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Review

Eco-industrial parks in China: Key institutional aspects, sustainability impacts, and implementation challenges

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ABSTRACT

To mitigate the negative impacts of industrial production the Chinese government initiated the eco-industrial parks programme in 2001. Enterprises within eco-industrial parks seek to reduce resource consumption and waste/pollution generation by reusing and recycling material and energy by-products. However, the actual sustainability outcomes of eco-industrial parks development and operation are still not clearly known. The aim of this paper is to provide a critical synthesis of the current evidence about the key institutional aspects, sustainability impacts, and implementation challenges related to eco-industrial parks development and operation through an institutional analysis based on the key policy documents and an extensive narrative-based review of the peer-reviewed literature. The results suggest that many stakeholders are involved in eco-industrial parks development and operation, with the main drivers of eco-industrial parks development anchored on the desire to sustain economic momentum without overburdening the environment, and the effort to reduce production costs and maintain economic competitiveness. However, eco-industrial parks development and operation has a series of positive and negative economic and environmental impacts, with some of the latter remaining rather pronounced, which suggests that good production practices do not often translate to positive environmental outcomes. There is practically negligible knowledge about the possible social impacts of eco-industrial parks, possibly due to their omissions from current standards. Some of the main challenges of the effective implementation of the eco-industrial parks programme include the (a) gaps of (and lack of adherence to) eco-industrial parks guidelines and standards, (b) disjoint between eco-industrial parks planning and implementation, (c) misconception and manipulation of key eco-industrial parks concepts, (d) limited scale of eco-industrial parks implementation, and (e) knowledge gaps and non-comprehensive assessment frameworks.

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1. Introduction

China has oriented its national economy towards the manufacturing and exports of goods since the Reform and Opening Policy of the late 1970s. In 1984, the Chinese government started setting up industrial parks in coastal cities, which increased rapidly in number reaching 2543 in 2019 (Piatkowski et al., 2019). Industrial parks produce more than 60% of the national industrial output (Fan et al., 2017b), and account for approximately 70% of the national energy consumption and 72% of greenhouse gas (GHG) emissions (Thieriot and Sawyer, 2015). Due to their ever substantial labour demand, industrial parks have also been linked to urbanisation and internal migration (Zhao et al., 2014).

Most of the early industrial parks (hereafter referred to as 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., 2017). 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).

Several national programmes have aimed to upgrade existing conventional parks to further mitigate the negative impacts of industrial park development and operation (DRC and OECD, 2017). The National Demonstrative Eco-Industrial Park (EIP) programme that started in the early 2000s has been one of the most prominent efforts. This 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).

According to policies such as the "*Guide for the Establishment of Eco-Industrial Parks Planning*" (SEPA, 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[1] 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 first national demonstrative eco-industrial parks (ND-EIPs) were approved for construction in 2001, and as of August 2019, 55 ND-EIPs were operational (with another 52 under development) that are mostly concentrated in the more developed coastal regions (Figs. 1–2) (Fan et al., 2017a). 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 Electronic 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 Ecopark 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.

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),[2] 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).

[1] 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., 2014).

[2] 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).

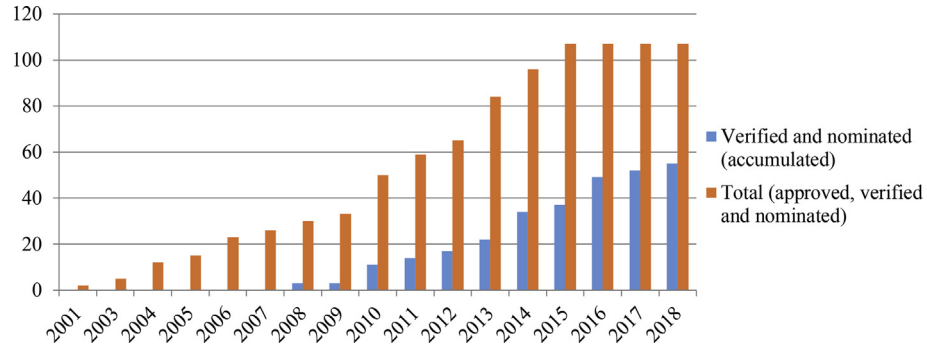

Fig. 1. Number of ND-EIPs in China. Source: Developed with data collected from the Ministry of Ecology and Environment.

Fig. 2. Distribution of ND-EIPs by type.

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). As discussed throughout this paper, different studies have reached very diverse conclusions regarding the role and impacts of EIPs in China.

The aim of this paper is to critically consolidate and synthesise the existing knowledge about some of the critical aspects of EIP development and operation in China. Through an institutional analysis and a narrative-based literature review this study explores the main legislation, stakeholders (and their relationships), sustainability impacts, and challenges of the EIP programme in China. Section 2 outlines the methodology of the institutional analysis and the literature review. Section 3 summarises important institutional aspects related to EIP development and operation. Section 4 outlines the main sustainability impacts of EIPs in China, and Section 5 discusses some of the main challenges for improving the performance of EIPs. Section 6 identifies the major policy and practice implications and future empirical and theoretical/conceptual research directions.

2. Methodology

This paper consolidates and synthesises the current evidence about the main institutional aspects, sustainability impacts and challenges of EIP development and operation in China through a combination of institutional analysis and narrative-based literature review. Fig. 3a identifies the different aspects explored in this paper, the adopted methods and the flow of information between sections. Essentially each section tackles a relevant question about the development and operations of EIPs in China, namely:

- how and why are EIPs promoted (Section 3)
- what are the impacts of EIP development and operation (Section 4)
- what are the challenges for EIP development and operation (Section 5)
- what are future policy and research priorities for EIPs (Section 6).

First, through an institutional analysis the study elicits the institutional landscape and the drivers of EIP development (Section 3). For the purpose of this paper a broad definition of institutions is adopted that includes policies (Hindriks and Guala, 2015) 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 3.1), (b) the procedures at the EIP level governing operation and management (Section 3.2), and (c) the funding that can be leveraged to develop and implement EIPs (cross-level issue) (Section 3.3).

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

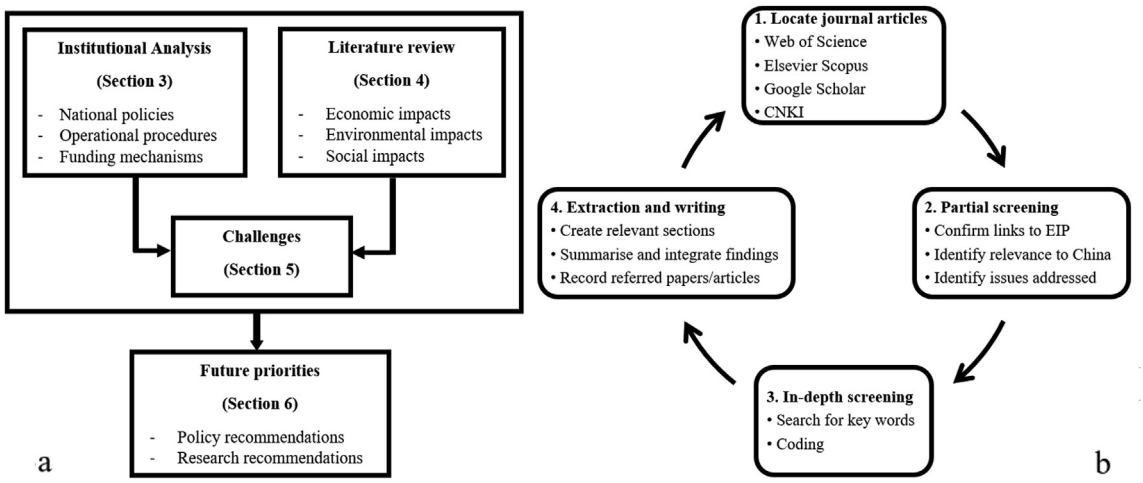

Fig. 3. Methods in relation to study sections and objectives (3a) and methodological approach of the literature review (3b). Source: Fig. 3b is adapted from Naidoo and Gasparatos (2018).

Ecology and Environment. This information is consolidated in tables and schematic diagrams that summarise the main policies, institutional processes and relations between stakeholders (Section 3).

Second, through an extensive narrative-based literature review the study identifies the main sustainability impacts of EIP development and operation (Section 5). This narrative-based literature review approach is used to identify the breadth of the current evidence base regarding EIP impacts, rather than offer a systematic analysis of literature patterns or meta-analysis of the actual impact levels. This is because most impact-related studies tend to (a) focus on different EIPs that contain very different industrial activities, and (b) use very different indicators, system boundaries, time scales and analytical methods (see below). Such differences complicate the deeper comparative analysis of these studies through a systematic review or meta-analysis protocol, and are beyond the focus of this study.

The literature review focuses mainly on peer-reviewed literature and is complemented with relevant reports (i.e. "grey literature"), where necessary. The study follows the review process outlined in Naidoo and Gasparatos (2018) (Fig. 3b), and identifies the peer-reviewed literature through academic portals such as Web of Science, Elsevier Scopus, and CNKI, reports, and non-peer-reviewed material through Google Scholar and Baidu (for documents in Chinese).

As the main function of the literature review is to identify the breadth and current evidence base regarding sustainability impacts of EIPs, a combination of keywords/phrases is used including "eco-industrial park" and "China" as thematic descriptors, and distinct keywords related to sustainability impacts, such as "greenhouse gas emissions", "pollution", "resource use", "land use change", "biodiversity" and "social conflicts", among others (see Table S2, Supplementary Electronic Material for the different studied impacts). The function of these keywords is to capture the broadest possible performance evaluation criteria proposed for EIPs, and has been informed through the main current EIP evaluation frameworks (e.g. UNIDO et al., 2017). The peer-reviewed articles identified through this literature search are scanned quickly by reading titles and abstracts to ensure their relevance to China and sustainability impacts. After this initial scan, papers that are not relevant are omitted. The relevant articles included in this review are read thoroughly to extract the information about sustainability impacts. Information elicitation is assisted through the identification and tracking of relevant keywords within the document.

The findings of the narrative review are synthesised in Section 4 across three broad impact categories, namely environmental, economic, and social impacts, with articles that focus on multiple impacts discussed in all relevant sub-sections. Table S2 in the Supplementary Electronic Material identifies the individual impacts and aggregate categories discussed in Section 4. As this study adopts a narrative-based literature review approach, it does not contain a deeper analysis of the literature patterns for the reasons described above. For the benefit of the reader Section 4.1 contains figures about the distribution of studies across impacts and methods, with summaries of each individual study included in Table S3 of the Supplementary Electronic Material.

3. Institutional aspects of EIP development and operation

A key feature of the EIP initiative in China has been the elaborate institutional landscape regulating EIP development and operation. Section 3.1 outlines the major relevant national policies. Section 3.2 highlights the main operational processes at the EIP level, and Section 3.3 depicts the main funding mechanisms facilitating investments in EIPs.

3.1. National policies for EIP development and operation

A series of laws and regulations define the overall institutional framework for the development, operation and regulation of EIPs (Table 1). 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 (Table 1). 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).

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

Table 1
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
SEPA	Provisions on the Application, Denomination and Management of National Demonstrative Eco-Industrial Parks (Trial); Guideline for Eco-Industrial Park Planning (Trial)**; The Application, Denomination and Management Provisions on Demonstrative Circular Economy Zones (Trial); Guideline for Circular Economy Zone Planning (Trial)	2003: Issued (SEPA, 2003) 2007: ** amended, effective in 2008	- Provides appropriate governing bodies, procedures and planning standards
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
SEPA	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
SEPA, 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

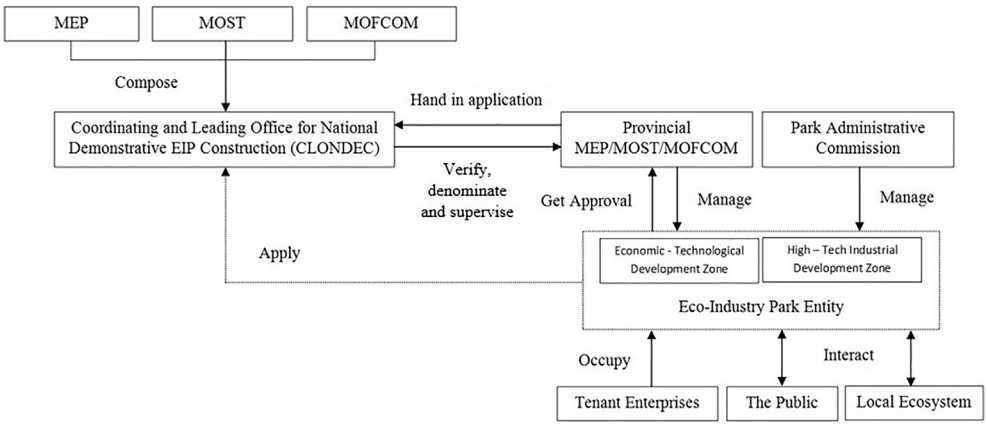

Fig. 4. Stakeholder connections during the development of national demonstrative EIPs.

issued by the Ministry of Environmental Protection (MEP), the Ministry of Science and Technology (MOST), and Ministry of Commerce (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.

Many different governmental departments, administrations, bureaus, and research/academic institutes provide appropriate guidance for the implementation of the aforementioned regulations and processes. Fig. 4 visualises the connections between the different governmental bodies and other stakeholders related to the operation of EIPs. Fig. 5 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 (Section 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).[3] Such events have inherently shaped some of the underlying national environmental regulations related to EIPs (Li and Lin, 2016) (Table 1). 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) and other regional agreements with Northeast Asian countries.

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).

Economic expectations at various levels (e.g. national, regional, enterprise) have also driven EIP development (Yu et al., 2015b). 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., 2015b). 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., 2015b), 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).

3.2. Processes for the 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 fulfills 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

[3] 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).

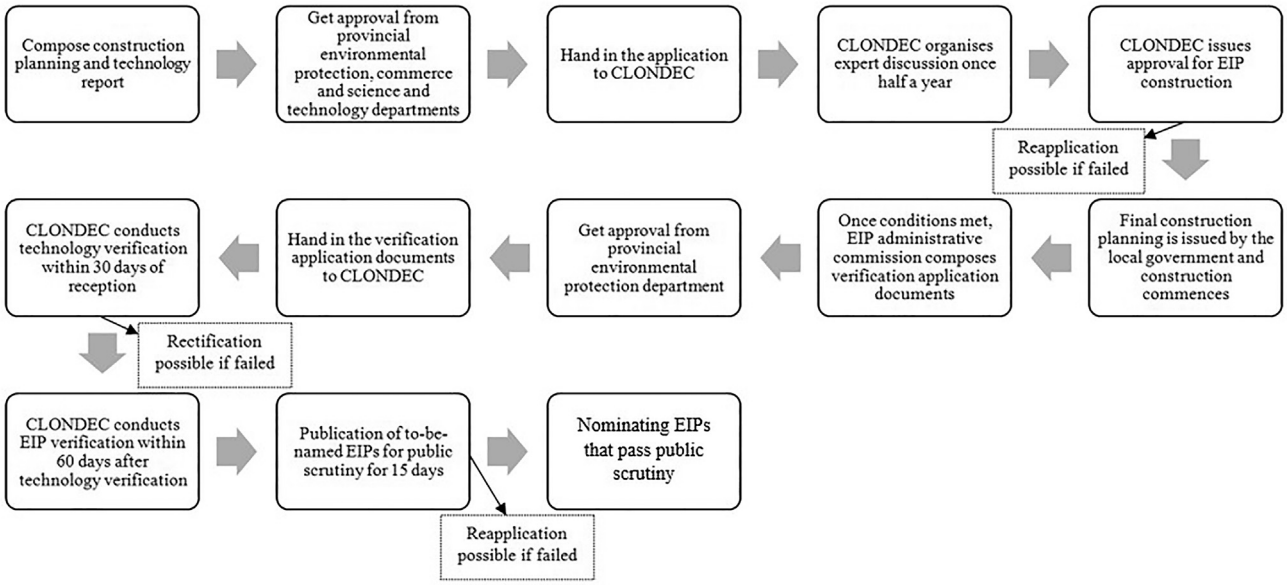

Fig. 5. Procedures for the application, verification and nomination of national demonstrative EIPs.

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, State Environmental Protection Agency (SEPA), MOFCOM, and MOST have also co-issued a set of standards for EIP development and operation (Table 2). 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 National Development and Reform Commission (NDRC and MOFCOM, 2017), and Ministry of Industry and Information Technology (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 2).

3.3. 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 (Fig. 6). 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) (Fig. 7).

The growth in EIP investment has likely followed similar trajectories. For example, Fig. 8 outlines aggregated investment trends for two Chinese EIPs, the Tianjin Economic and Technological Development Area (TEDA) and Beijing Economic and Technological Development Area (BDA). 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 Ecopark 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 (Asian Development Bank, 2019), and private domestic investment, among others (Piatkowski et al., 2019). Table 3 summarises some other funding schemes applicable for EIP development.

Table 2
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).

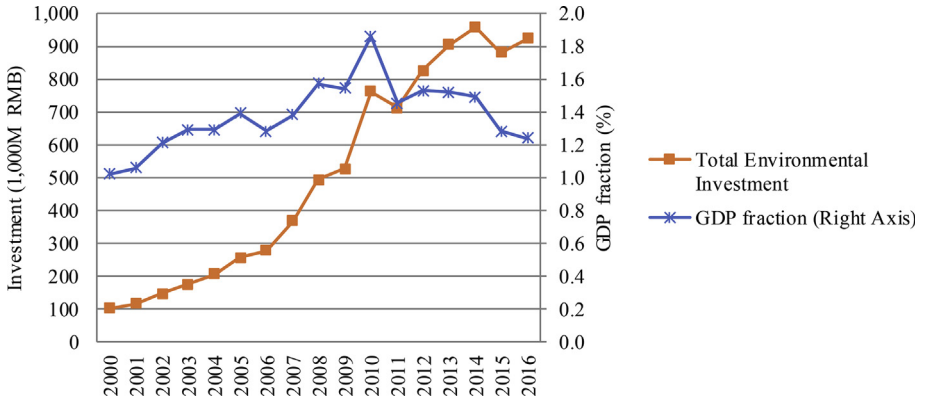

Fig. 6. Amount of environmental investment (left y-axis) and its GDP fraction (right y-axis) Source: Developed with data collected from the National Bureau of Statistics of China.

4. Sustainability impacts

With the long span of EIP development and operation in China, there has been relatively well-developed peer-reviewed literature outlining EIP impacts. Section 4.1 outlines the broad patterns of this peer-reviewed literature, while Sections 4.2-4.4 focuses on the economic, environmental and social impacts, respectively.

4.1. Broad literature patterns

The literature selection approach outlined in Section 2 identified 41 different studies. These studies have mainly focused on the economic and environmental impacts of EIPs, with practically no studies on social impacts (Fig. 9). Between them, the different studies focused on many different EIPs using very different methods, indicators and system boundaries. For example some studies focused on single EIPs (e.g. Yu et al., 2015a) 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). Sections 4.2-4.4 discuss the main patterns for each impact category and Table S2-3 in the Supplementary Electronic Material contains more detailed summaries and characteristics for each study.

4.2. Economic impacts

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).[4] Fan et al. (2017a) 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

[4] It should be noted that the average annual IAV growth for the entire Chinese economy between 2005 and 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).

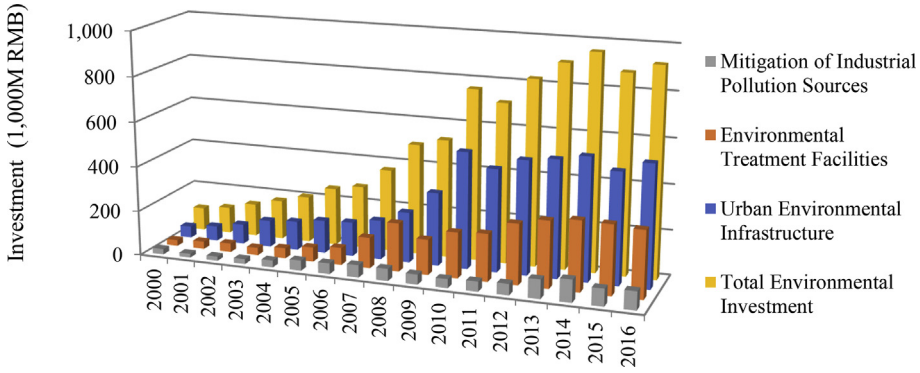

Fig. 7. Breakdown of environmental investments by category. Source: Developed with data collected from the National Bureau of Statistics of China.

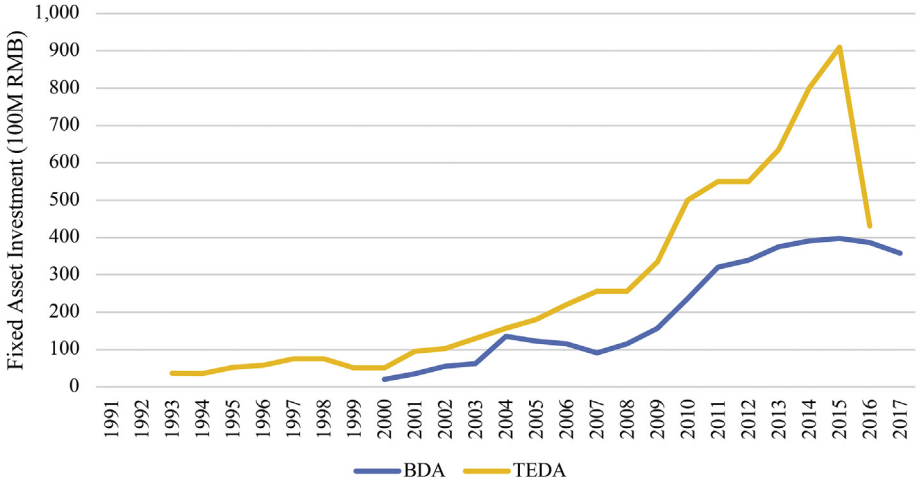

Fig. 8. Investment in fixed assets for two EIPs. Note: Tianjin Economic and Technological Development Area (TEDA), Beijing Economic and Technological Development Area (BDA). Source: Developed with data collected from the annual reports of TEDA and BDA.

Table 3
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):

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). Some EIPs have attracted many high-tech industries, which sometimes account for >60% of their overall economic output (Zhang et al., 2009). 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).

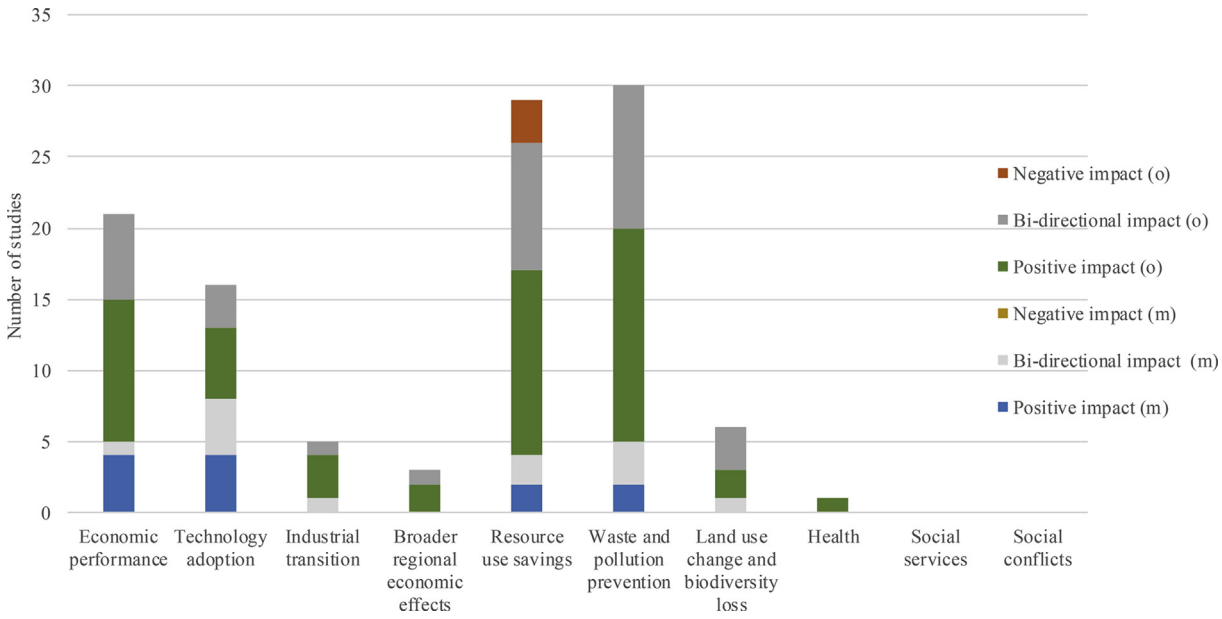

Fig. 9. Impacts and direction of impact for the reviewed studies. Note: (m) denotes impacts derived from modelled data, and (o) observed data.

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., 2017a). 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 Demonstrative Park have accounted for a significant fraction of the regional economic output (>30%), being major drivers of regional economic development (Table S1 Supplementary Electronic Material).

4.3. Environmental impacts

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). 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., 2017a) 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 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. Resource use efficiency is one of the main aspects of the Standard for National Demonstration Eco-Industrial Parks (HJ 274–2015) (MEP, 2015), but 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). Resource savings also 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. 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., 2015c). 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).

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). 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). 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., 2015b), 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).

4.4. Social impacts

Considering their substantial economic and environmental impacts (Sections 4.2-4.3), EIPs can have profound societal effects (Huang et al., 2019). 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 (Fig. 9). 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). 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., 2019a). 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 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). Measures, plans and websites of many EIPs consulted during the development of this paper often mention social infrastructure such as hospitals or schools, which are fully or partly developed by the respective EIPs. Despite the many studies raising the need to develop such services in the context of EIPs in China (Huang et al., 2019), this review 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). 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). This review 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).

5. Challenges for the effective development and implementation of EIPs

Despite the extensive promotion and support of EIPs from the national, provincial and local governments, their development and implementation still faces many challenges. Sections 5.1-5.5 critically discuss these major challenges including the (a) gaps of (and lack of adherence to) EIP guidelines and standards (Section 5.1), (b) disjoint between EIP planning and implementation (Section 5.2), (c) misconception and manipulation of key EIP concepts (Section 5.3), (d) limited scale of EIP implementation (Section 5.4), and (e) knowledge gaps and non-comprehensive assessment frameworks (Section 5.5).

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). 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., 2017a). The needs for large-scale technological innovation (Wang et al., 2019b), 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., 2014).

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 4), 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 3.2), though it is not clear if this happens for most EIPs (MEE, 2018).

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),[5] 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) (Section 5.2).

5.3. Misconception and manipulation of key concepts

The designation of circular economy as a key national development strategy (Sections 3.1 and 4), "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 byproducts/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 on (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 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 3.2). For example, some have manipulated rules encouraging good industrial practices if they 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).

5.4. Limited scale of implementation

As already discussed, EIP implementation entails the adoption of relevant practices at three scales: (a) cleaner production at the enterprise level, (b) industrial symbiosis at the inter-enterprise level, and (c) symbiosis within the broader region (Geng et al., 2009) (Section 1, 3). Major constraints for forging stronger symbiotic relationships at the enterprise and inter-enterprise level include policy constraints, financial concerns, and managerial issues (Chen et al., 2017). Such constraints can be challenging for meaningfully integrating small and medium-sized enterprises, especially in view of their significant effect in Chinese economy and the environment (UNCRD, 2018).

In some cases EIPs have formed symbiotic relationships outside their organisational boundaries to enhance production capacity (Li et al., 2015), and to meet economic objectives (Shi and Chertow, 2017). The meaningful integration of EIP processes into broader regional activities through industrial symbiosis could enhance regional sustainability (Zhao and Guo, 2018), and thus should be promoted (Liu et al., 2018b). One of the most promising pathways to forge such broader symbiotic relationships is the diversion of some of the valuable waste streams generated by local communities to EIPs (and vice versa) (UNIDO, 2019). The integration of surrounding communities into EIP operation is still problematic (Fujii et al., 2016), due to, among others, the (a) insufficient disclosure and communication of information about waste generation and need (Zhu and Côté, 2004), (b) lack of incentives for households to classify waste (Lu and Sidortsov, 2019), (c) lack of key technologies to utilise municipal waste in EIPs (Mian et al., 2017), (d) lack of policy and financial support to strengthen such relationships (Dong et al., 2016), (e) value conflicts between municipal waste treatment and recycling agencies, and EIPs (Meng et al., 2018), and (f) labour shortage for waste collection (Steuer et al., 2018).

5.5. Gaps in knowledge and assessment frameworks

EIPs have multiple environmental and socioeconomic impacts (Section 4) (Shi et al., 2012c). There are significant knowledge gaps about many impacts, both thematically and methodologically. Methodologically, most studies exploring environmental impacts tend to use simulations and proxy measures, thus reducing the

[5] 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.

ability to understand the actual extent of some effects (Section 4.3) (Fig. 9). Thematically, there are very few studies exploring the impacts of EIPs on biodiversity/ecosystem services (Section 4.3) and the society at large (Section 4.4) (Qu et al., 2015b) (Fig. 9).

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 3.2). 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 4.4, 5.4).

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).

6. Future directions for EIP development and operation

6.1. Policy recommendations

As discussed in Sections 3.2 and 5.1, 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 3.2, 4, 5.1). Thus 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.

As the implementation and verification of EIP practices is not binding, many of the EIPs approved for construction have not requested for verification after five years. This means they would have to restart the whole process according to the current regulations (MEP et al., 2015). Ongoing monitoring is sometimes not 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 have not been properly articulated. The above suggest 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.

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. 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. To 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).

6.2. Future research

This study identifies three major research and practice gaps that need to be bridged 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 (Fig. 9, Geng and Côté, 2004), which should be noted that they have not been considered in national standards (Huang et al., 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. Fig. 9 suggests that many impact studies either use simulation and modelling, or proxy measures to assess the impacts of EIPs (see also Table S2, Supplementary Electronic 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.

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 up-taking from the different stakeholders and avoid catering to specific vested interests.

7. Conclusions

Since the inception of the national demonstrative EIP development programme in 2001, 55 industrial parks have been verified as EIPs as of 2018, with another 52 under transformation. This paper provided a comprehensive outlook of the main institutional aspects, sustainability impacts, and challenges of EIP development and operation in China through an institutional analysis and literature review. The study critically elicits China's relatively unique experience in EIP development and implementation, and provides useful insights to other emerging countries still relying on manufacturing using conventional and outdated technologies about the major elements that should be targeted to harness the true sustainability potential of EIPs.

The paper identifies the negative environmental impacts associated with the rapid industrialisation 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.

The review of 41 peer-reviewed papers on 31 EIPs or industrial parks with EIP practices shows that despite some evidence about the positive effects of EIPs on economic output, resource use, and environmental pollution, there are major concerns about the overall sustainability of EIPs, including (a) the absolute level of resource use and pollutant/GHG emissions, (b) the fact that the same impact might be positive or negative depending on different study factors, and (c) the serious knowledge gaps about the social impacts of EIPs as only health impacts were mentioned in one paper. Overall, the current academic literature on EIPs literature is very geared towards the economic (33 papers focusing on 19 parks) and environmental impacts (36 papers focusing on all 31 parks), with practically no studies empirically exploring the social impacts of EIP development.

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, (d) the limited scale of EIP implementation, and (e) the gaps in EIP knowledge and assessment frameworks.

A major limitation of this study was the inability to adopt a systematic review or meta-analysis approach to analyse the peer-reviewed literature, as most impact-related studies tend to focus on various EIPs with majorly different industrial activities), and use somewhat different indicators, system boundaries, time scales and analytical methods. Future research should seek to consolidate the existing literature and target the challenges mentioned above in a more systematic manner. The research should aim to focus on understudied impacts (e.g. social impacts), adopt direct approaches to impact assessment, and improve current evaluation frameworks by developing indicators for understudied impacts and integrating them meaningfully in comprehensive performance frameworks.

CRediT authorship contribution statement

Hongru Hong: Conceptualization, Formal analysis, Methodology, Funding acquisition, Investigation, Writing - original draft. **Alexandros Gasparatos:** Conceptualization, Methodology, Supervision, Funding acquisition, Writing - review & editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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