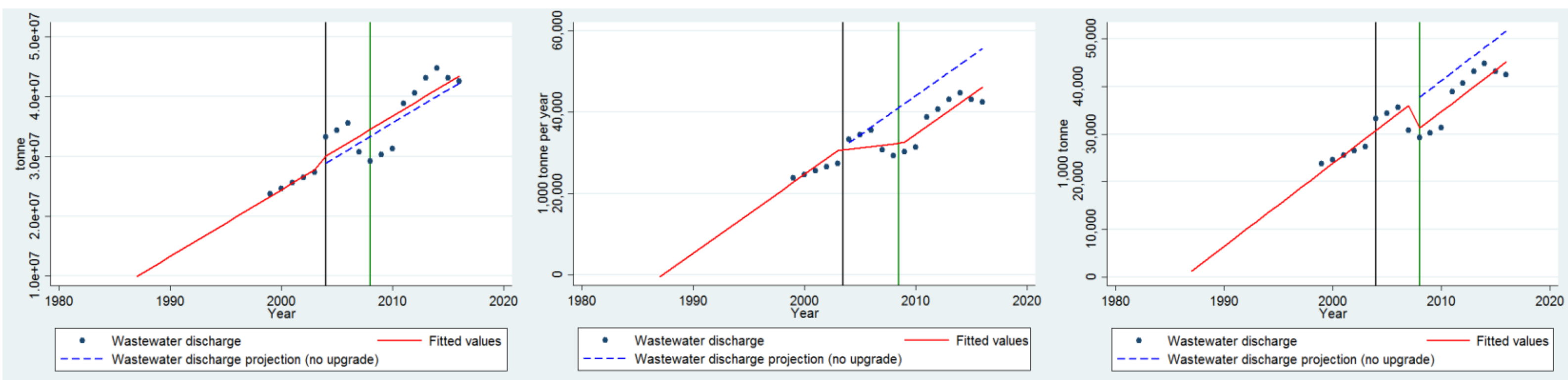
Reclaimed water sales ratio



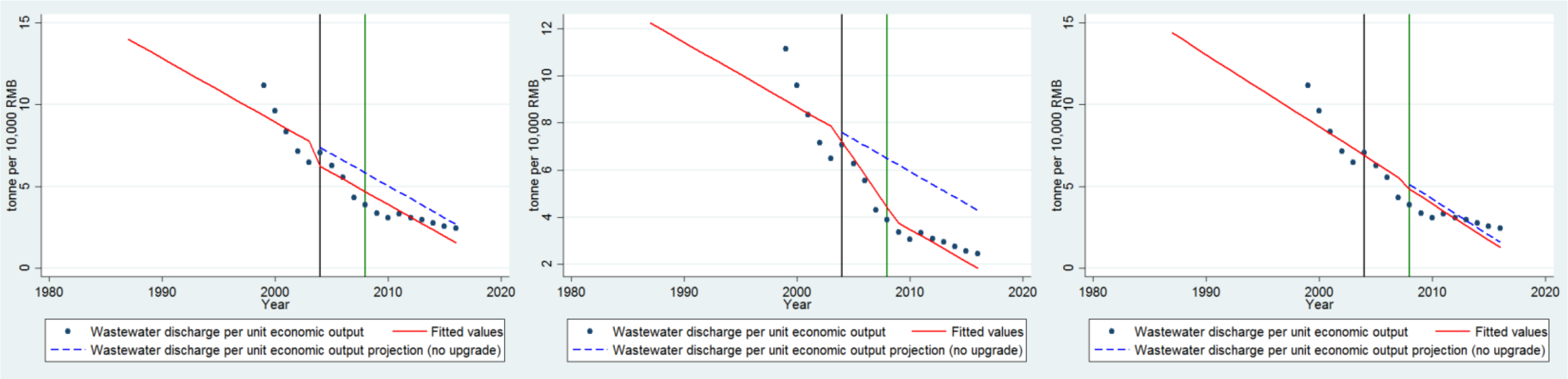
GHG emissions



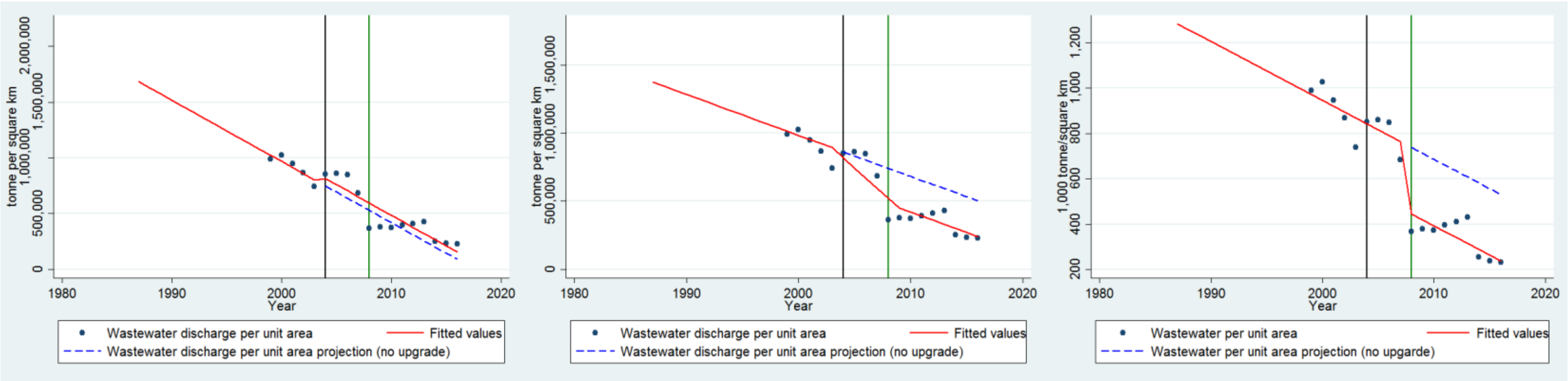
GHG emissions per unit economic output



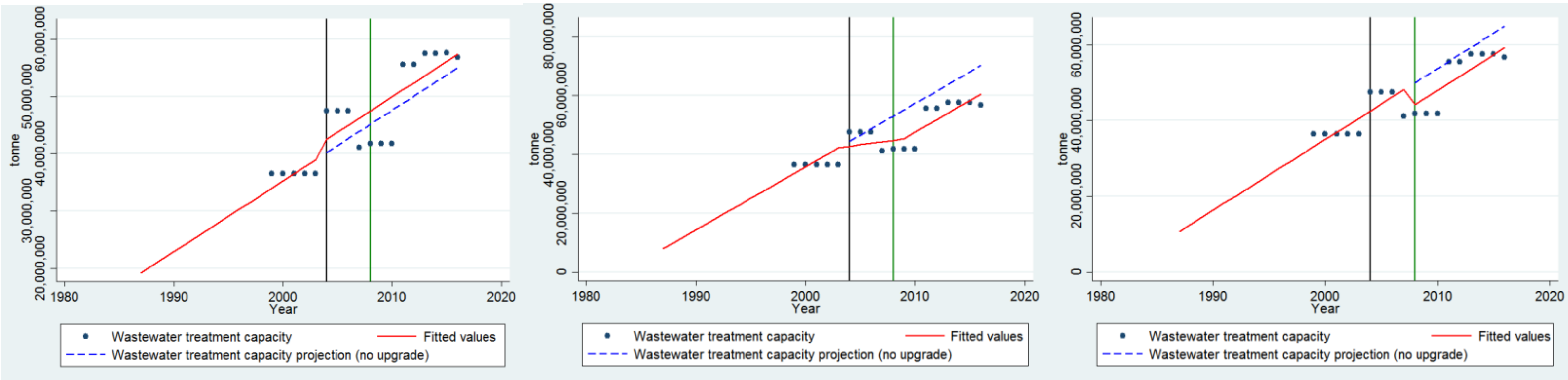
Wastewater discharge



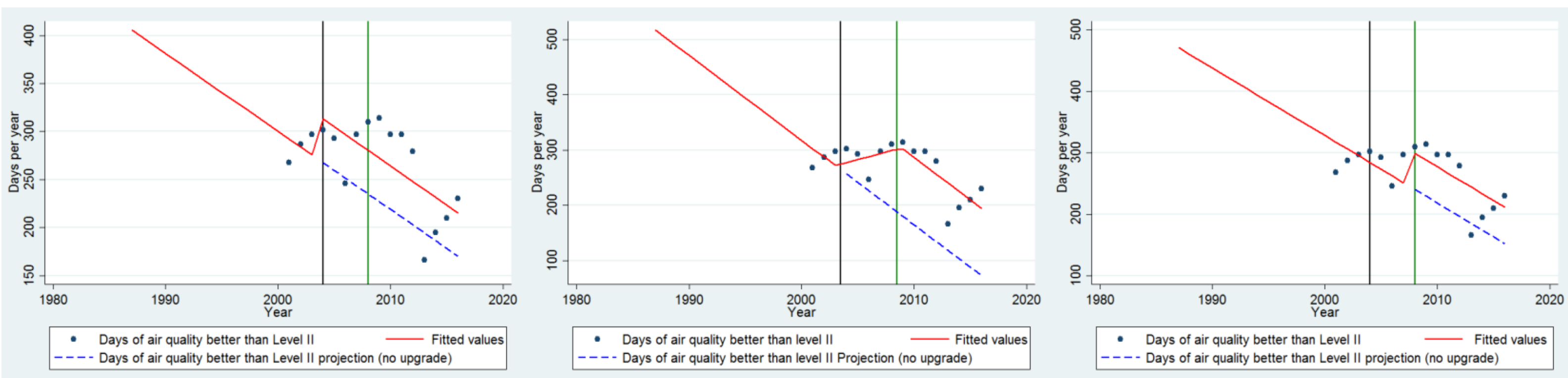
Wastewater discharge unit per output



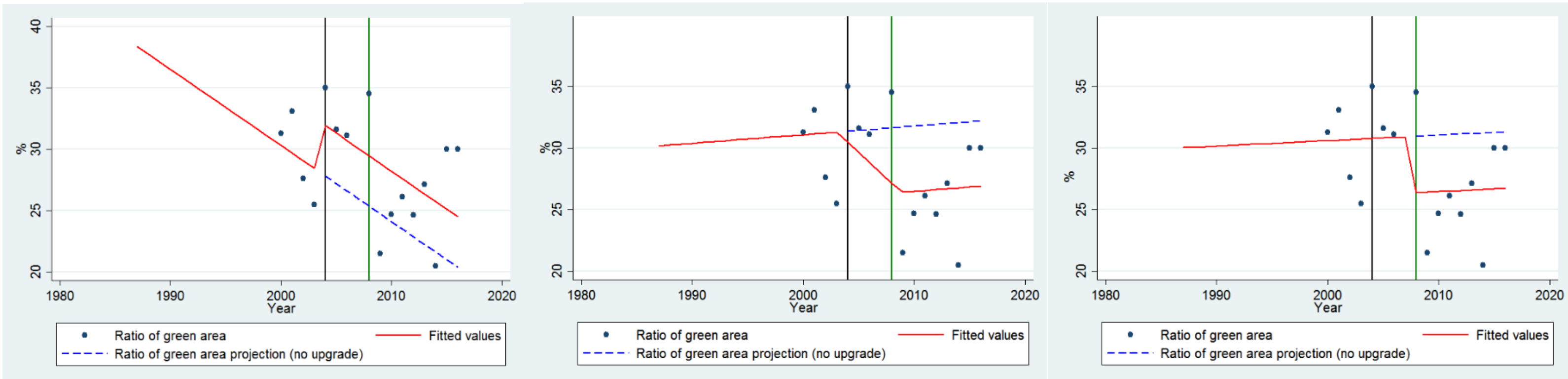
Wastewater discharge per unit area



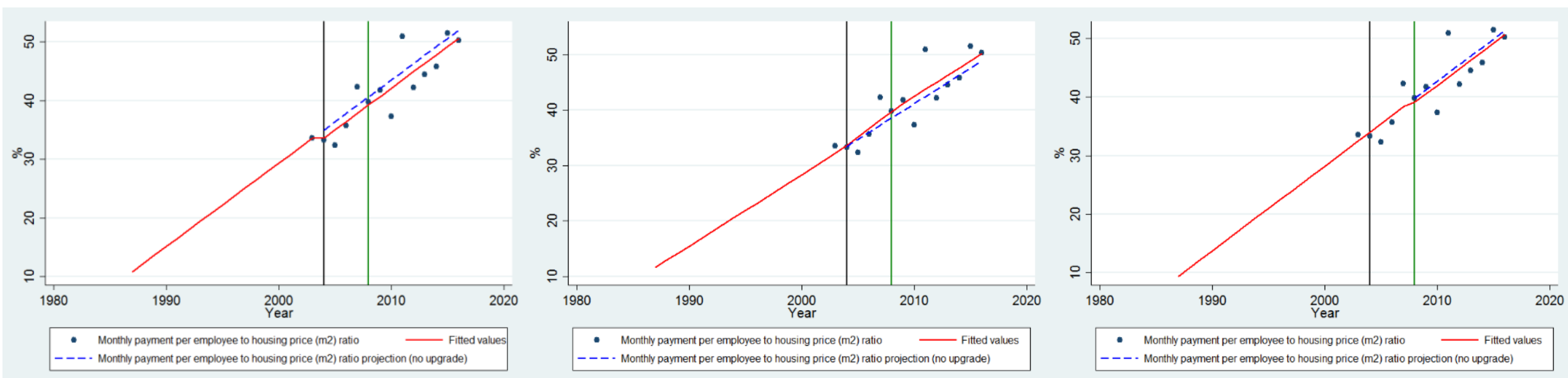
Wastewater treatment capacity



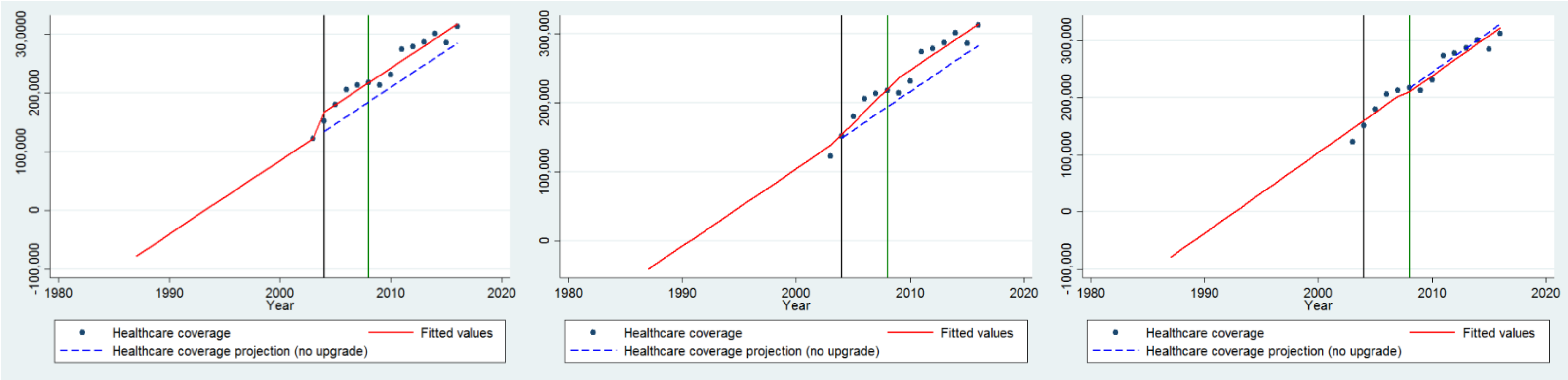
Air quality better than Level II



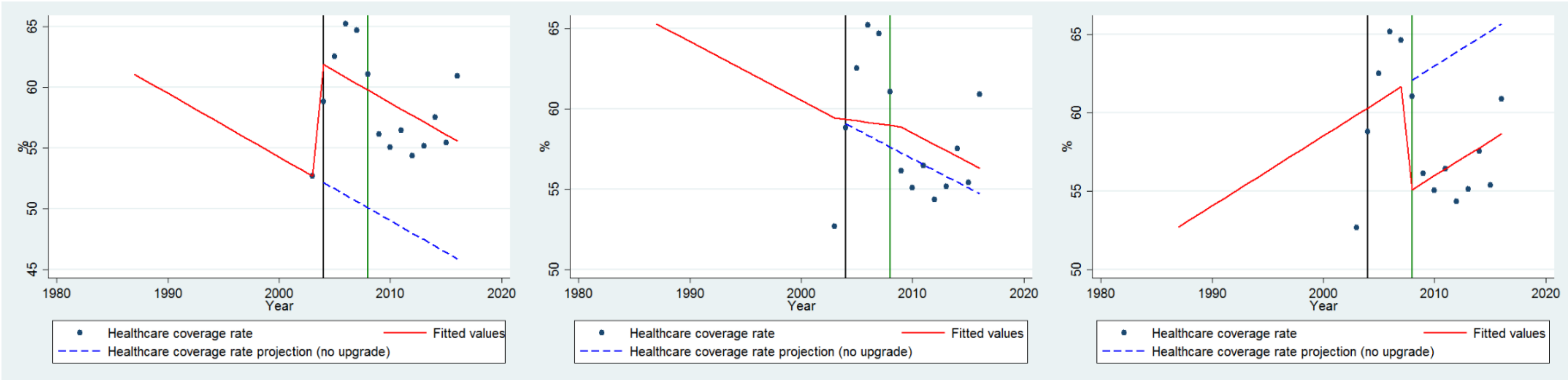
Ratio of green area



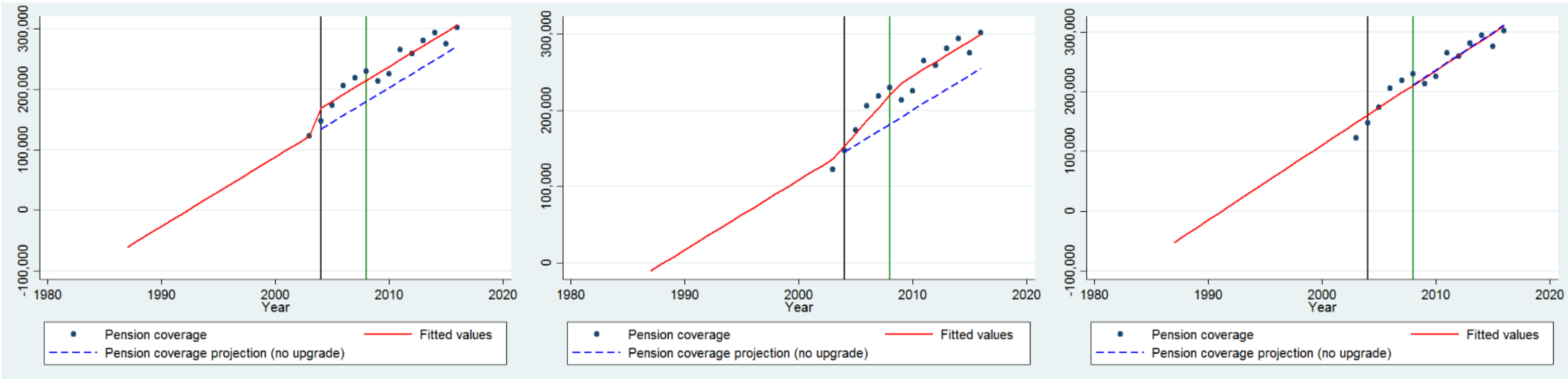
Monthly payment per employee to housing price per m^2 ratio



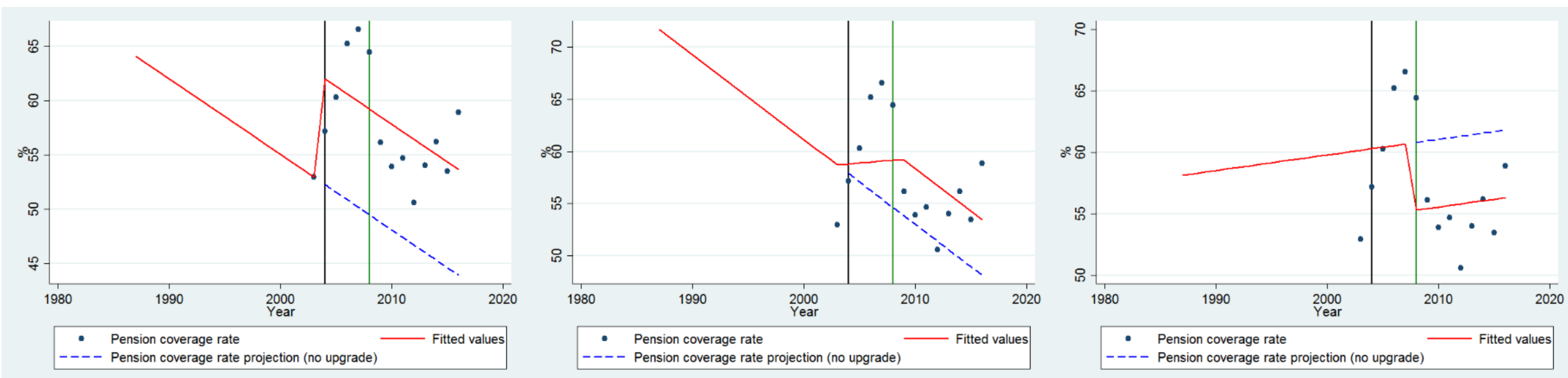
Healthcare coverage



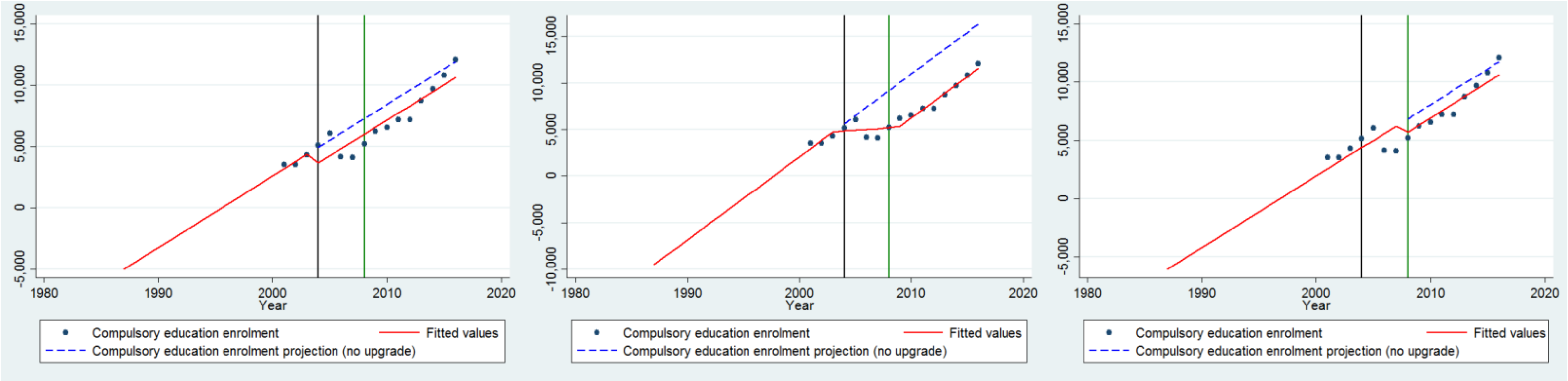
Healthcare coverage rate



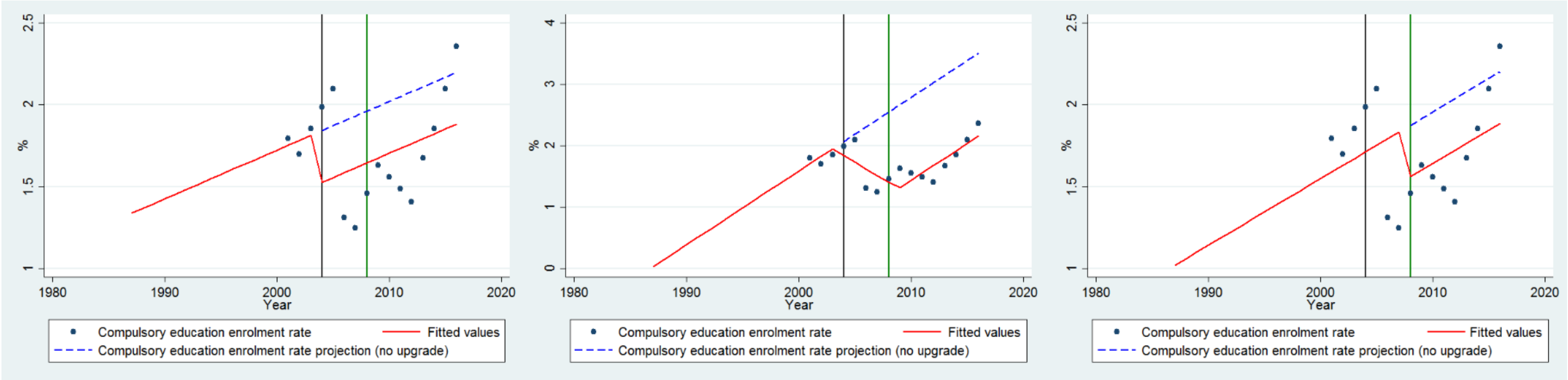
Pension coverage



Pension coverage rate



Compulsory education enrolment



Education enrolment rate

Table S7: major infrastructure and environmental actions taken by BDA

EIP	Field of action	2001	2004	2009	2011	2012	2014	2016	2017
BDA	Energy			Thermal plant phase 7			Upgrade of three coal power/heat plants (250m RMB investment); de-coal and prohibition of high-polluting fuel implemented		Full de-coal implemented
	Wastewater	Jinyuanjingkai wastewater treatment plant phase 1 (20000t/d)	Jinyuanjingkai wastewater treatment plant phase 2 (30000t/d)		East District wastewater treatment plant phase 1 & 2 (50000t/d)		Upgrade of Jinyuanjingkai and East District wastewater treatment plants started	East District wastewater treatment plant phase 3 & 4 (50000t/d, 230m RMB investment); South District wastewater treatment plant (20000t/d)	
	Reclaimed water			BDA reclaim water plant phase 1 (20000t/d)	East District reclaim water plant phase 1 (20000t/d)	East District reclaim water plant phase 2 (20000t/d)			
	Desulfurisation		Desulfurisation of thermal plant phase 1				Upgrade of Jinyuanjingkai and Ludong Section wastewater treatment plants, which improved surface water to IV level.		
	Denitrification							Denitrification of 800t boilders	
	Transportation							Exhaust gas emission improved for heavy logistic trucks	

This is the end of the thesis.