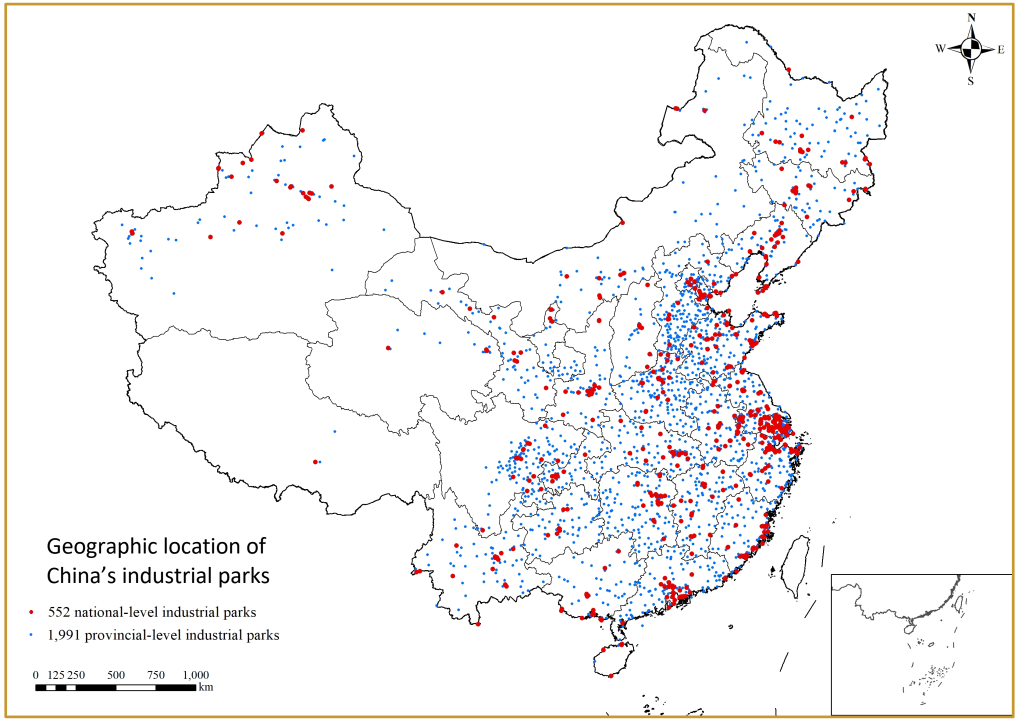
Eco-industrial Development

Global perspective and China's exploration



Dec. 4, 2019; School of Environment

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Self introduction

Self introduction

Education

- 2000/3-2004/1, Tsinghua University, Organic Chemistry, Ph.D
- 1996/9-1999/7, Sichuan University, Leather Science and Technology, Master
- 1992/9-1996/7, Sichuan University, Leather Science and Technology, Bachelor

Self introduction

Research experience

- 2012/11-present, School of Environment, Tsinghua University, Associate professor
- 2015/02-2016/02, Yale School of Forestry & Environmental Studies, Visiting fellow
- 2009/8-2012/10, , School of Environment (former Department of Environmental Science and Technology), Tsinghua University, assistant professor
- 2007/3-2009/5, Department of Environmental Science and Technology, Tsinghua University, postdoctoral
- 2004/2-2007/2, TH-UNIS Insight Chemical Industrial Technology Co. Ltd, vice chief engineer

Self introduction

Research interest

- Industrial ecology, in particular material/energy metabolism/GHG mitigation/water stewardship in industrial park, industrial symbiosis, and eco-industrial park.
- Researchgate: https://www.researchgate.net/profile/Jinping_Tian2

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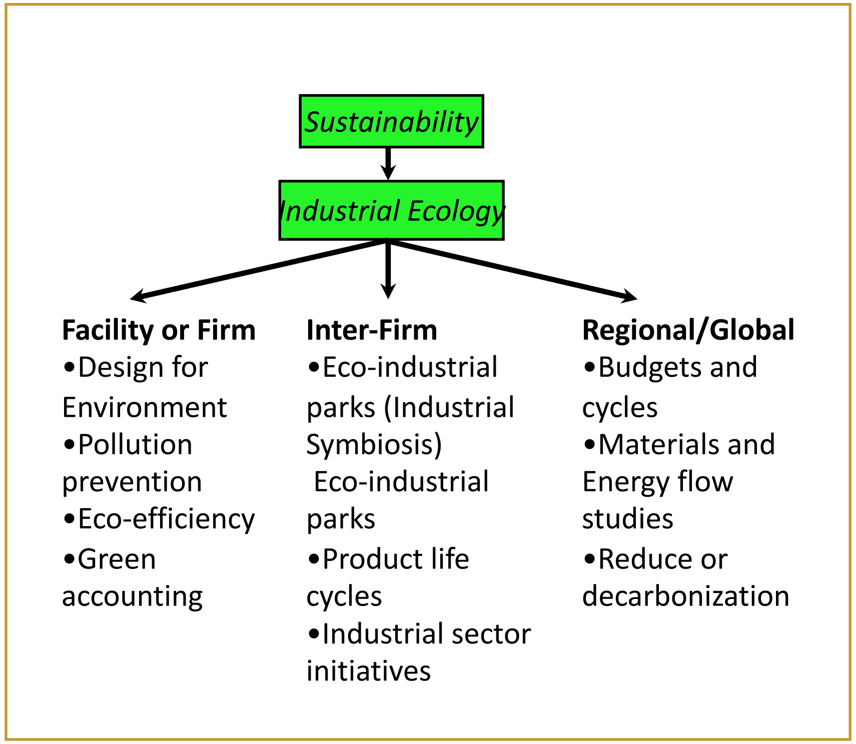
Today's Topics

1. Concepts and basic knowledge on IE, EIP, and IS
2. Innovation of eco-industrial park development globally
3. Review of eco-industrial park development in China

Concepts and basic knowledge on IE, EIP, and IS

"Industrial ecology （IE） is the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources."

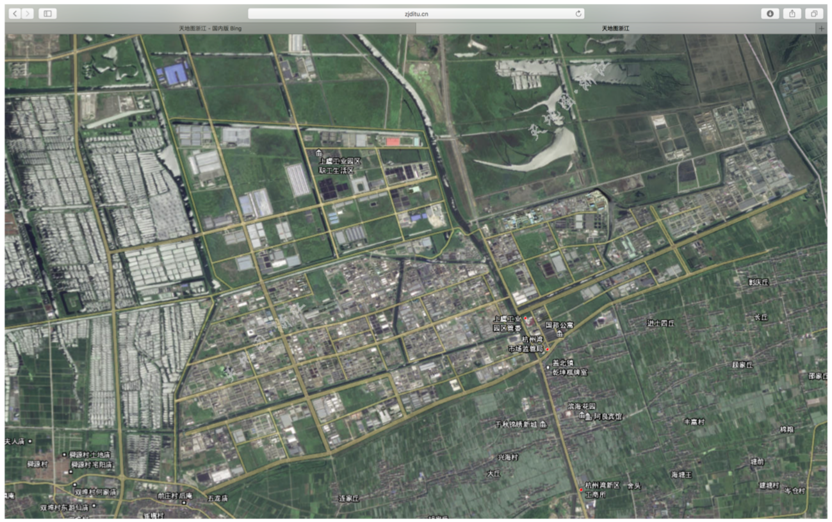
Source: Robert White 1994 President, US National Academy of Engineering
Courtesy of Prof. Marian Chertow and Prof. Thomas Graedel

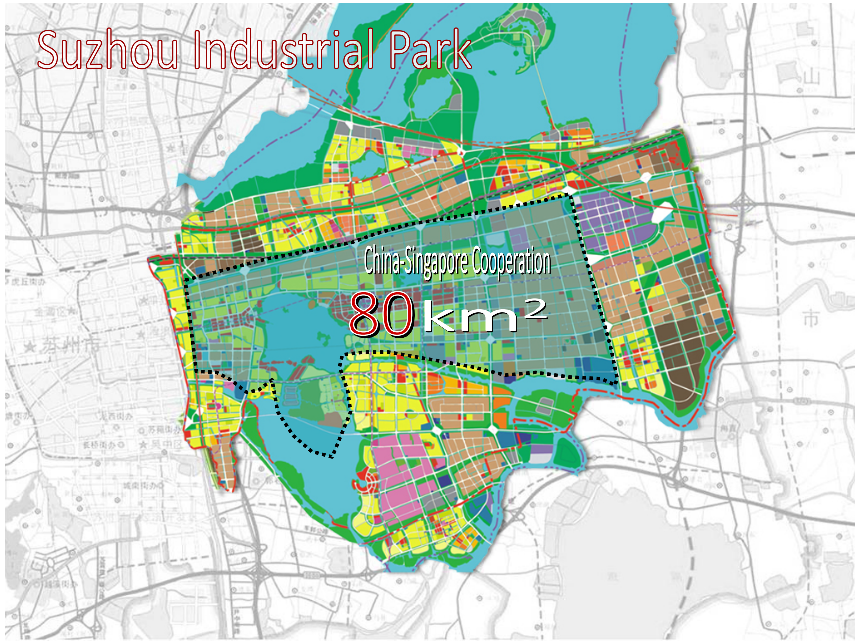


Source: Lifset, R. and T. E. Graedel. 2001. "Industrial Ecology: Goals and Definitions." In *Handbook for Industrial Ecology*, edited by R. U. Ayres and L. Ayres. Brookfield: Edward Elgar.

What is industrial park?

- Industrial estate: A large tract of land, sub-divided, and developed for the use of several firms simultaneously, distinguished by its shareable infrastructure and close proximity of firms (Peddle 1993).

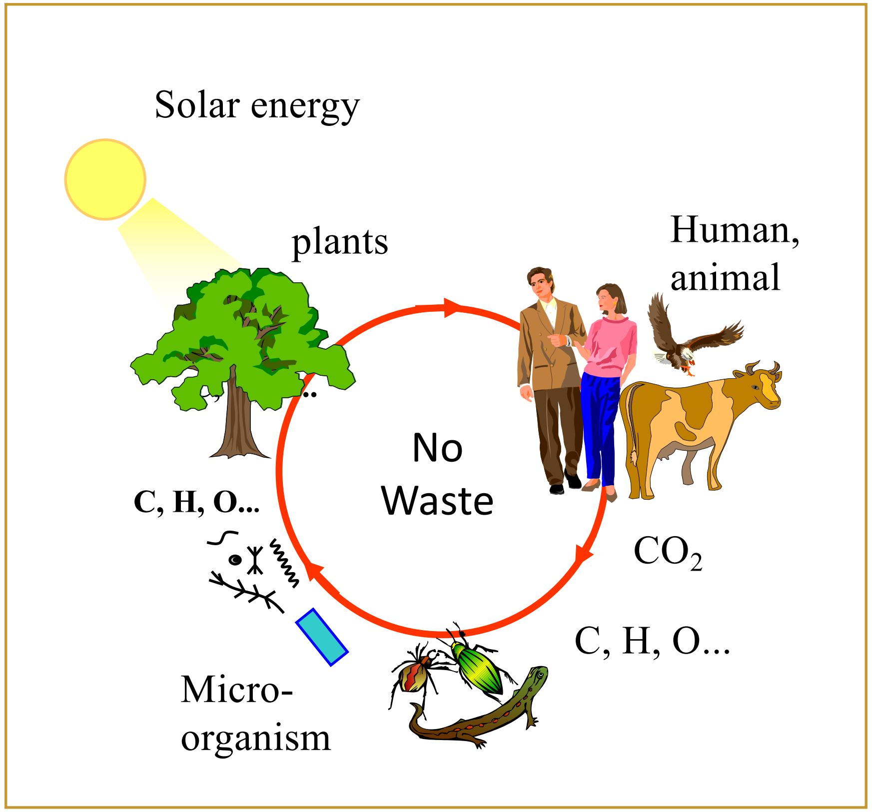




Second source: UNEP, 1997, Environmental management of industrial estate.

Industrial ecosystem

The traditional model of industry activity, in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of, should be transformed into a more integrated model: an industrial ecosystem. In such a system the consumption of energy and materials is optimized and the effluents of one process.. , serve as the raw material for another process.

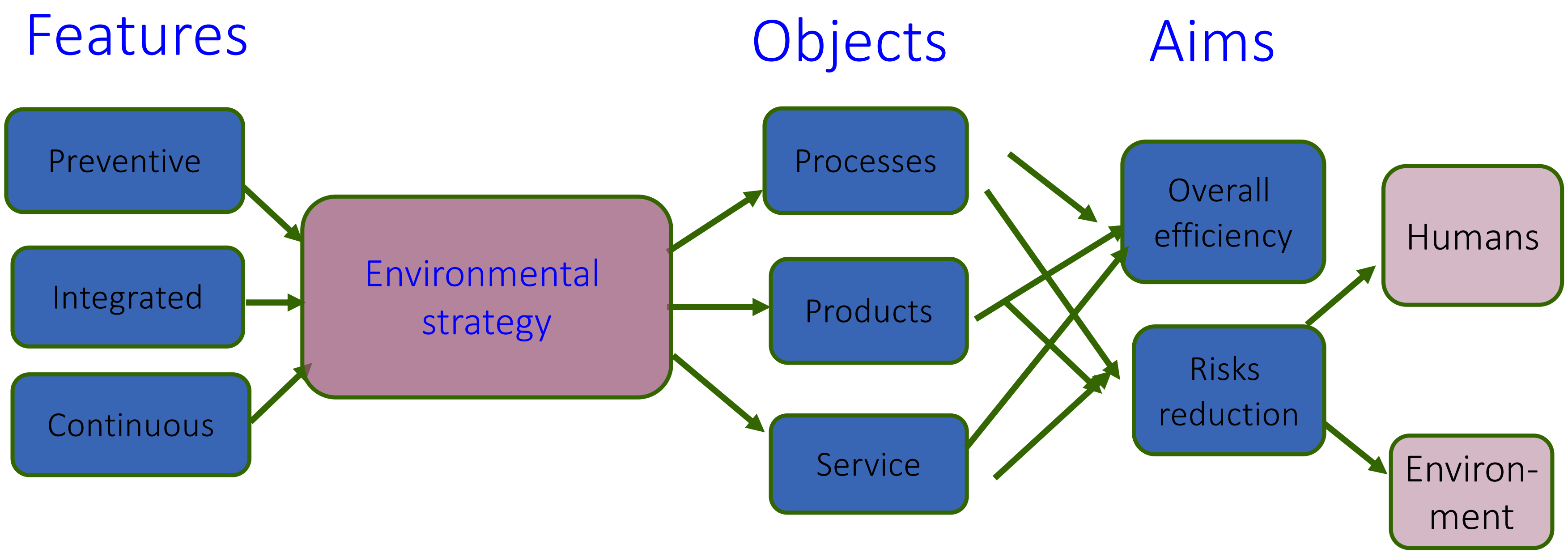


Frosch RA. and Gallopoulos, NE.1989. Strategies for manufacturing. Sci. Am. 266:144-52.

Source: Prof. Jin, Yong, 2007, Nanjing

Definition of Cleaner Production

"The continuous application of an integrated preventive environmental strategy applied to processes, products, and services to increase overall efficiency and reduce risks to humans and the environment."—— (United Nations Environment Programme, 1996)



Courtesy of and Source: adapted from http://www.unep.org/

Industrial Symbiosis

[simbi'əusis, -bai-]

Symbiosis between crocodile and bird

Symbiosis between hornbill rhinoceros

Symbiosis between clown fish-anemone

The clown fish protects the anemone from other fish that would eat it, while the anemone's stinging tentacles keep the clown fish's predators away.

Industrial Symbiosis （IS）

Definition by Marian in 2000

- Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by *geographic proximity*.

Definition by NISP in 2012

- Industrial symbiosis engages diverse organizations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes.

Source: Rachel Lombardi, Peter Laybourn, 2012, Redefining industrial symbiosis: crossing academic - practioner boundaries, Journal of Industrial Ecology, 16(1): 28-37

Eco-industrial park definition

PCSD	An *eco-industrial park* is “a **community** of **businesses** that **cooperate** with each other and with the local community to efficiently **share** resources (information, materials, water, energy, infrastructure and natural habitat), leading to **economic gains**, **gains in environmental quality**, and **equitable enhancement of human resources** for the business and local community”.
Indigo	An *eco-industrial park or estate* is a community of manufacturing and service businesses located together on a common property. Member businesses seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of individual benefits each company would realize by only optimizing its individual performance.
EPA	An *eco-industrial park* is a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues including energy, water, and materials. By working together, the community of businesses seeks a collective benefit that is greater than the sum of the individual benefits each company would realize if it optimized its individual performance only”.

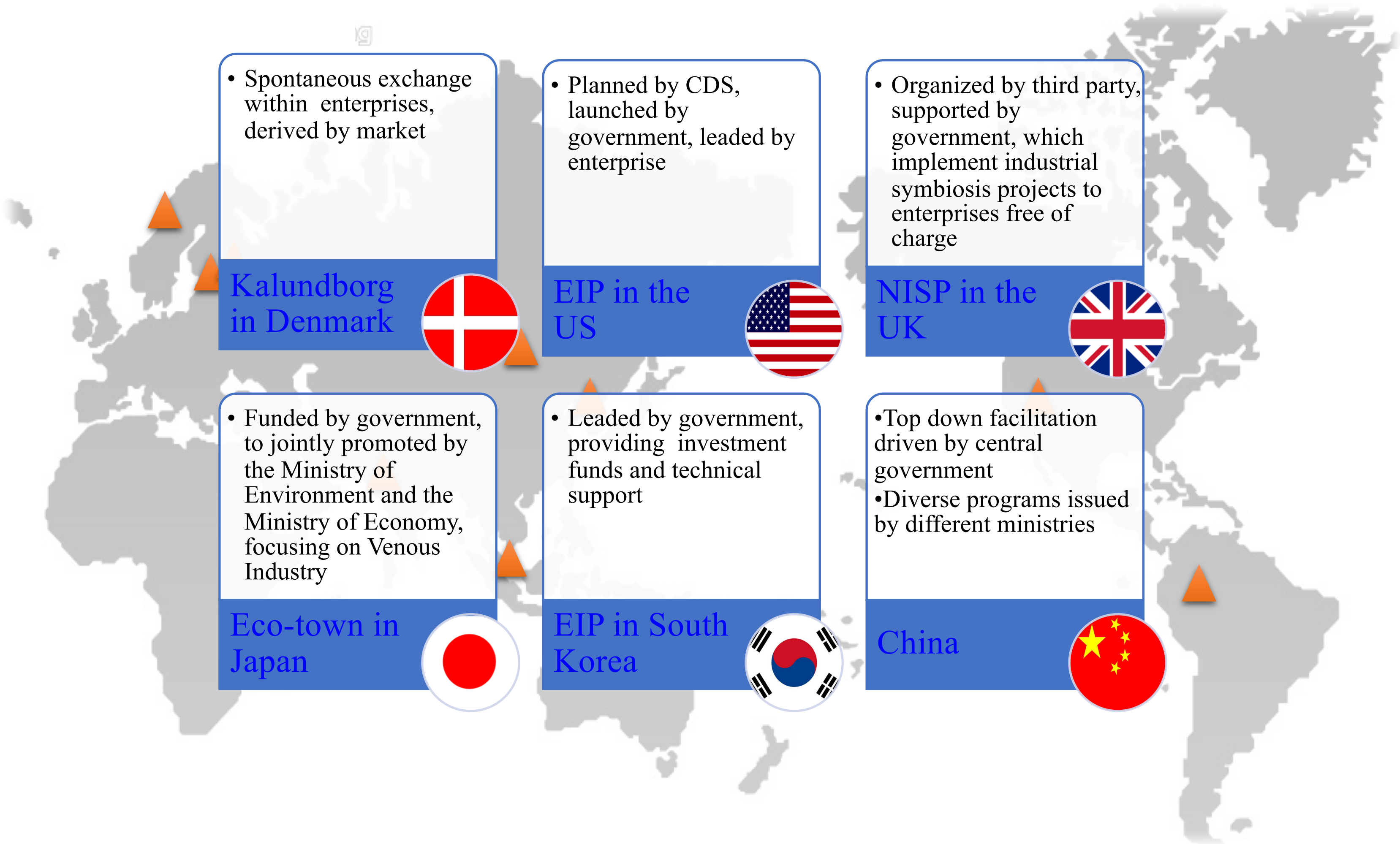
Source：*Eco-industrial Park Handbook for Asian Developing Countries*, Indigo Development Working Papers in Industrial Ecology (1997-2001), and field experience in the Philippines, Thailand, and China.

Goal of an Eco-industrial park

- The goal of an EIP is to improve the economic performance of the participating companies while minimizing their environmental impacts. Components of this approach include green design of park infrastructure and plants (new or retrofitted); cleaner production, pollution prevention; energy efficiency; and inter-company partnering. An EIP also seeks benefits for neighboring communities to assure that the net impact of its development is positive.

Source: Ernest A. Lowe. Eco-Industrial Park Handbook for Asian Developing Countries, 2001

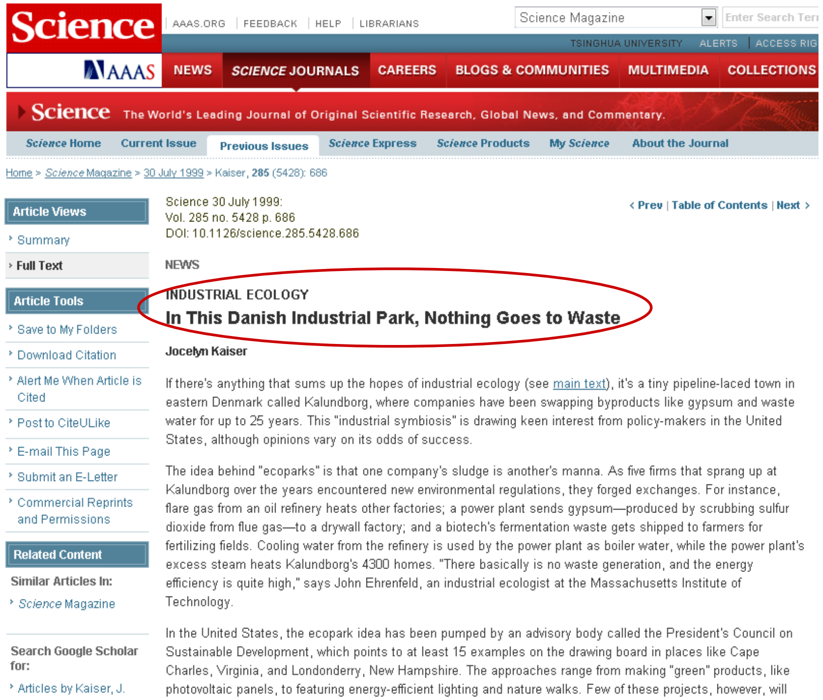
Overview of typical Eco-industrial Park development globally



Industrial symbiosis in Kalundborg Demark

Some local high school students prepared a science project in 1989 in which they made a scale model of all the pipelines and connections in their small community.

Following this high school project, still on display in Kalundborg, came the European media and then academics to describe the existing network from a broader environmental perspective.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Science 30 July 1999:
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DOI: 10.1126/science.285.5428.686

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NEWS

INDUSTRIAL ECOLOGY

In This Danish Industrial Park, Nothing Goes to Waste

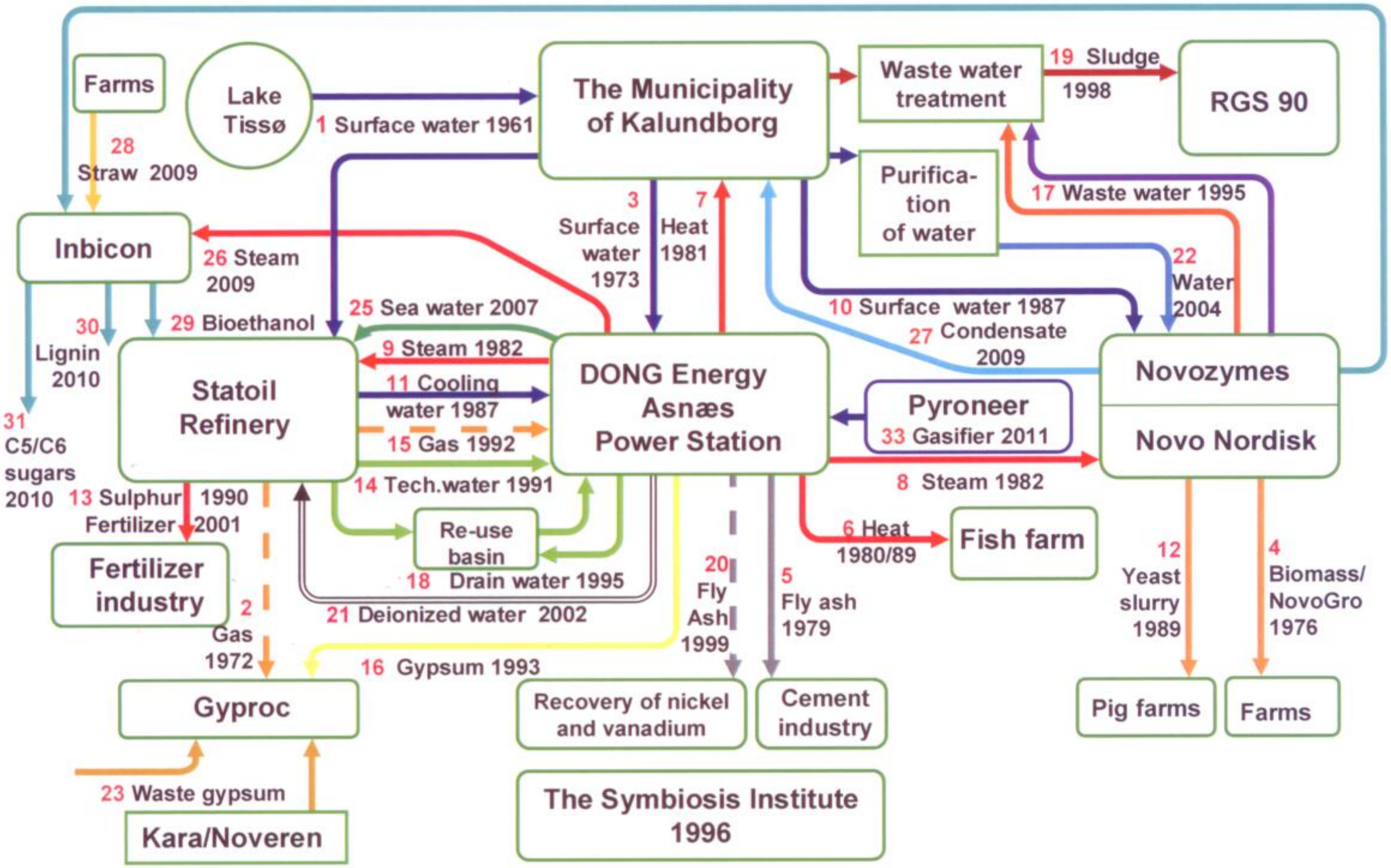
Jocelyn Kaiser

If there's anything that sums up the hopes of industrial ecology (see main text), it's a tiny pipeline-laced town in eastern Denmark called Kalundborg, where companies have been swapping byproducts like gypsum and waste water for up to 25 years. This "industrial symbiosis" is drawing keen interest from policy-makers in the United States, although opinions vary on its odds of success.

The idea behind "ecoparks" is that one company's sludge is another's manna. As five firms that sprang up at Kalundborg over the years encountered new environmental regulations, they forged exchanges. For instance, flare gas from an oil refinery heats other factories; a power plant sends gypsum—produced by scrubbing sulfur dioxide from flue gas—to a drywall factory; and a biotech's fermentation waste gets shipped to farmers for fertilizing fields. Cooling water from the refinery is used by the power plant as boiler water, while the power plant's excess steam heats Kalundborg's 4300 homes. "There basically is no waste generation, and the energy efficiency is quite high," says John Ehrenfeld, an industrial ecologist at the Massachusetts Institute of Technology.

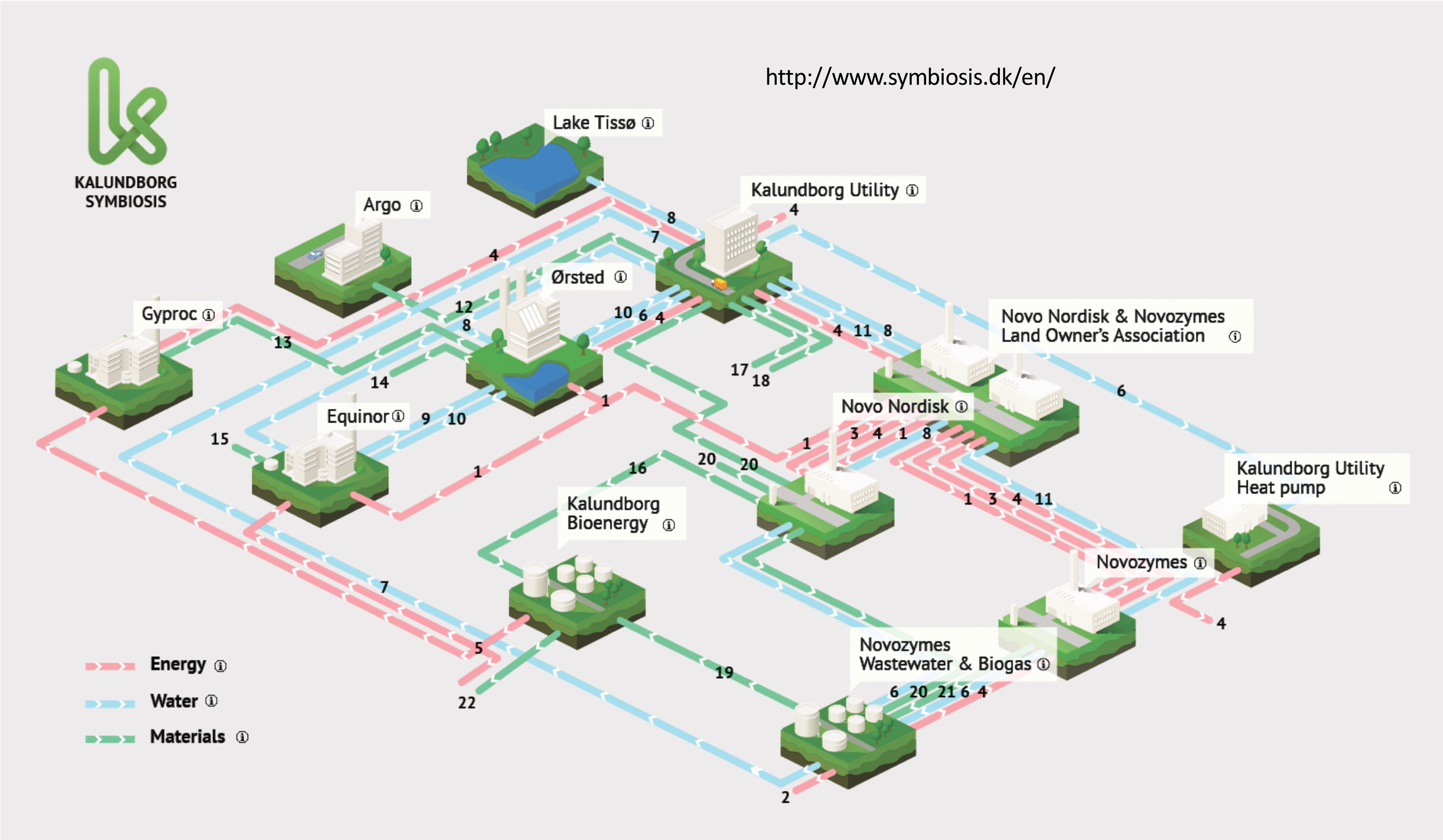
In the United States, the ecopark idea has been pumped by an advisory body called the President's Council on Sustainable Development, which points to at least 15 examples on the drawing board in places like Cape Charles, Virginia, and Londonderry, New Hampshire. The approaches range from making "green" products, like photovoltaic panels, to featuring energy-efficient lighting and nature walks. Few of these projects, however, will

Physical linkage in Kalundborg (2011)



Source: Marian Chertow and John Ehrenfeld, Organizing self-organizing systems: toward a theory of industrial symbiosis. Journal of Industrial Ecology. 2012. 16(1): 13-27.

Visualization of industrial symbiosis in Kalundborg Demark



UK National Industrial Symbiosis Program

NISP™
NATIONAL INDUSTRIAL SYMBIOSIS PROGRAMME

EVOLUTION OF NISP: Path to a sustainable, low carbon economy

Stages of evolution NISP

Pilot Region → Mature Region → National Programme → Sector Engagement → Market intelligence → RED IBIS

Regional Economic Development through Intelligence Based Industrial Symbiosis (RED IBIS

Develop regional economic advantage through opportunities identified by an IS approach to optimise regional resource and asset use (materials, energy, water, logistics, experts, knowledge, innovation and capacity, etc) to move toward a sustainable, low carbon economy.

- Began as 3 regional pilots in 2002/3
- World's first fully facilitated National Industrial Symbiosis Programme
- Government supported private sector
- 12 regional offices across the UK
- 50+ NISP practitioners in place across all regions
- Funded by UK Government (Defra)
- Engaging with companies on a "work with the willing" basis
- Thousands more completed and signed-off synergies for England, Scotland and Wales was generated

Courtesy of Peter Laybourn - NISP Programme Director

Source: 2009, RSIS, Kalundborg; Resources, Conservation and Recycling 55 (2011) 703–712

IS network in NISP, UK

Each dot refers to individual symbiont company

Georeferenced dataset

NISP's central database: CRISP (Core Resource for Industrial Symbiosis Practitioners)

Geographic proximity is considered a "hallmark" of industrial symbiosis

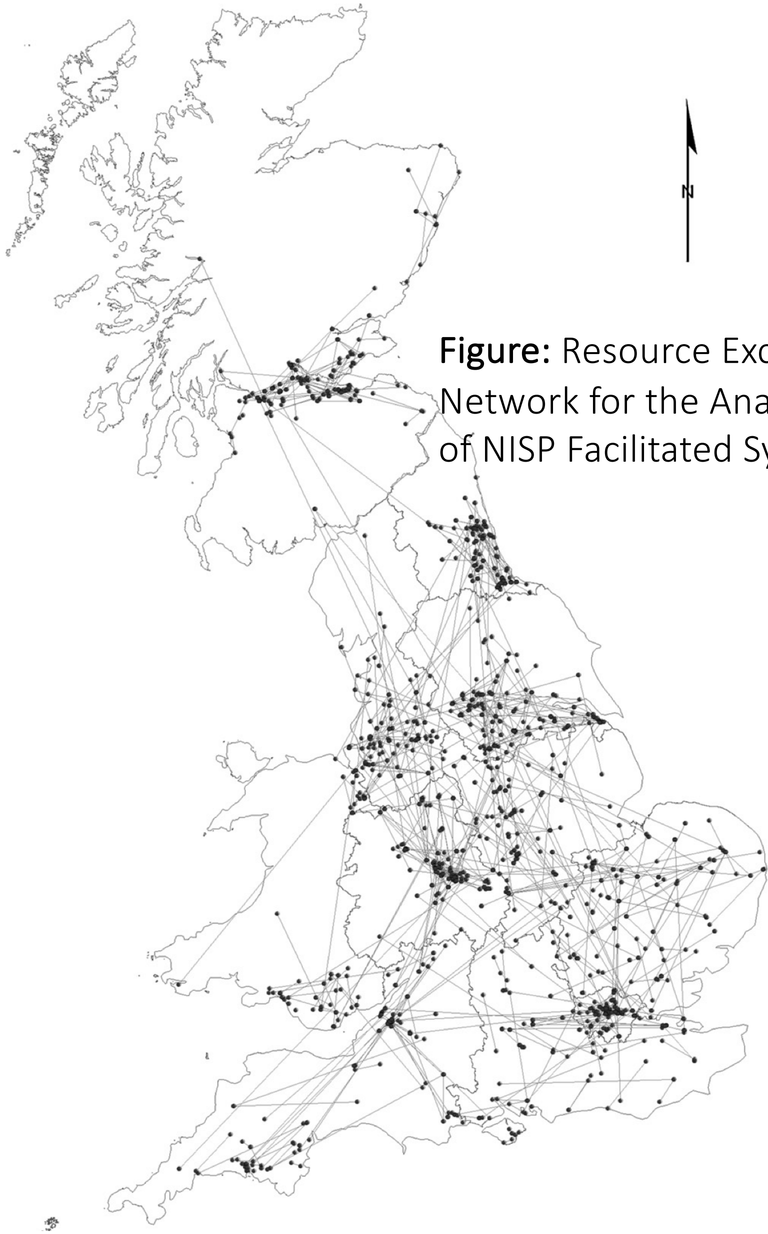


Figure: Resource Exchange Network for the Analysed Dataset of NISP Facilitated Synergies

Source: Paul D. Jensen, et al., Quantifying 'geographic proximity': Experiences from the United Kingdom's National Industrial Symbiosis Programme. Resources, Conservation and Recycling 55 (2011) 703–712

The cumulative frequency curve for all NISP synergies indicates that a quarter of all resources are reused or recycled within a 9.6 mile (15.4 km) radius of production; whilst half and three-quarter of all resources are reused or recycled within a 20.4 mile (32.6 km) and 39.1 mile (62.6 km) radius of origin, respectively.

Table 1
Resource movement distances (miles).

	Minimum	Lower quartile	Median	Upper quartile	Maximum
Coatings	0.7	2.2	5.4	18.3	72.7
WEEE	0.4	7.7	11.4	24.5	171.1
Infrastructure	0.5	11.2	11.8	44.5	199.0
Glass	6.5	10.4	18.6	28.1	47.3
Paper & cardboard	0.3	12.3	20.5	35.4	269.2
Foodstuffs Inc. oils	0.5	9.9	17.6	35.0	126.2
Compost & soils	0.6	8.8	17.8	26.7	86.3
Minerals	0.3	9.4	18.1	35.5	259.7
Organic chemicals	3.6	8.6	18.8	36.6	137.2
Wood products	0.1	6.7	18.1	28.2	105.6
Composite packaging	0.7	6.0	18.3	29.2	137.5
Misc. plastics	0.2	11.7	20.4	32.5	173.3
Metals	0.5	9.2	31.0	67.1	242.4
Ashes & slags	2.7	11.4	25.9	46.9	61.5
Fuels[a]	4.1	18.4	34.4	45.6	55.0
Aqueous sludge	16.7	29.4	36.9	67.0	124.2
Textiles	0.9	15.6	44.5	78.4	201.0
Inorganic chemicals	9.4	28.7	52.2	116.7	139.1
Rubber	7.5	26.1	62.0	84.4	129.9
Hazardous wastes[b]	0.7	9.0	26.0	60.8	259.7
All resources	0.1	9.6	20.4	39.1	269.2

Note: resource grouping and Table 1 stream titles are derived from NISP's bespoke waste stream categories.
[a] The Fuels stream title refers to resources that are known to have been used in power production.
[b] Hazardous waste movement figures derive collectively from synergies that claimed hazardous waste diversion outputs.

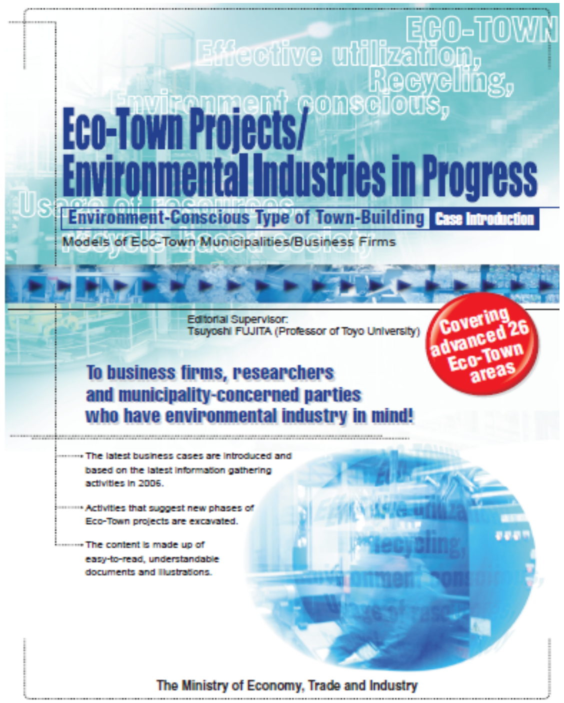
The median distance materials travelled within a symbiotic relationship is 20.4 miles.

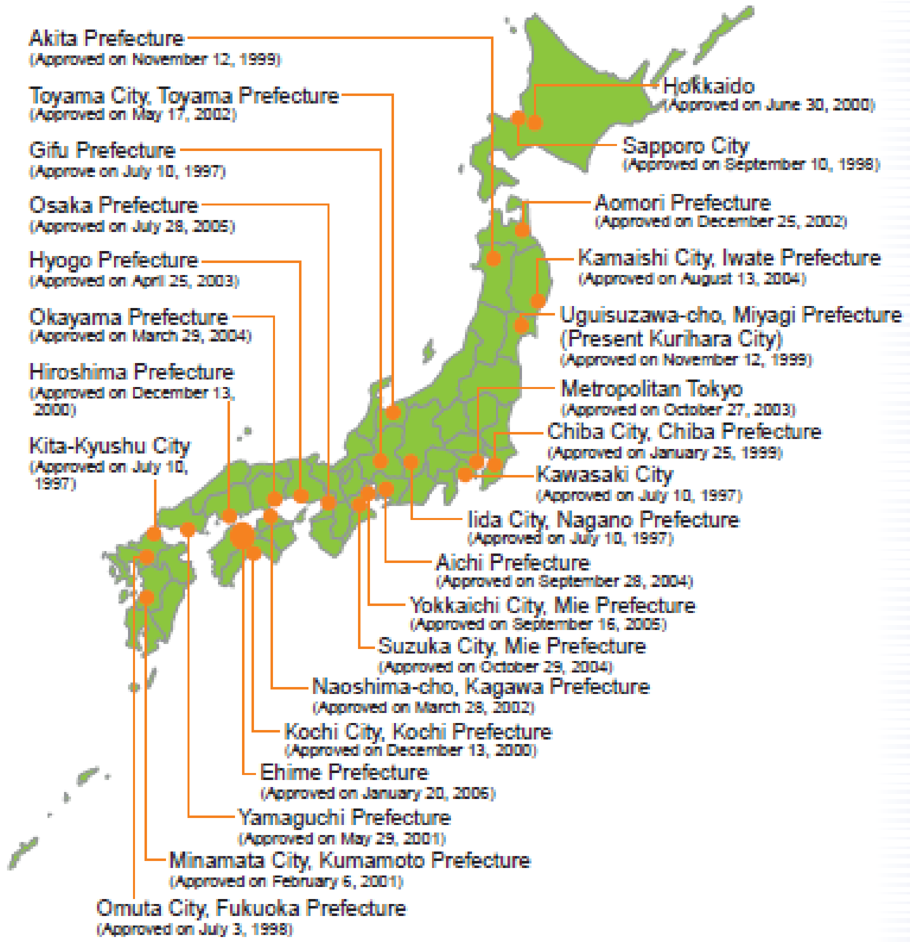
Source: Paul D. Jensen, et al., Quantifying 'geographic proximity': Experiences from the United Kingdom's National Industrial Symbiosis Programme. Resources, Conservation and Recycling 55 (2011) 703–712

Eco-town Development in Japan

The Ministry of Economy, Trade and Industry and the Ministry of Environment approved Eco-Town Plans for 26 areas as of the end of January 2006, and they provided financial support to 62 facilities located within appropriate areas.

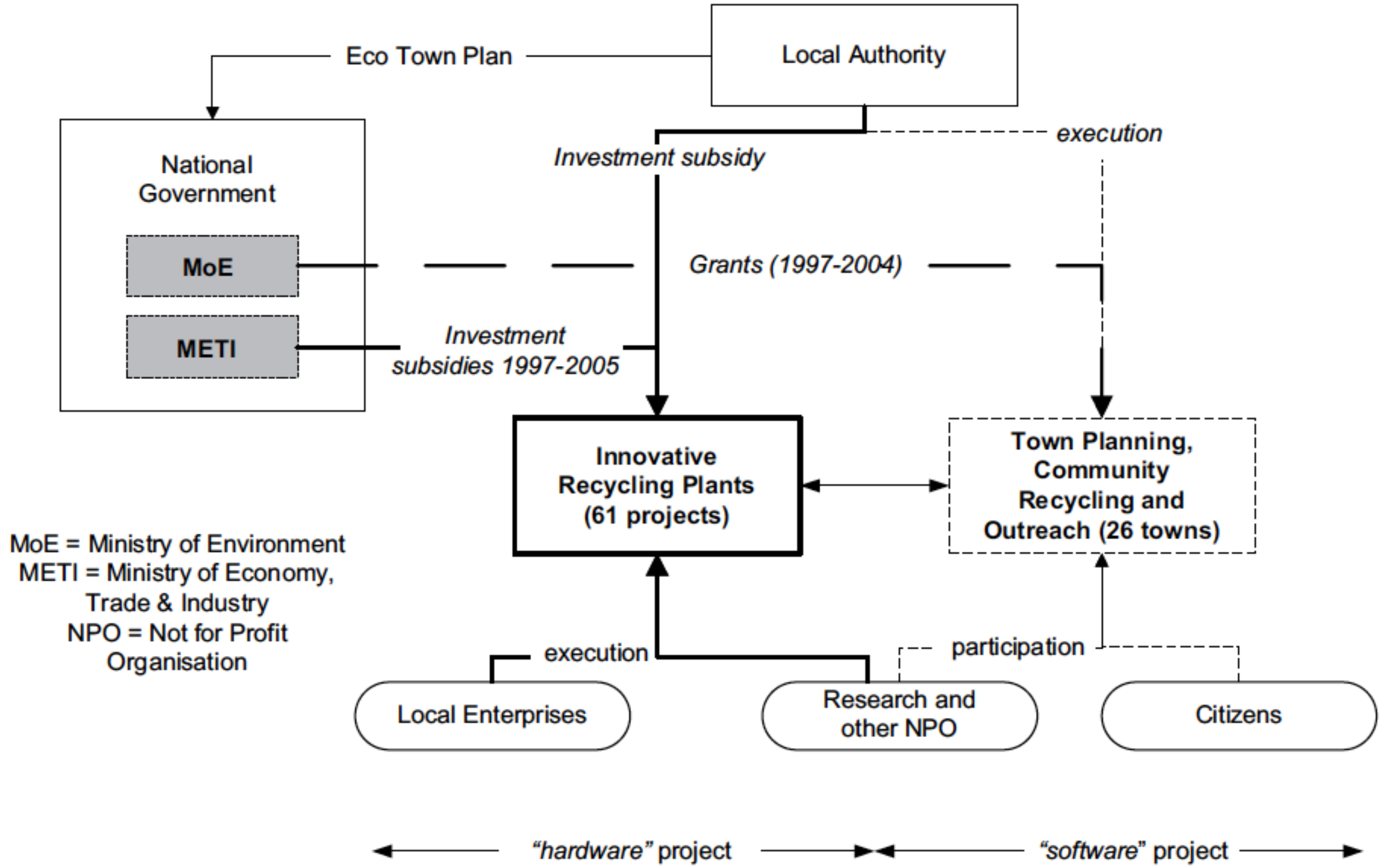
Eco-Towns in Japan have been developed through a national initiative, which was inaugurated in 1997 by the Ministry of Health, Labour and Welfare (waste management was transferred to MoE in 2001) and Ministry of International Trade and Industry (presently METI). The aim was two fold: to extend the life of existing landfill sites and to revitalise local industries.





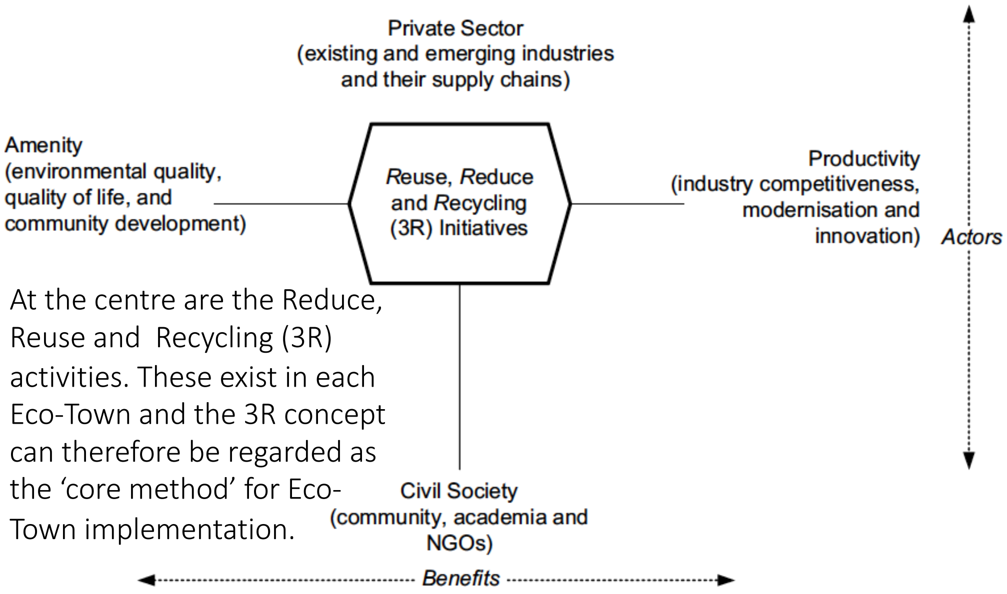
Source: Fujita, 2009, RSIS, Kalundborg

Operation of the National Eco-Town Program in Japan

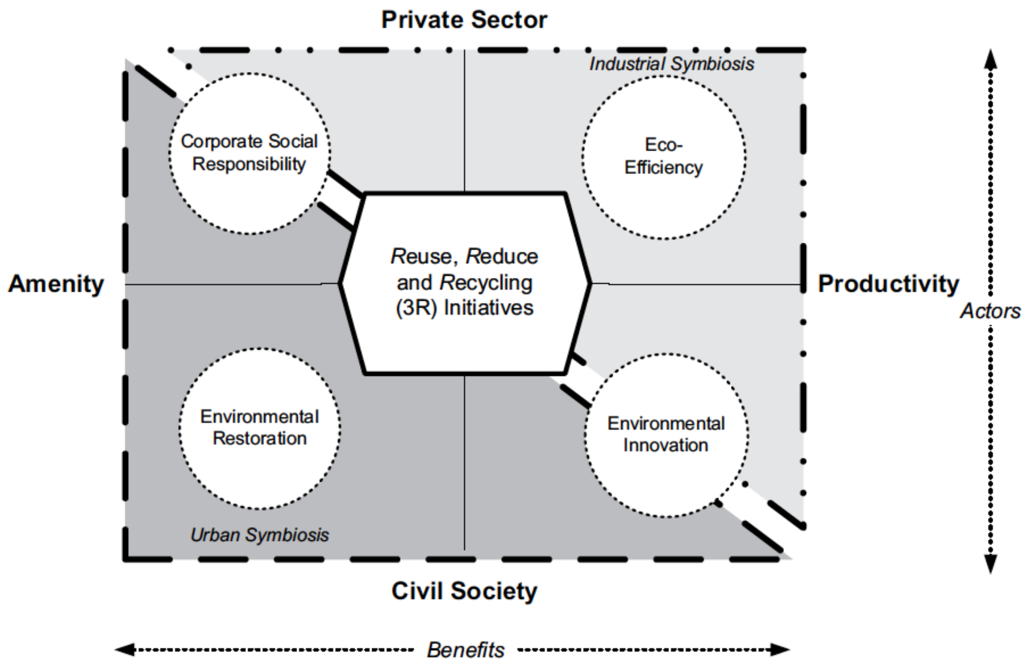


Rene Van Berkel, Tsuyoshi Fujita, Shizuka Hashimoto, Yong Geng, Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997–2006. Journal of Environmental Management 90 (2009) 1544–1556

Impacts of the Eco-Town Program in Japan



At the centre are the Reduce, Reuse and Recycling (3R) activities. These exist in each Eco-Town and the 3R concept can therefore be regarded as the 'core method' for Eco-Town implementation.



Visualisation of the impact areas in the Eco-Towns

Contribution of Eco-Towns to sustainable industrial development

Rene Van Berkel, Tsuyoshi Fujita, Shizuka Hashimoto, Yong Geng, Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997–2006. Journal of Environmental Management 90 (2009) 1544–1556

Impact of scale, recycling boundary and type of waste on symbiosis and recycling in Japanese Eco-towns

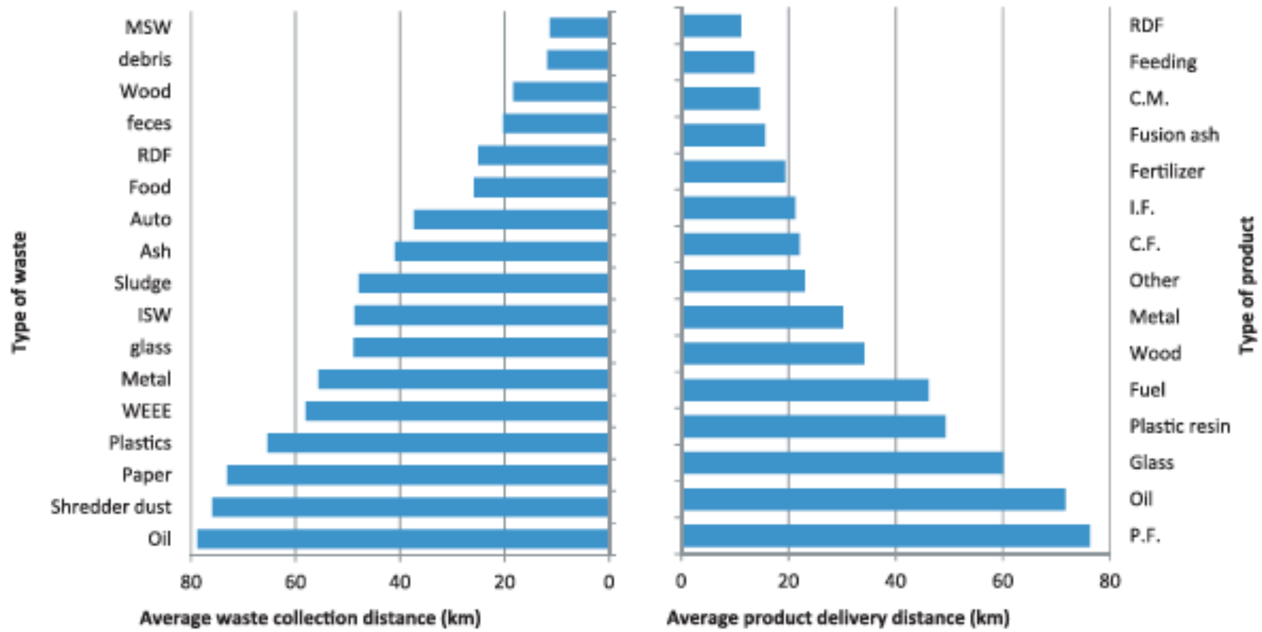


Figure 8 Average transportation distance of different types of wastes and products. WEEE = waste electronic and electrical equipment; RDF = refuse-derived fuel; MSW = municipal solid waste; ISW = industrial solid waste; CM = construction material; IF = iron production feedstock; CF = cement production feedstock; PF = paper production feedstock and recycled paper.

Chen, X., T. Fujita, S. Ohnishi, M. Fujii, and Y. Geng. 2012. The impact of scale, recycling boundary and type of waste on symbiosis and recycling: An empirical study of Japanese eco-towns. Journal of Industrial Ecology DOI: 10.1111/j.1530-9290.2011.00422.x

Evolution of the Korean EIP master plan

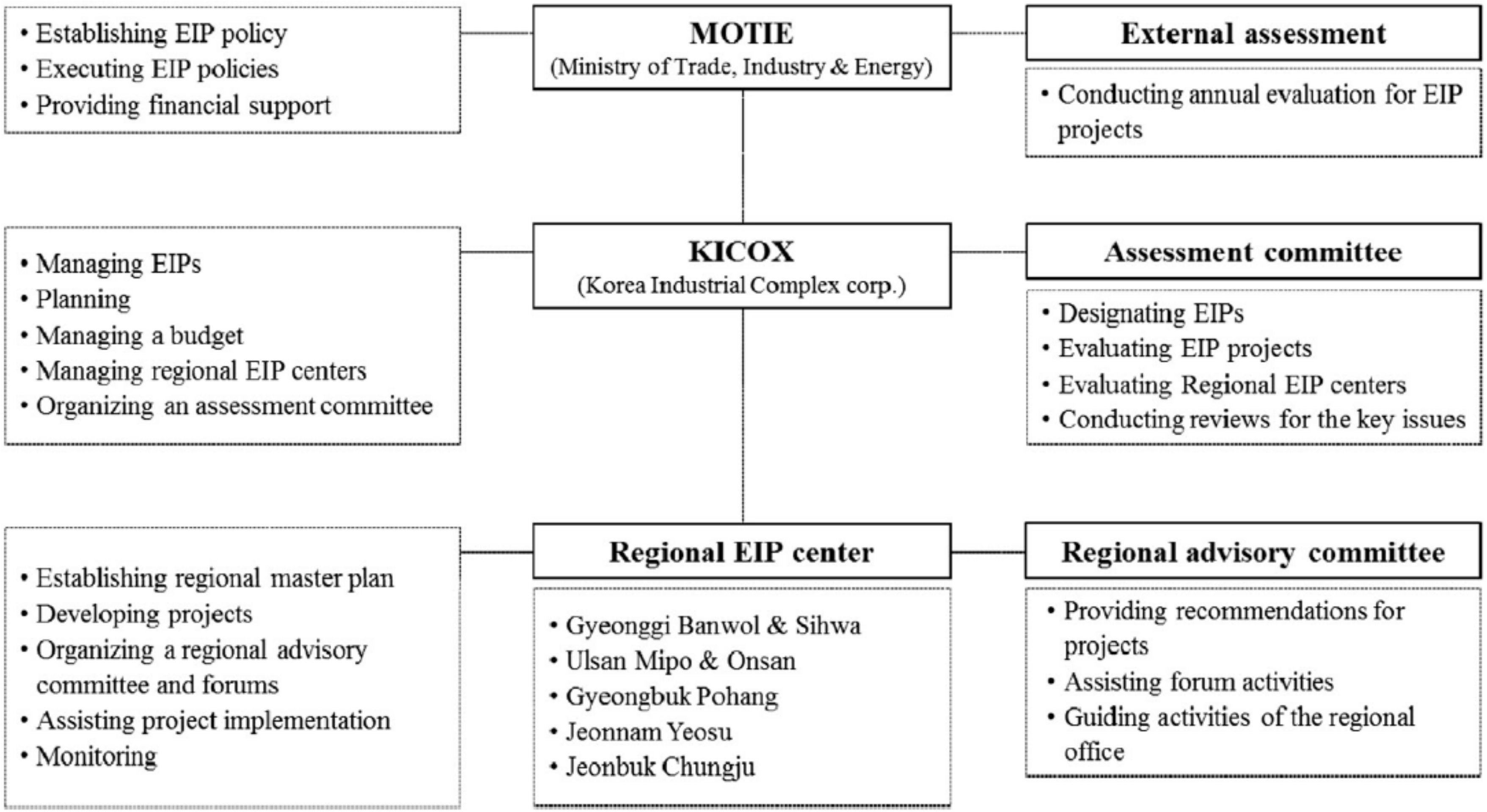
Evolution of the Korean EIP master plan.

	First phase	Second phase	Third phase
MOCIE (2003)	2004–2008 Transformation of pilot ICs into EIPs	2009–2013 Expansion of EIP transformation	2014–2018 Construction of new EIPs
KNCPC (2004)	2005–2009 Pilot experimentation (five existing ICs)	2010–2014 Expansion of resource-circulating network (>20 existing ICs)	2015–2019 Establishment of the Korean EIP model (two new ICs)
KICOX (2008–2010)	2005.11–2010.05 Pilot experimentation (five existing ICs)	2010.06–2014.12 Expansion of resource-circulating network (38 ICs)	2015.01–2019.12 Establishment of the Korean EIP model (national network)

*ICs: industrial complexes.

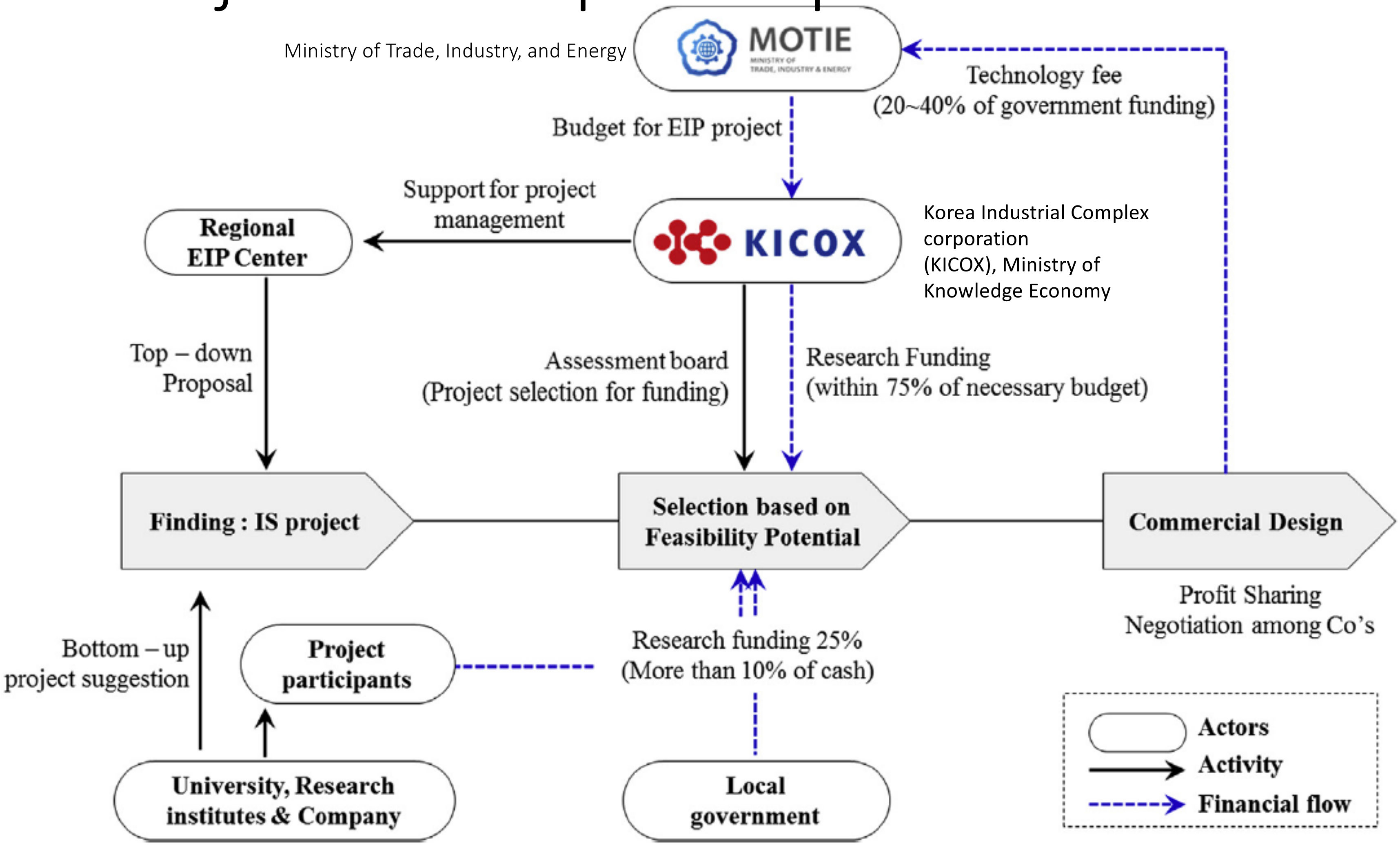
Source: Jun Mo Park, Joo Young Park, Hung-Suck Park. A review of the National Eco-Industrial Park Development Program in Korea: progress and achievements in the first phase, 2005-2010. Journal of Cleaner Production 114 (2016) 33-44

Organizational structure of the Korean EIP program



Source: Jun Mo Park, Joo Young Park, Hung-Suck Park. A review of the National Eco-Industrial Park Development Program in Korea: progress and achievements in the first phase, 2005-2010. Journal of Cleaner Production 114 (2016) 33-44

EIP Project development process in Korean



Source: Jun Mo Park, Joo Young Park, Hung-Suck Park. A review of the National Eco-Industrial Park Development Program in Korea: progress and achievements in the first phase, 2005-2010. Journal of Cleaner Production 114 (2016) 33-44

Industrial Symbiosis in the Korean National Eco-Industrial Park Program: Evolution over the 10 Years between 2005–2014

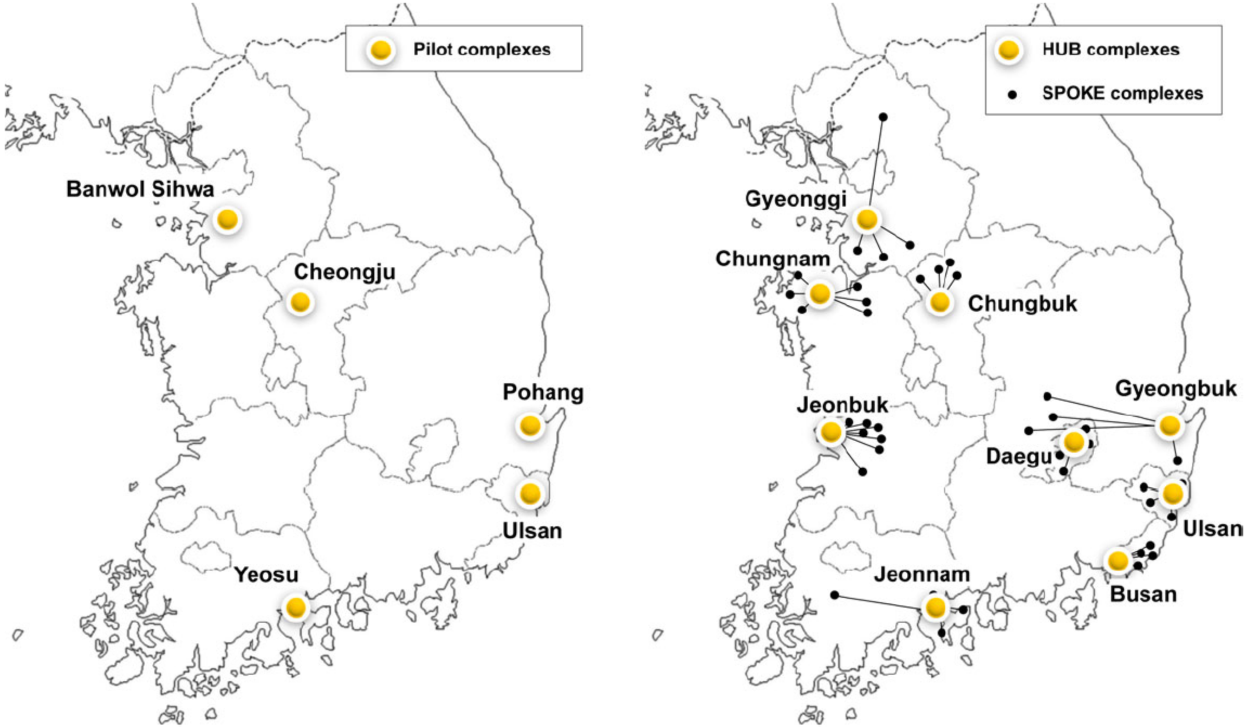
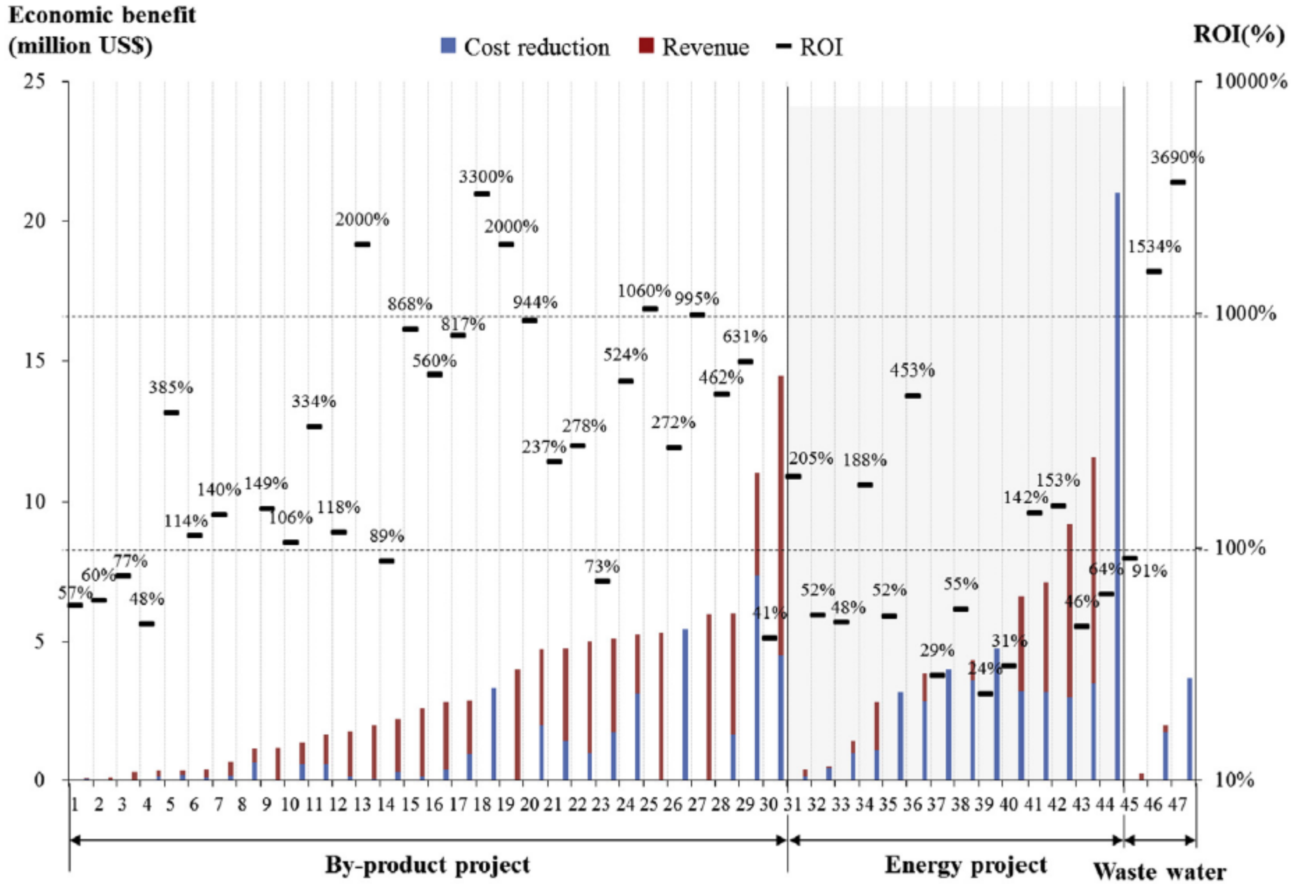


Figure 1 Target industrial complexes in the first phase (left) and the second phase (right).

Scaling-Up of Industrial Symbiosis in the Korean National Eco-Industrial Park Program: Examining Its Evolution over the 10 Years between 2005–2014. Jooyoung Park, Jun-Mo Park, Hung-Suck Park. Journal of Industrial Ecology. 2018

Economic benefits from 47 projects associated with EIP development in Korean



Economic benefits from 47 projects, arranged by project type and amount of benefit: cost reductions (blue bars, left axis), revenue generated (red bars, left axis), and return on investment (black dots, right axis). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Industrial Symbiosis in the Korean National Eco-Industrial Park Program: Evolution over the 10 Years between 2005–2014

Distance (km)

	1st phase		2nd phase		Overall
	Number of Networks	Average Distance	Number of Networks	Average Distance	Average Distance
By-products	47	50.90	289	54.23	53.76
Energy	7	1.21	83	26.77	24.78
Wastewater	8	10.83	2	5.06	9.68
Total	62	40.12	374	47.87	

Figure 5 Number of industrial symbiosis projects according to the distance between participating firms (above) and the average distance of industrial symbiosis according to the type of resources exchanged in the first and the second phases (below). km = kilometers.

Scaling-Up of Industrial Symbiosis in the Korean National Eco-Industrial Park Program: Examining Its Evolution over the 10 Years between 2005–2014. Jooyoung Park, Jun-Mo Park, Hung-Suck Park. Journal of Industrial Ecology. 2018

Industrial Symbiosis in the Korean National Eco-Industrial Park Program: Evolution over the 10 Years between 2005–2014

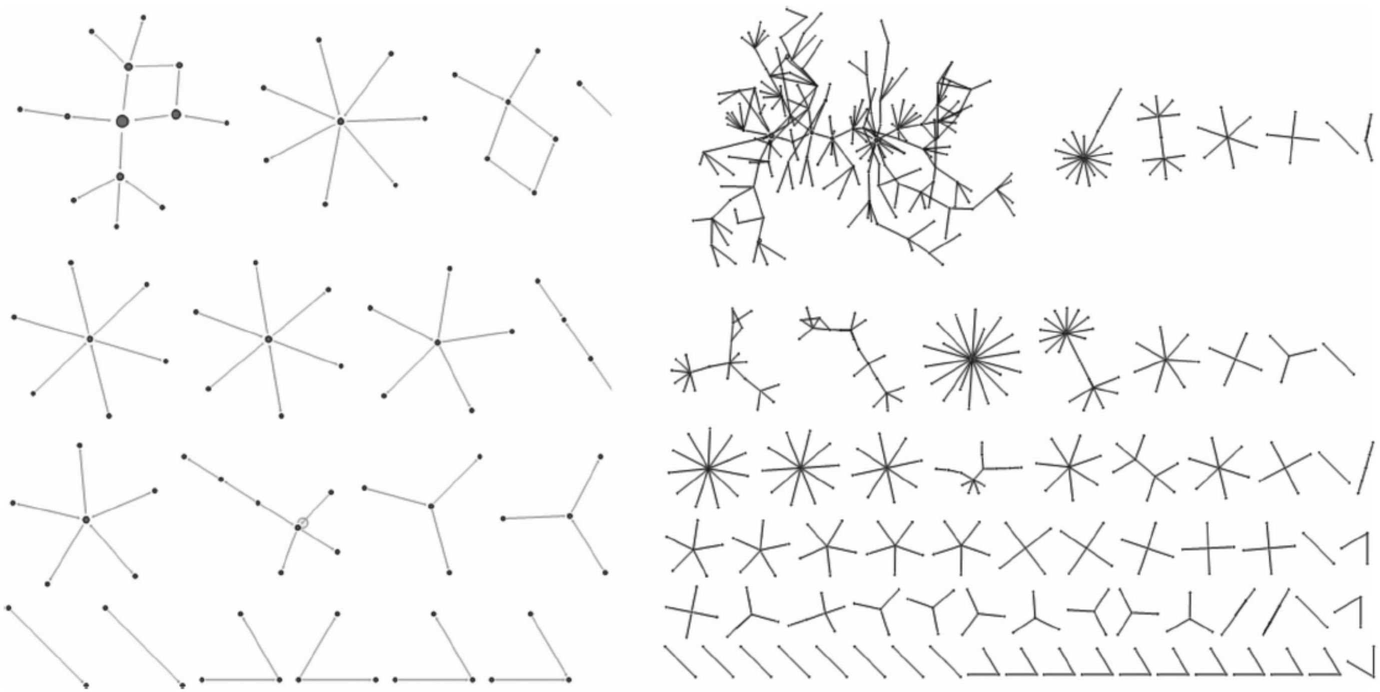
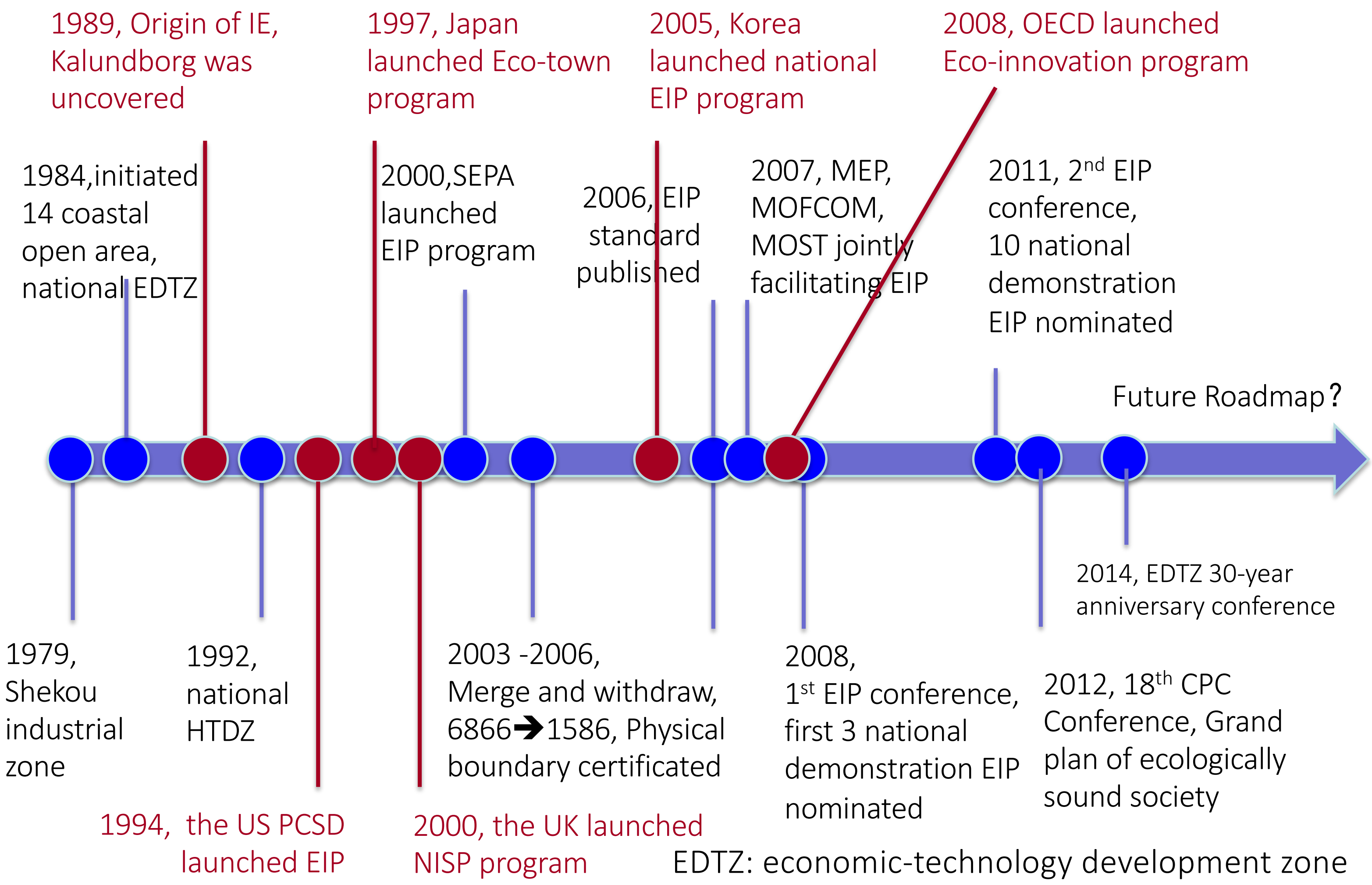


Figure 3 Networks of industrial symbiosis at the end of the first phase (left) and the second phase (right).

Nodes: participating firms   Edges: material exchanges and connections

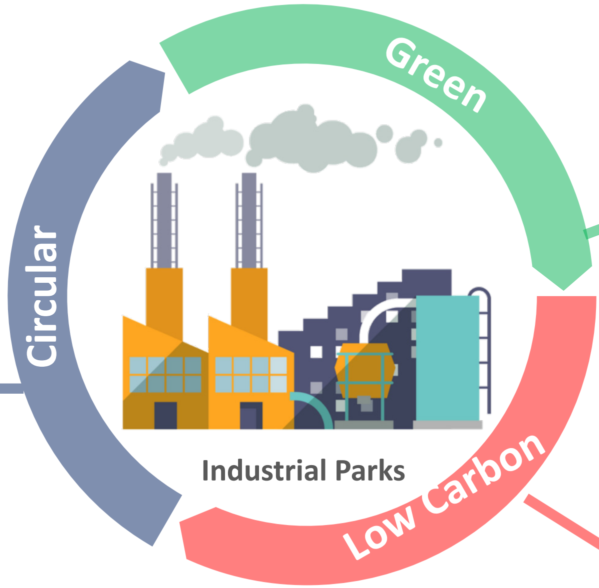
Scaling-Up of Industrial Symbiosis in the Korean National Eco-Industrial Park Program: Examining Its Evolution over the 10 Years between 2005–2014. Jooyoung Park, Jun-Mo Park, Hung-Suck Park. Journal of Industrial Ecology. 2018

Eco-industrial park development in China



Programs by the Chinese Government to Promote the Sustainable Development of IPs

Circular Transformation of Industrial Parks Program (CTIP)
- ✓ Led by National Development and Reform Commission (NDRC) and Ministry of Finance (MOF)
- ✓ Started in 2011
- ✓ 129 national IPs have been approved as demonstrations or pilots



National Demonstration Eco-industrial Park Program (NDEIP)
- ✓ Led by Ministry of Ecology and Environment (MEE), Ministry of Commerce (MOFCOM), and Ministry of Science and Technology (MOST)
- ✓ Started in 2007
- ✓ 93 approved national demonstrations and pilots

National Low-carbon Industrial Park Pilots (NLCIP)
- ✓ Led by Ministry of Industry and Information Technology (MIIT) and National Development and Reform Commission (NDRC)
- ✓ Started in 2013
- ✓ 51 approved national demonstrations and pilots

Courtesy of Prof. Bin Zhu, Tsinghua University

The "Circular Transformation of Industrial Parks (CTIP)" Program

- In 2011, the National Development and Reform Commission (NDRC) and the Ministry of Finance (MOF) jointly launched the "Circular Transformation of Industrial Parks (CTIP)" program.
  - ✓ CTIP means that the existing IPs of various types will follow circular economy principles (i.e. "reduce", "reuse" and "recycle", with priority given to "reduce") to optimize spatial layout, adjust industrial structure, develop key technologies for linking various components of circular economy, extend the industrial chain appropriately and link its various parts into a circular loop, build infrastructure and public service platforms, and renovate organizational and administrative … sustainable development.

Objective	**By 2020, circular transformation should be carried out in 57% of national IPs and 50% of provincial IPs**			
Main Tasks	**1. Rationalize spatial layout**	**2. Optimize industrial structure**	**3. Build circular industrial linkages**	**4.Utilize resources efficiently**
	5.Centralize pollution treatment	**6. Make infrastructure green**	**7. Standardize operational management**	

Courtesy of Prof. Bin Zhu, Tsinghua University

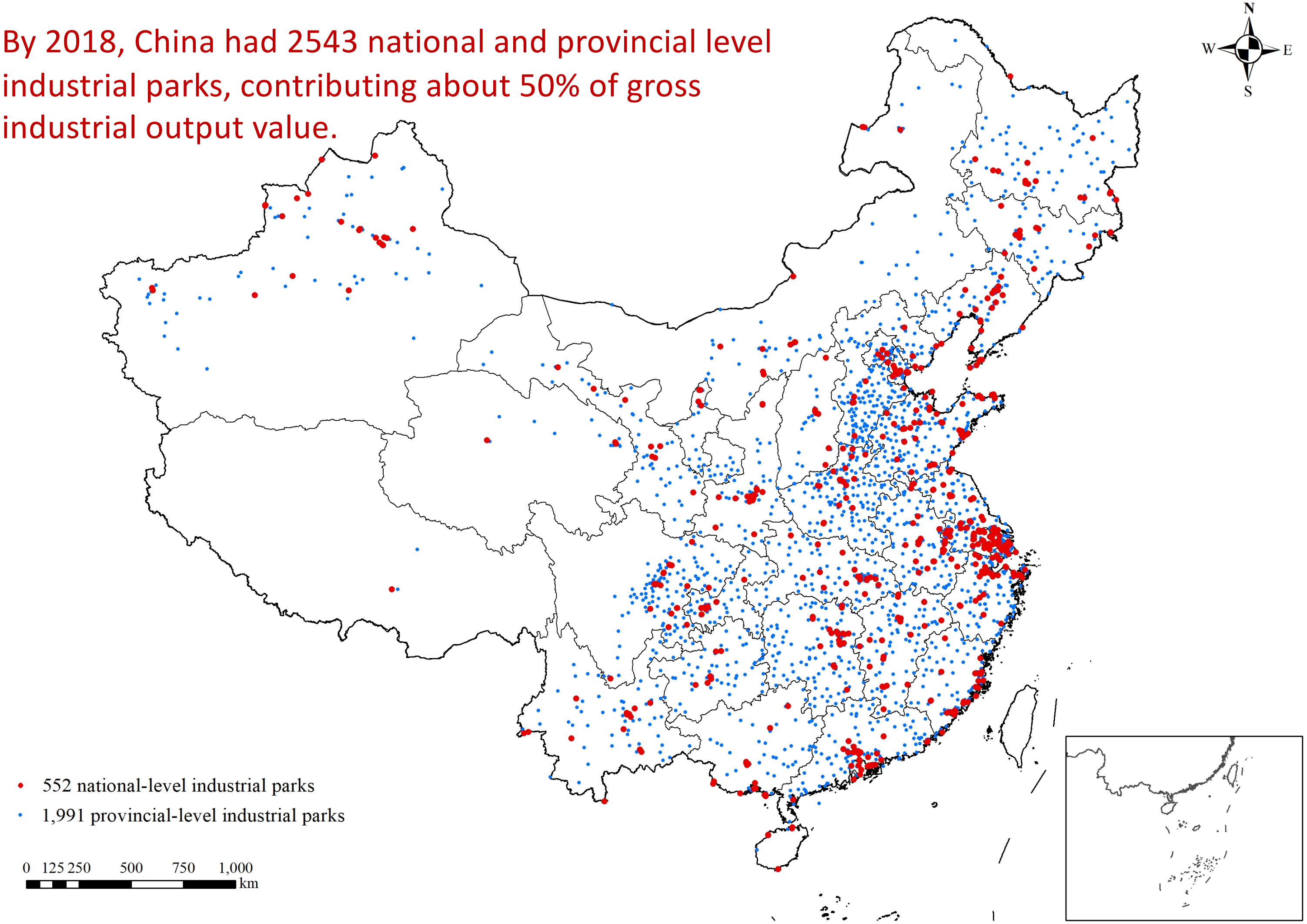
National Demonstration Eco-industrial Park Program (NDEIP), and National Low-Carbon Industrial Park Pilots (NLCIP)

	NDEIP	NLCIP
Purpose	Eco-industrial Parks are a new type of IPs designed according to cleaner production requirements, circular economy theories, and industrial ecology principles, aiming at closed-loop flow of materials, multi-level utilization of energy, and minimization of waste generation.	The program aims to promote wide use of renewable energy, accelerate low-carbon transformation of key energy-intensive industries, foster a large number of low-carbon enterprises, and popularize some low-carbon management models that are fit for China's industrial parks.
Objectives	The demonstration parks should be national leaders in economic development, materials saving and recycling, pollution prevention and control, and park management, and serve as models and promoters for the sustainable development of various types of IPs.	The pilot parks should achieve large reduction in carbon emissions in terms of per unit industrial value added. Significant achievements should also be made in low-carbon transformation of traditional industries and the development of new low-carbon industries.
Key tasks	1. Prevent and control pollution during the whole process to improve environmental quality. 2. Pay high attention to development planning to promote green transition of the parks. 3. Develop and implement eligibility criteria for projects wishing to enter into parks, and strengthen auditing for cleaner production. 4. Highlight the unique features of the parks, and create radiation effect to promote regional development. 5. Strengthen fine management for parks, and promote their core competitiveness. 6. Effectively prevent environmental risks, and safeguard the environmental safety of parks. 7. Encourage "pioneering", with a view to promoting innovative environmental management mechanisms.	1. Make great effort to promote low-carbon production. 2. Actively promote innovative low-carbon technologies and their application. 3. Carry out innovative low-carbon management. 4. Strengthen low-carbon infrastructure construction. 5. Increase international cooperation.

Courtesy of Prof. Bin Zhu, Tsinghua University

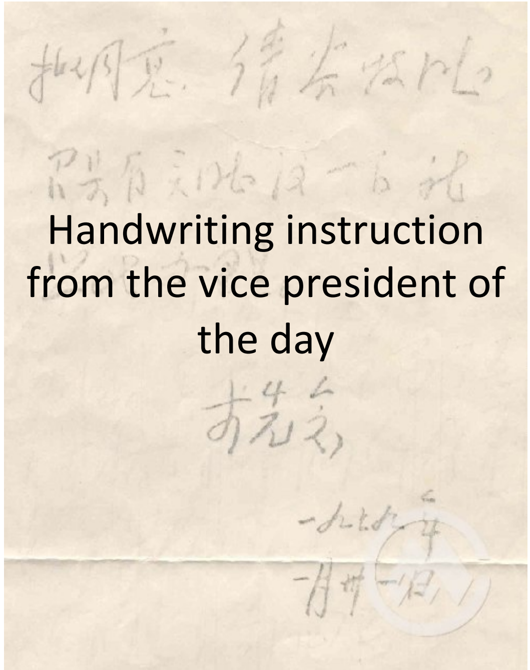
Industrial Parks Development in China

By 2018, China had 2543 national and provincial level industrial parks, contributing about 50% of gross industrial output value.



Establishment of the first industrial zone in China
---Shekou Industrial Park in the Shenzhen *SEZ*

Report submitted to the central government on establishing industrial zone in Bao'an district Guangdong Province by China Merchant in Hong Kong subdivision



'Inclined to agree with your proposal. Mr. Gu, Mu (the Vice Premier), please convene the staffs related to discuss the proposal and implement accordingly'.

Source: http://1872.cmhk.com/zhizui/291.html Accessed March 30, 2015

The former old street in Shekou

Time is money, efficiency is life

Overview of Shekou industrial zone in 2008

The earlier pioneer of Shekou industrial zone.

Source: http://news.xinhuanet.com/photo/2008-10/20/content_10221083.htm Accessed on March 30, 2015


Beijing ETDA (Economic & Technological Development Area


Kunshan High-tech development zone

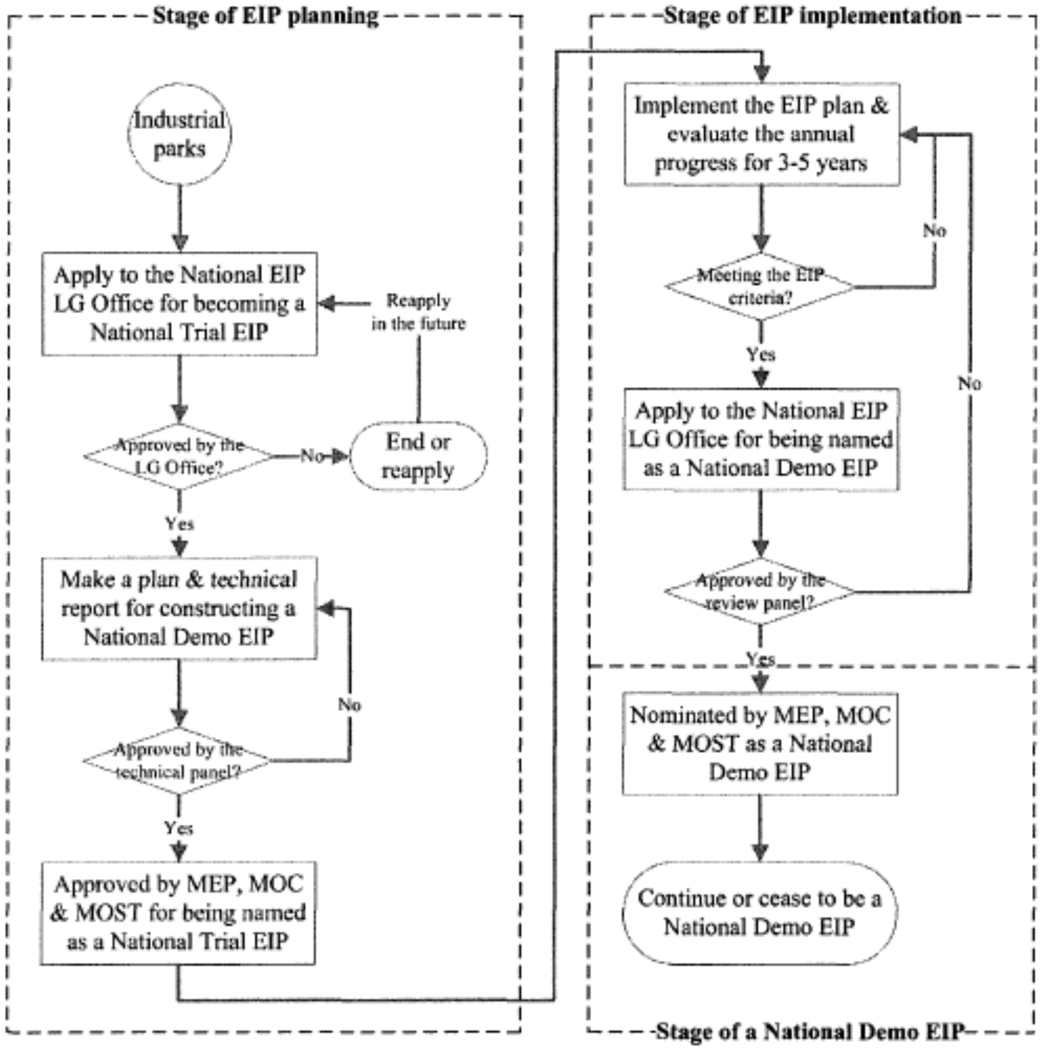

TEDA (Tianjin Economic & Technological Development Area


Suzhou Industrial Park


Hangzhou ETDA


Guangzhou Development Zone

Procedure for eco-industrial park planning, implementation, and nomination in China

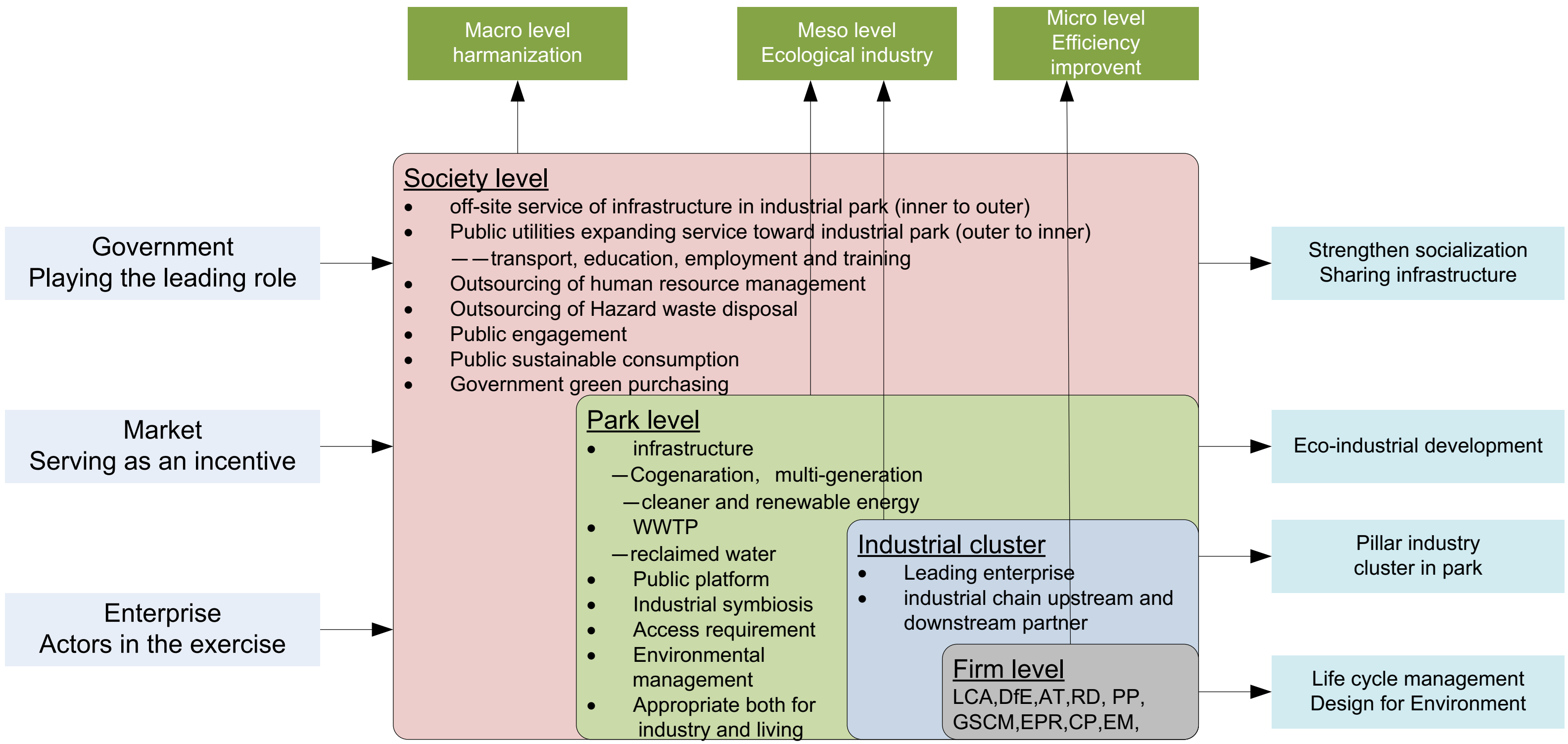


Source: Dr. Han Shi

Eco-industrial park planning in China

- Overview of the industrial park
- Retrospective analysis of the environmental impact
- Claim the necessary of EIP development
- Overall design of the EIP development
- Ecological development of the pillar industries
- Resource and energy integration planning
- Pollution prevention planning (gaseous, liquid, solid waste， and others)
- Risk assessment and emergency response system
- Low carbon development planning
- Investment projects and the expected outputs
- Supporting measures (administration, duties and roles of different sectors)
- Scenario analysis

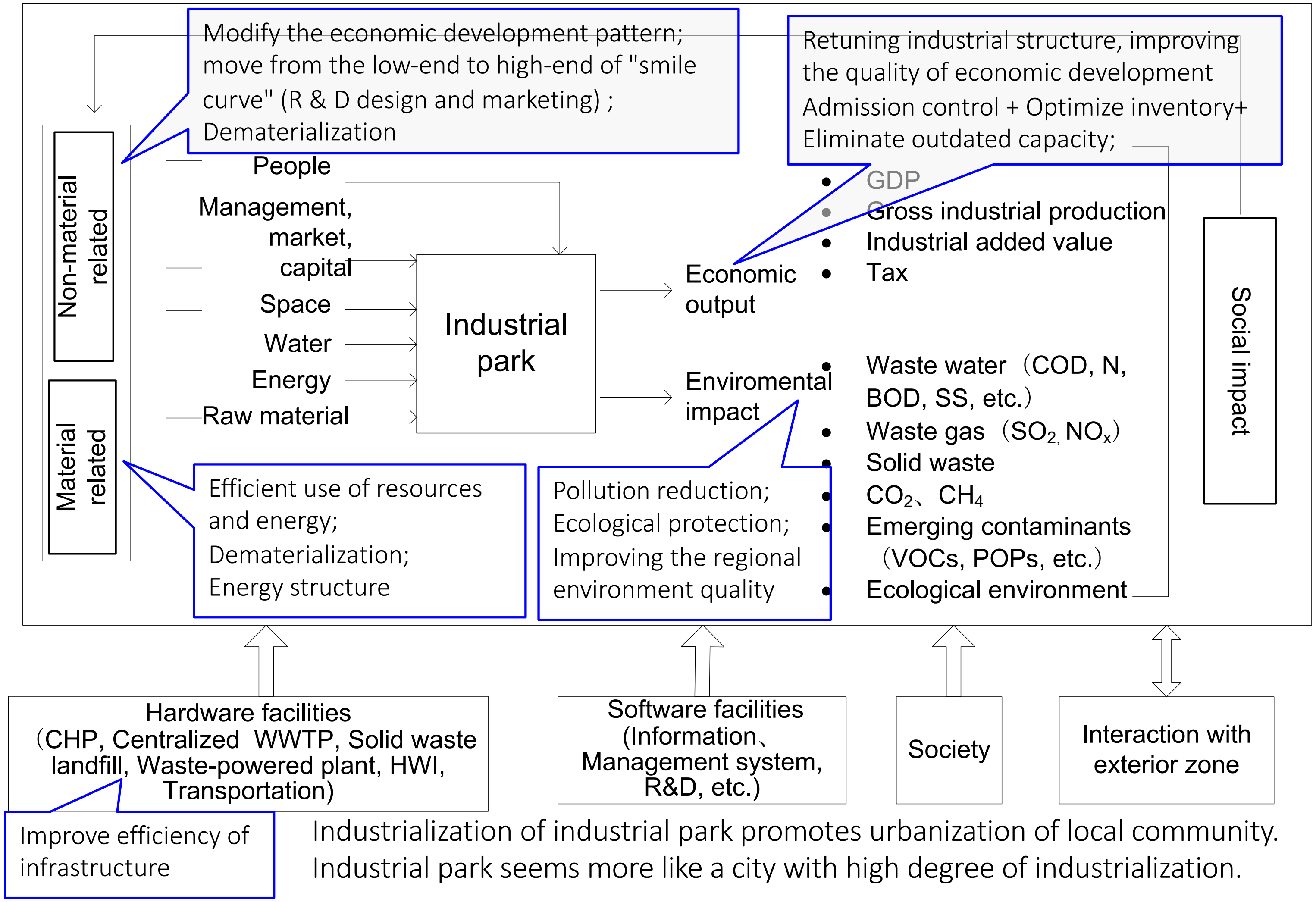
Chinese EIP development model



LCA：Life cycle assessment; EM：EnvironmeNTal management; AT: Advanced technology; GSCM：Green supply chain management; DfE：Design for Environment; CP：Cleaner production; RD:R&D platform; EPR：Extended producer responsibility; PP: pollution prevention

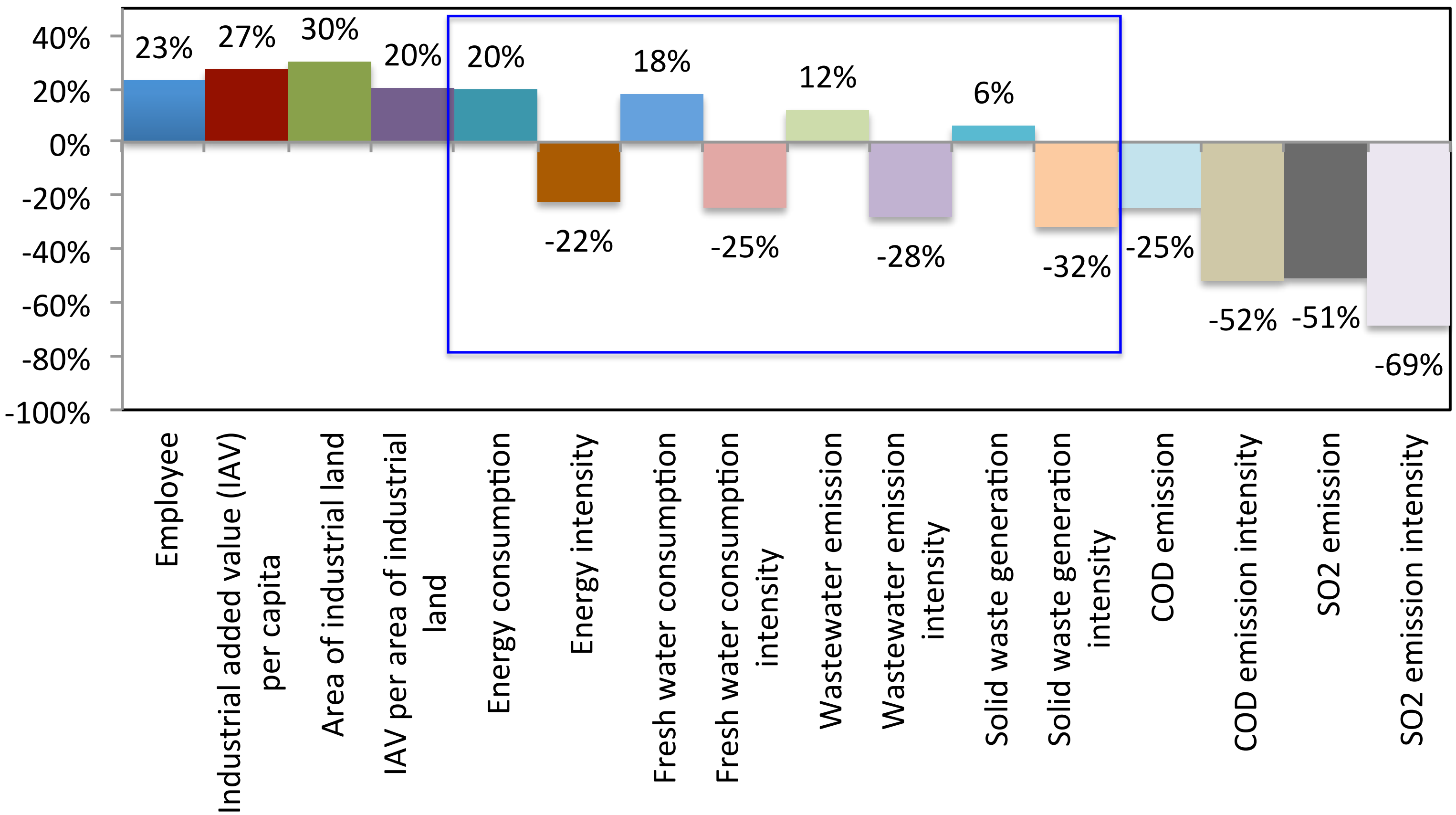
Tian, Jinping; Liu, Wei; Li, Xing; Lai, Binjie; Chen, Lujun. 2012, Study of eco-industrial park development mode in China. China Population, Resource, and Environment. 7, 60-66. (In Chinese)

Key components in an (eco)-industrial park



Industrialization of industrial park promotes urbanization of local community.
Industrial park seems more like a city with high degree of industrialization.

Performance of Chinese Eco-industrial Parks



IAV: industrial added value

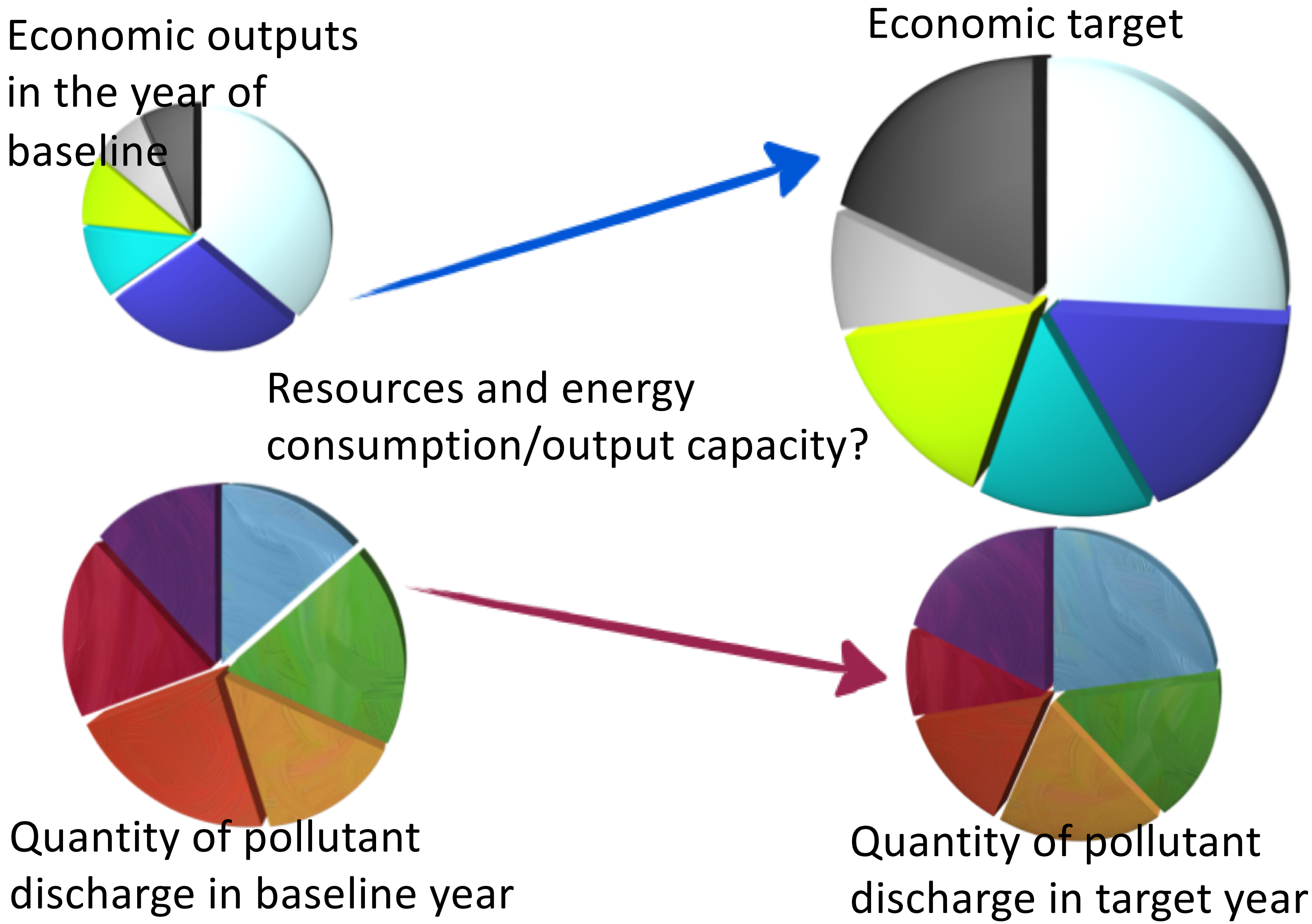
Tian, Jinping; Liu, Wei; Lai, Binjie; Li, Xing; Chen, Lujun. Study of the performance of eco-industrial park development in China. Journal of Cleaner Production. 2014, *64*, 486-494.

Measures supporting EIP performance improvement based on Chinese practice

- Cleaner production and environmental management
  - Mandatory CP audit (CP promotion law amended in Feb 2013), ISO14001 certification
- Infrastructure sharing
  - Cogeneration of heat and power (CHP), concentrated wastewater treatment plant (CWWTP), reclaimed water usage, and bulk solid waste recycling
  - Transiting coal-fired CHPs to natural gas fired CHPs
  - Transiting heat and power generation CHPs toward heat, power, hot water, and cooling cogeneration
  - CHP acting as a scavenger (waste-to-energy), such as sludge of CWWTP
- Energy-saving practices at the firm level
  - Energy audit, doing small things
- Pillar industries
- Industrial symbiosis

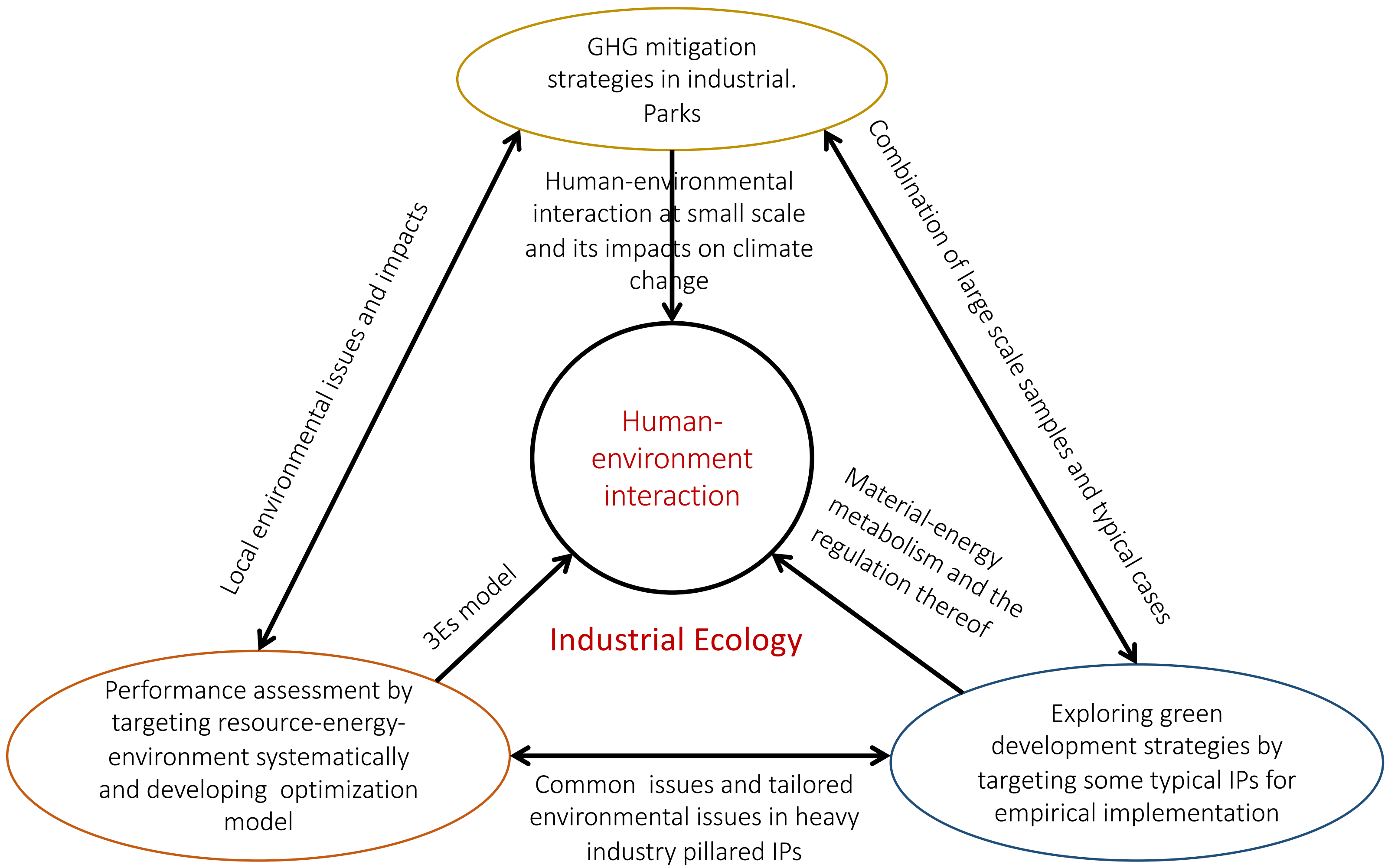
Tian, Jinping; Liu, Wei; Lai, Binjie; Li, Xing; Chen, Lujun. Study of the performance of eco-industrial park development in China. Journal of Cleaner Production. 2014, *64*, 486-494.

Eco-industrial park development roadmap in China



Greenhouse gas mitigation in Chinese eco-industrial parks by targeting energy infrastructure

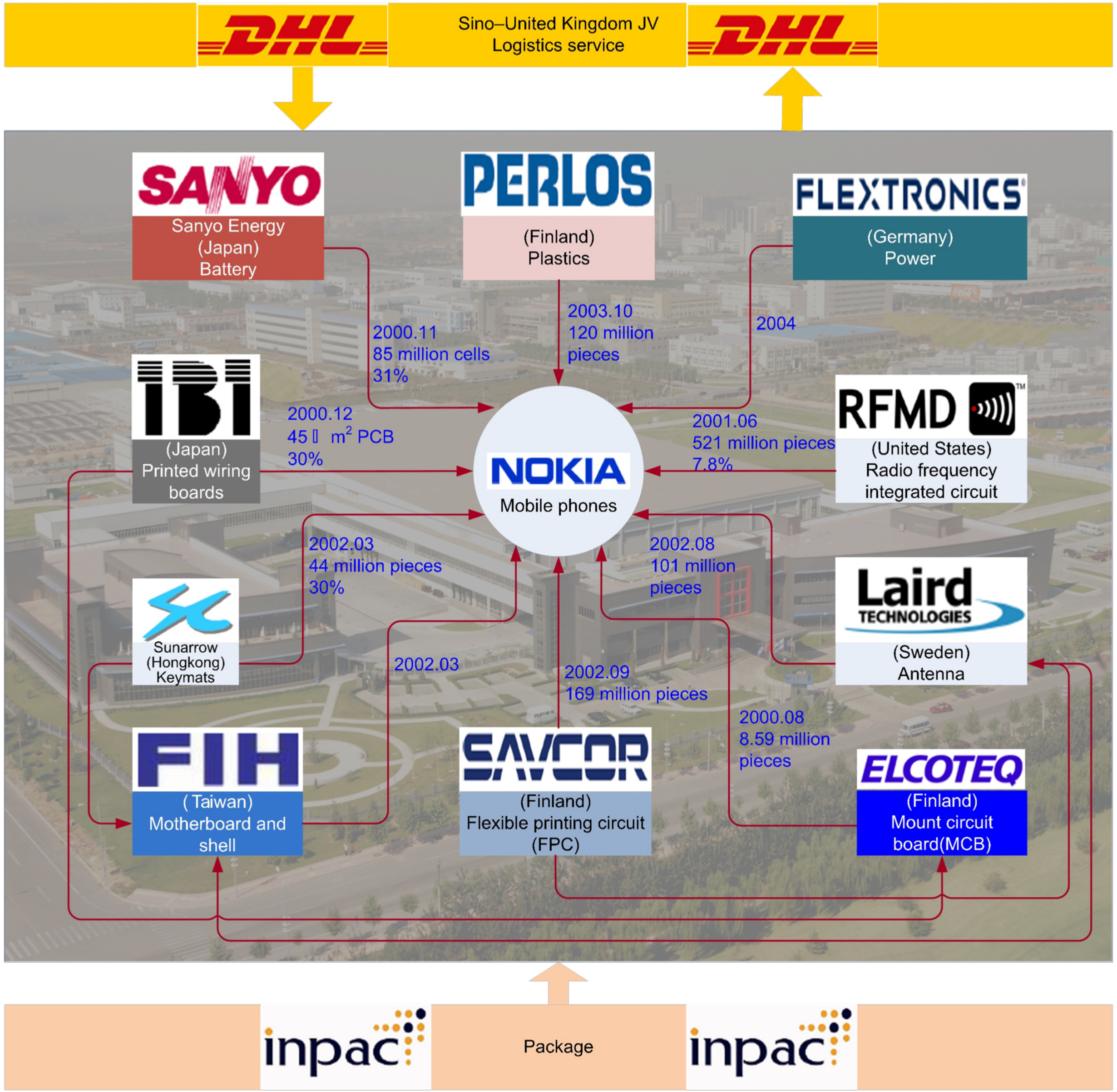
Research in my group by targeting industrial parks



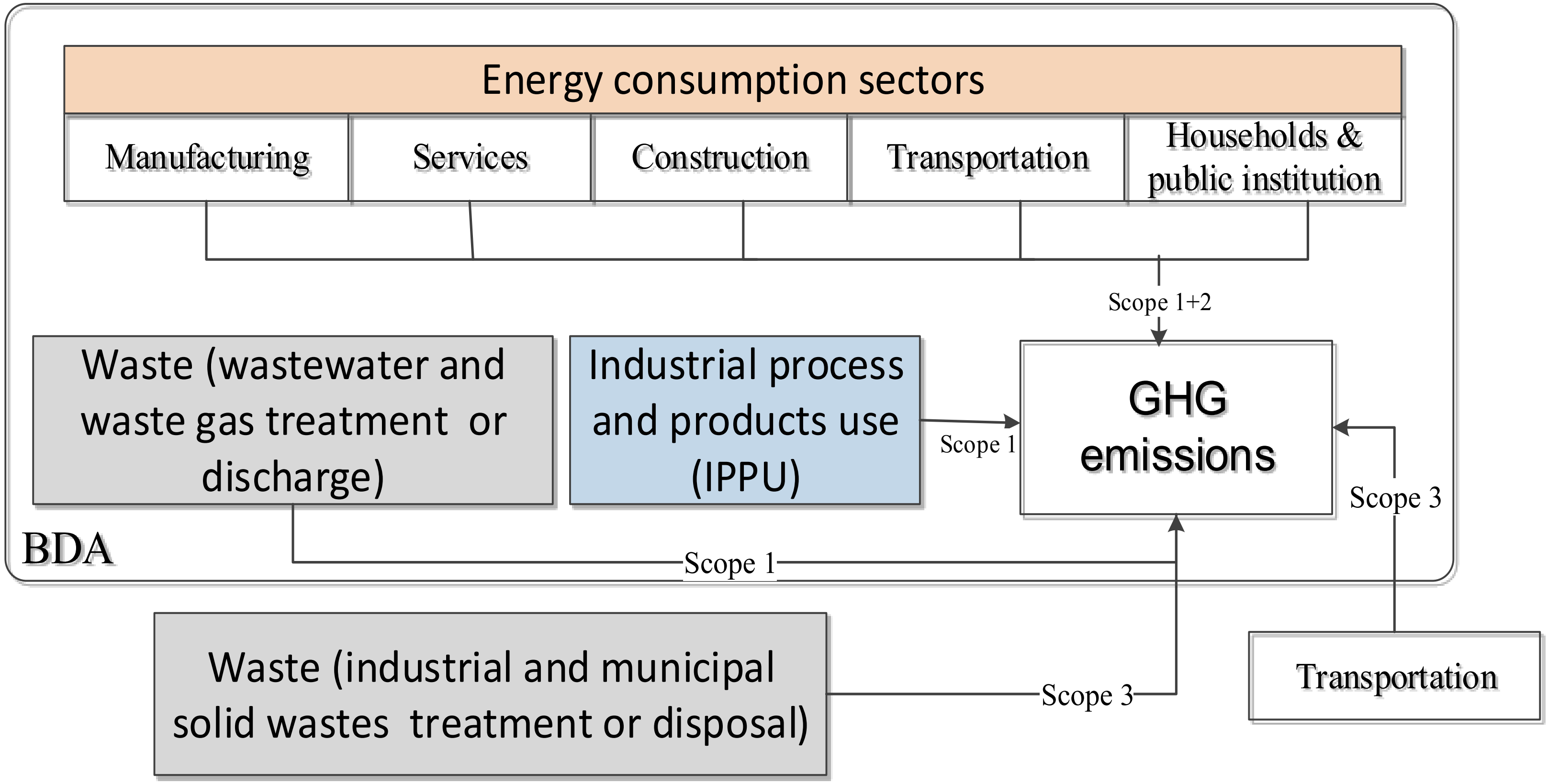
Beijing Economic-Technological Development Area (BDA)

http://www.bda.gov.cn/cms//www/index.html

Xingwang (star network) industrial park

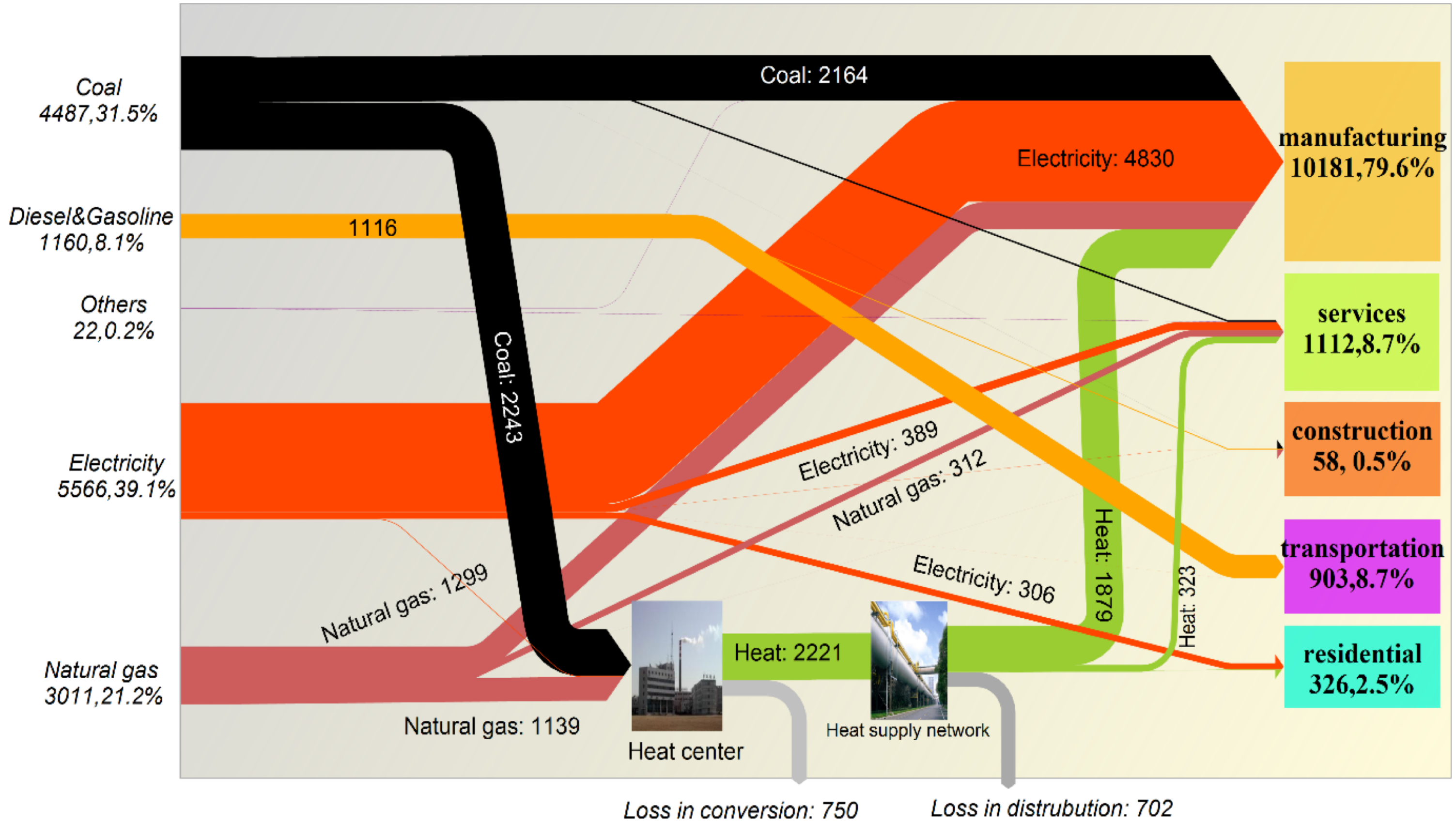


GHG accounting boundary and scope



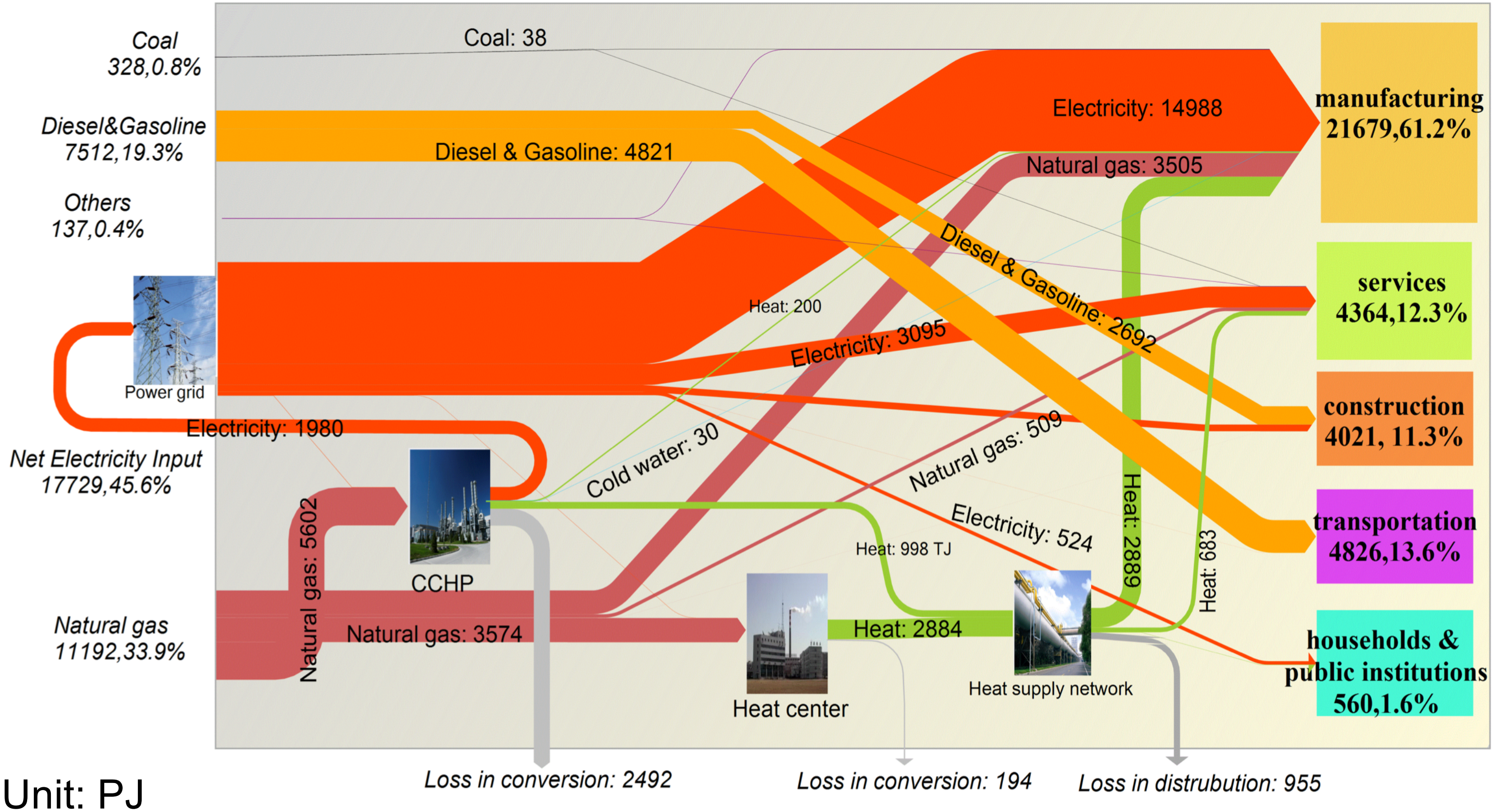
GHG: not only CO_2, CH_4, N_2O, HFCs, PFCs and SF_6, but also NF_3, VOCs, NH_3

Energy flow of BDA in 2005



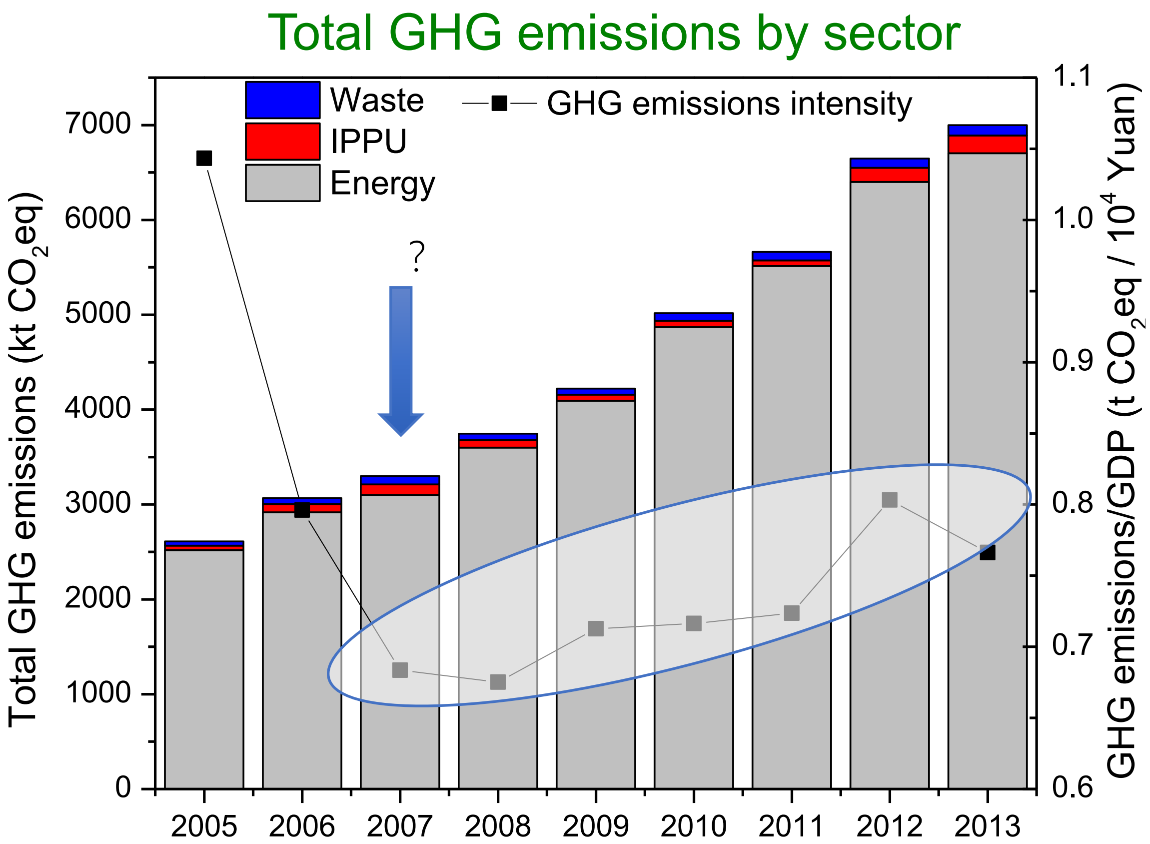
Unit: PJ (Petajoule 10^{15} J)

Energy flow of BDA in 2013



Unit: PJ

GHG emissions in the Beijing Economic and technological development area (BDA)

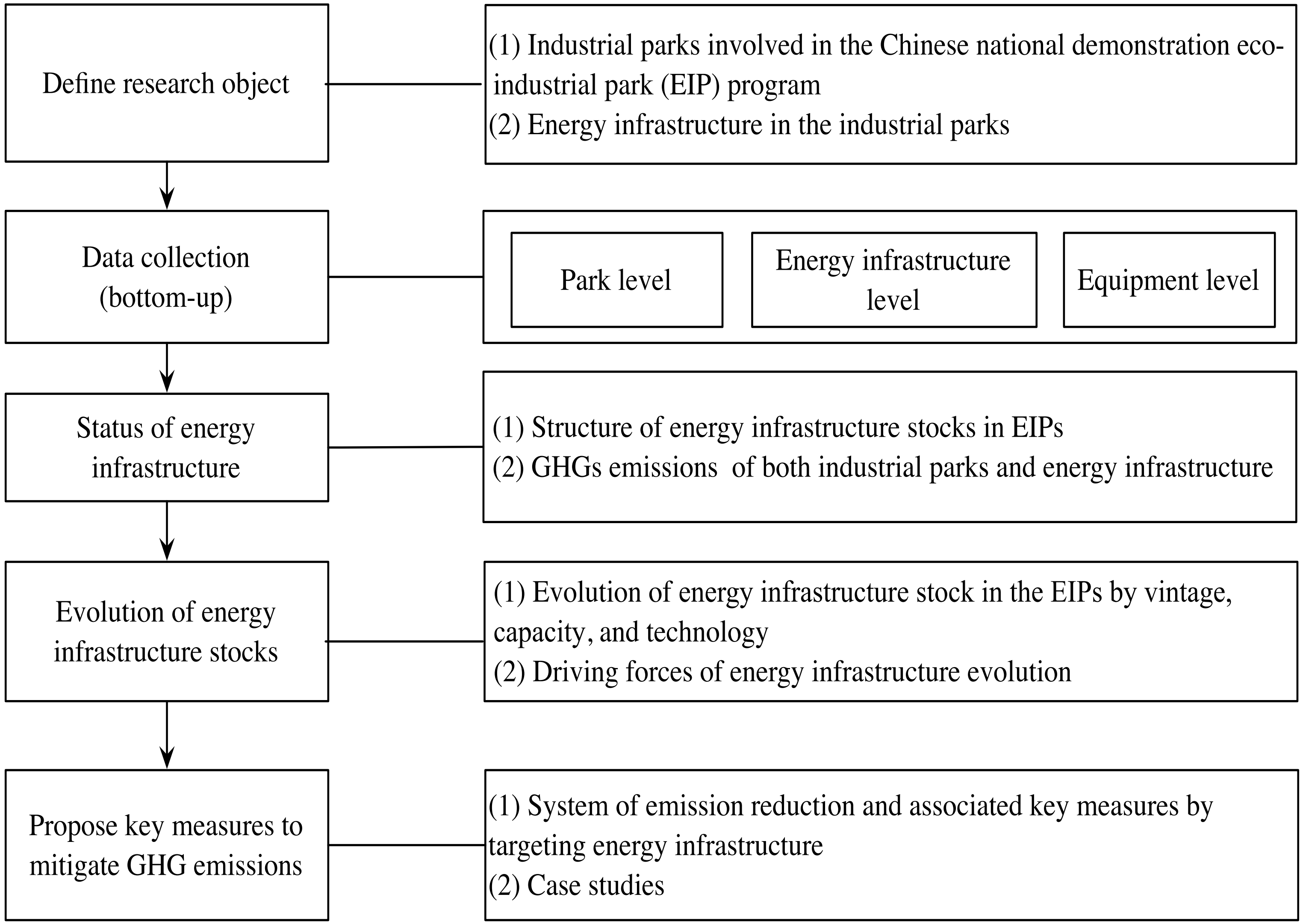


- In 2013, the total emissions are 7.0 Mt, 95.8% from energy use, 2.7% from IPPU and 1.6% from waste.
- Energy-related emissions dominated in the total emissions (94.0-97.8%).
- From 2005-2013, emissions increased by 1.7 times, emission intensity decreased by 27%

Liu, Wei Tian, Jinping, Chen, Lujun. Greenhouse gas emissions in China's eco-industrial parks- A case study of the Beijing Economic Technological Development Area *Journal of Cleaner Production*. 2014, 66, 384-391.

Research questions

- What is the feature of energy infrastructure stocks in Chinese industrial parks and their GHG emission?
- What are the key measures to mitigate the GHGs emissions of the industrial parks, and
- What about the cost-effectiveness of the key measures identified?
- Research objects--- Eco-industrial parks---the industrial parks listed in the Chinese national demonstration eco-industrial park (EIP) program as the research object.


Define research object
(1) Industrial parks involved in the Chinese national demonstration eco-industrial park (EIP) program
(2) Energy infrastructure in the industrial parks
Data collection (bottom-up)
Park level
Energy infrastructure level
Equipment level
Status of energy infrastructure
(1) Structure of energy infrastructure stocks in EIPs
(2) GHGs emissions of both industrial parks and energy infrastructure
Evolution of energy infrastructure stocks
(1) Evolution of energy infrastructure stock in the EIPs by vintage, capacity, and technology
(2) Driving forces of energy infrastructure evolution
Propose key measures to mitigate GHG emissions
(1) System of emission reduction and associated key measures by targeting energy infrastructure
(2) Case studies

Energy infrastructure in industrial parks

- A shareable energy utility that is located within the physical boundary of an industrial park and provides secondary energy for the park by converting primary energy into, for example, heat or electricity.
- Largely of three types:

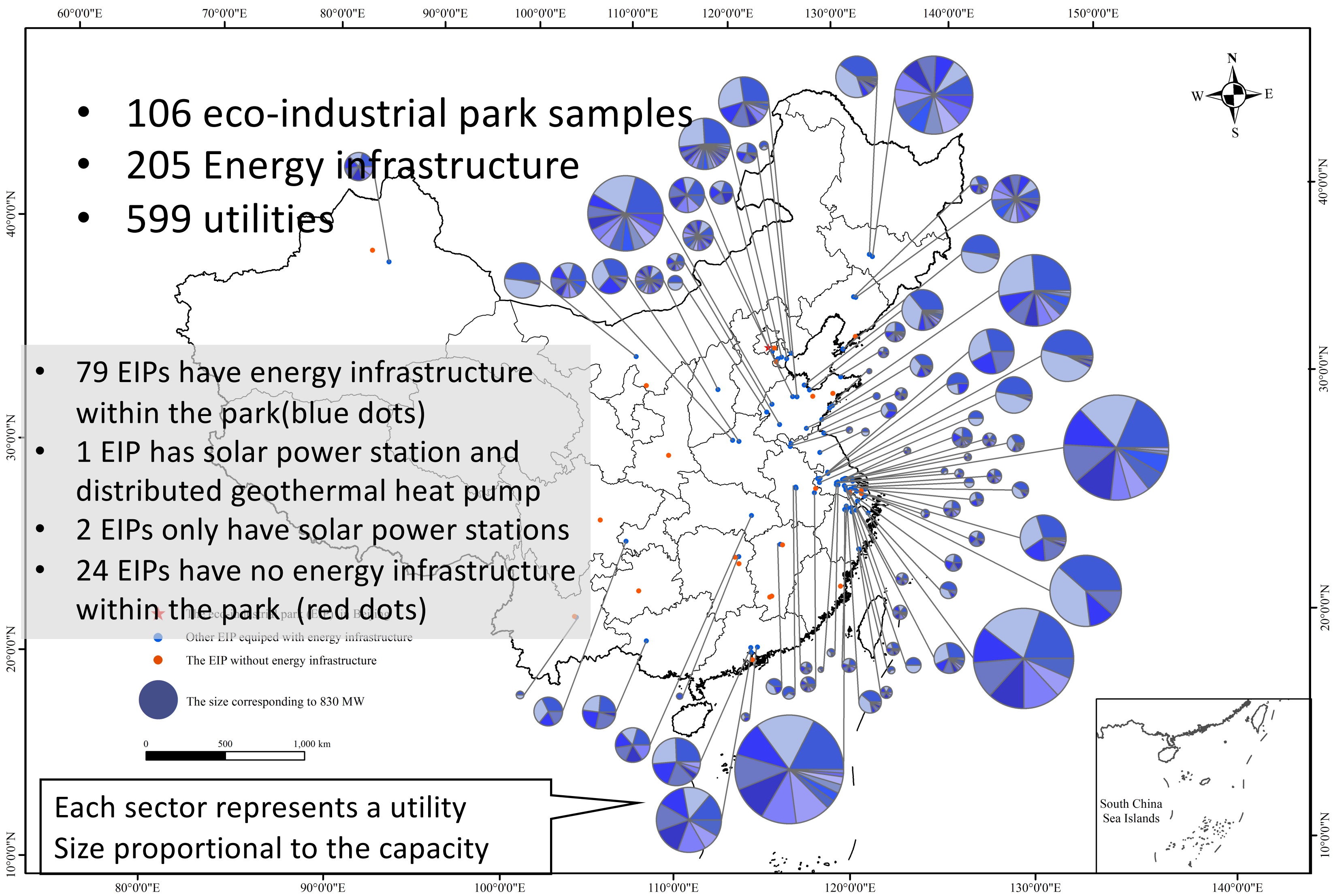
–combined heat and power (CHP) plants

–electricity-generating plants, and

–heat-generating plants

- 106 eco-industrial park samples
- 205 Energy infrastructure
- 599 utilities

- 79 EIPs have energy infrastructure within the park(blue dots)
- 1 EIP has solar power station and distributed geothermal heat pump
- 2 EIPs only have solar power stations
- 24 EIPs have no energy infrastructure within the park (red dots)



Each sector represents a utility
Size proportional to the capacity

EIP: eco-industrial park

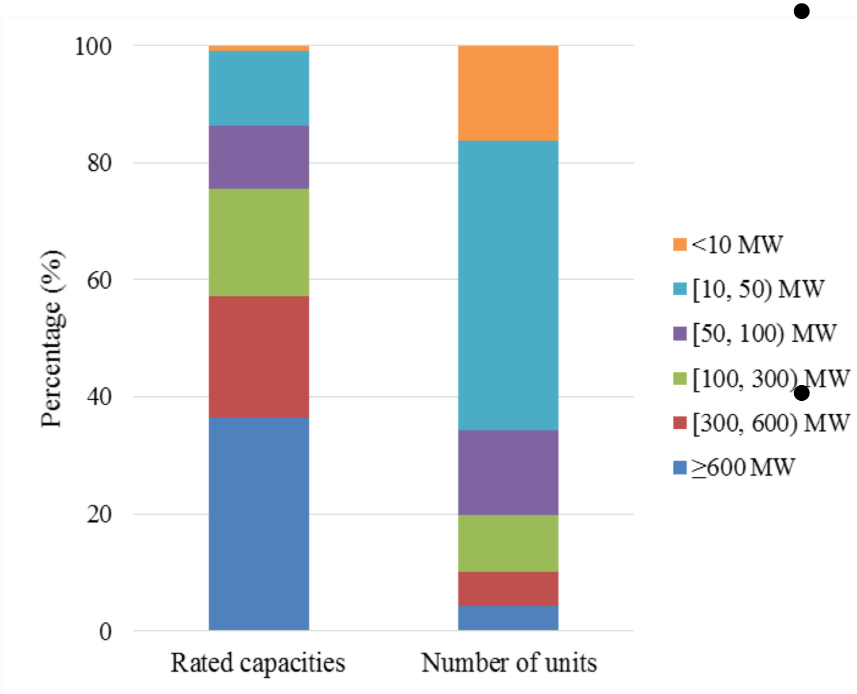
Status quo of energy infrastructure stocks in the EIPs

% of Cap.	Fuel type	Energy output	Number		Capacity	
			Utility	Unit	(MW)	Share (%)
87.5%	Coal	CHP	91	276	18059.5	34.44
		Electricity	13	40	22580	43.07
		Heat	18	122	5244.3	10.00
7.4%	NG	CHP	11	22	2151.2	4.10
		Electricity	1	1	127	0.24
		Heat	5	26	1613.8	3.08
	Petrol	CHP	0	1	6	0.01
		Heat	2	10	165.1	0.31
	Coal gangue	CHP	1	5	42	0.08
		Electricity	2	4	870	1.66
0.67%	Chemical reaction heat	CHP	4	11	88	0.17
		Electricity	4	7	176	0.34
		Heat	2	3	87.8	0.17
1.3%	MSW	CHP	8	15	168	0.32
		Electricity	8	20	265	0.51
	Sludge	CHP	4	8	230	0.44
		Heat	1	1	13.1	0.02
1.04%	Biomass	CHP	1	4	39	0.07
	Biogas	Electricity	2	3	4.5	0.01
	Solar	Electricity	20	20	82.7	0.16
	Wind	Electricity	4	4	121.5	0.23
	Hydro	Electricity	1	2	270	0.51
	Geothermal	Heat	3	3	27.4	0.05
	Total		206	608	52431.9	100

EIP: eco-industrial park

Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Journal of Industrial Ecology, 2018. 22(1), 106-120.

Organization of energy infrastructure units in the 106 EIPs



- Large units (≥ 300 MW) account for 57.2% of the total capacity but only 10.0% of the number of utilities.
- Small units (≤100 MW) account for 24.5% of the total capacity and 80.1% of the total number of units

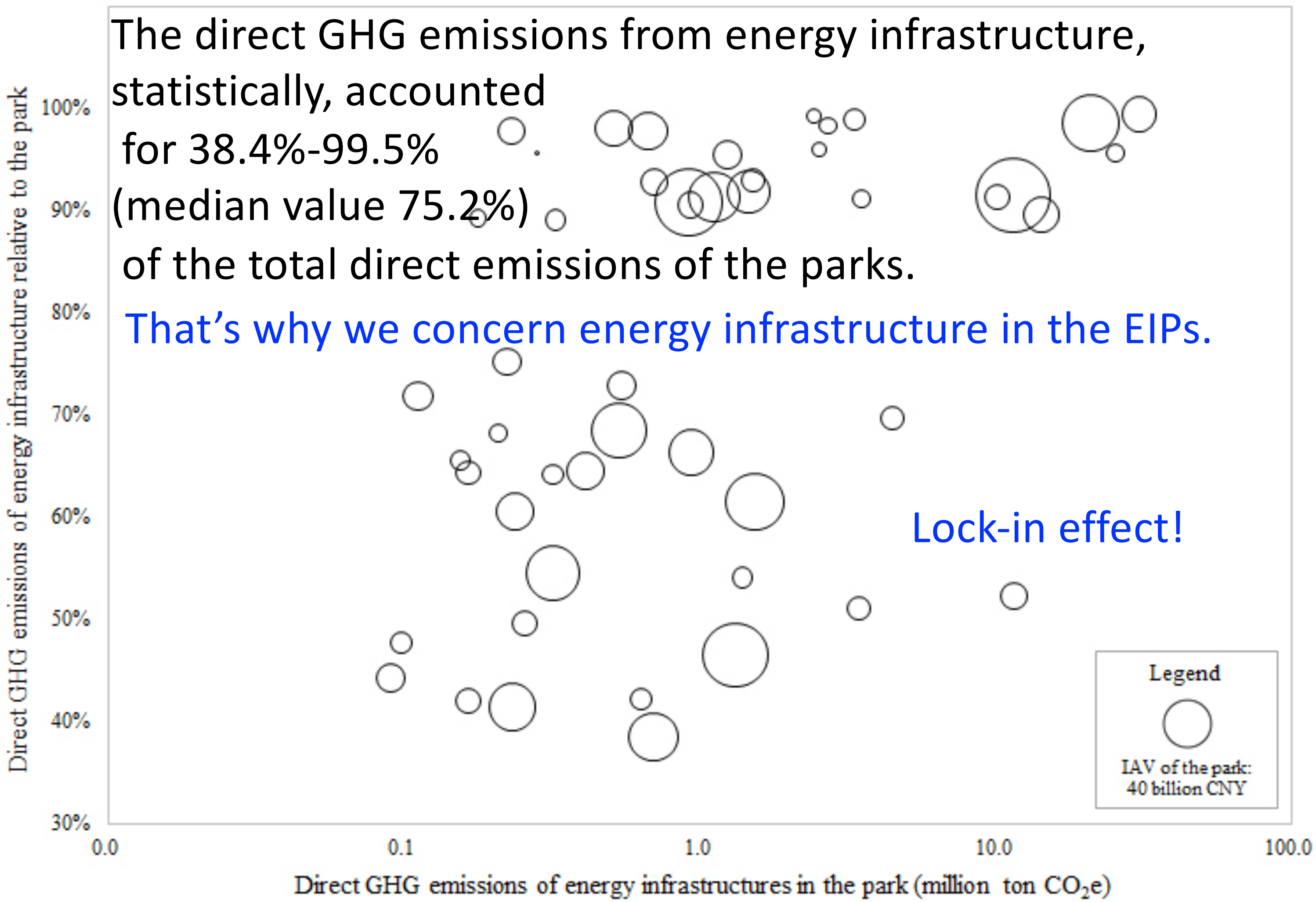
Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Journal of Industrial Ecology, 2018. 22(1), 106-120.

GHG emissions of Chinese industrial parks

The direct GHG emissions from energy infrastructure, statistically, accounted for 38.4%-99.5% (median value 75.2%) of the total direct emissions of the parks.

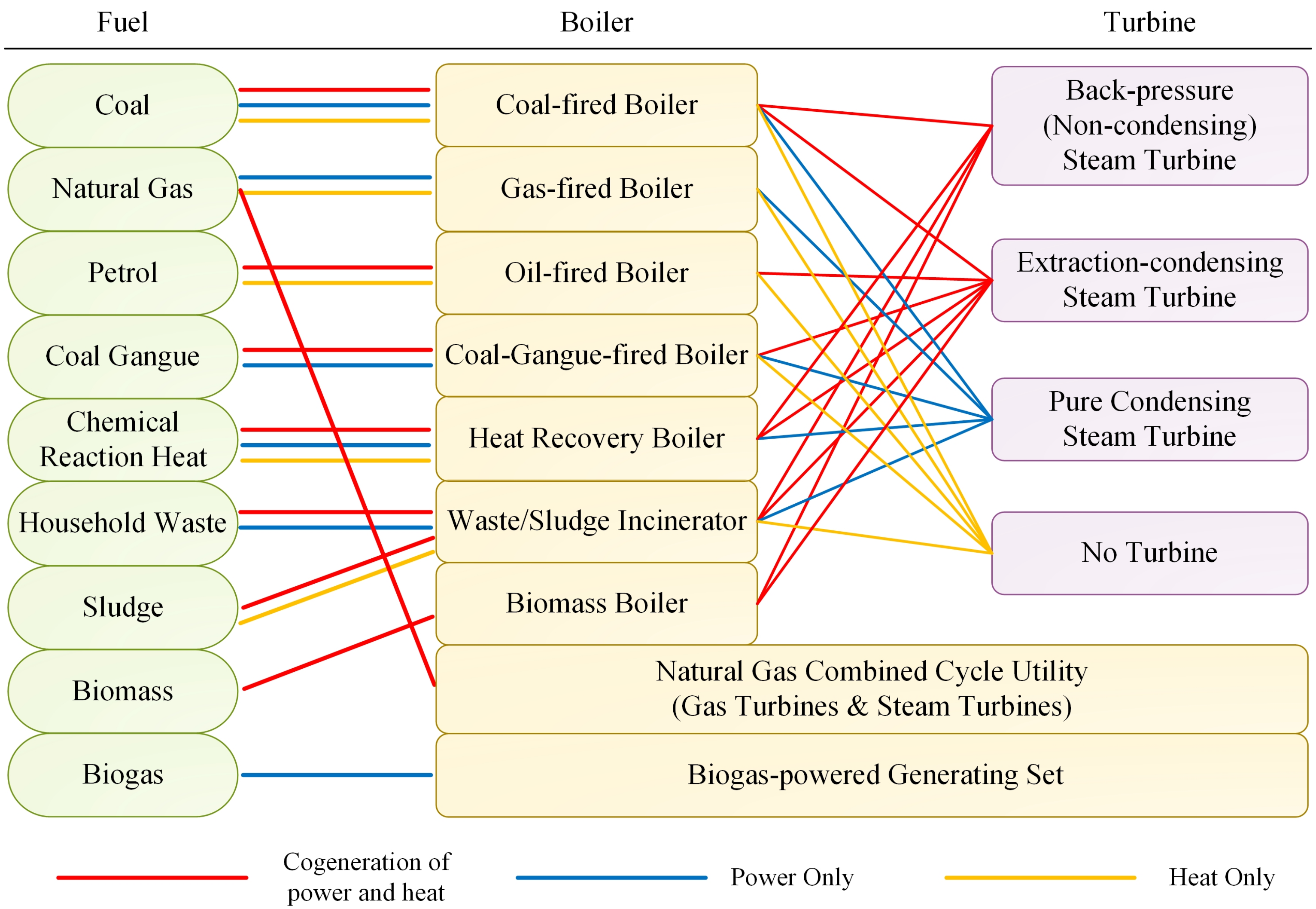
That’s why we concern energy infrastructure in the EIPs.

Lock-in effect!



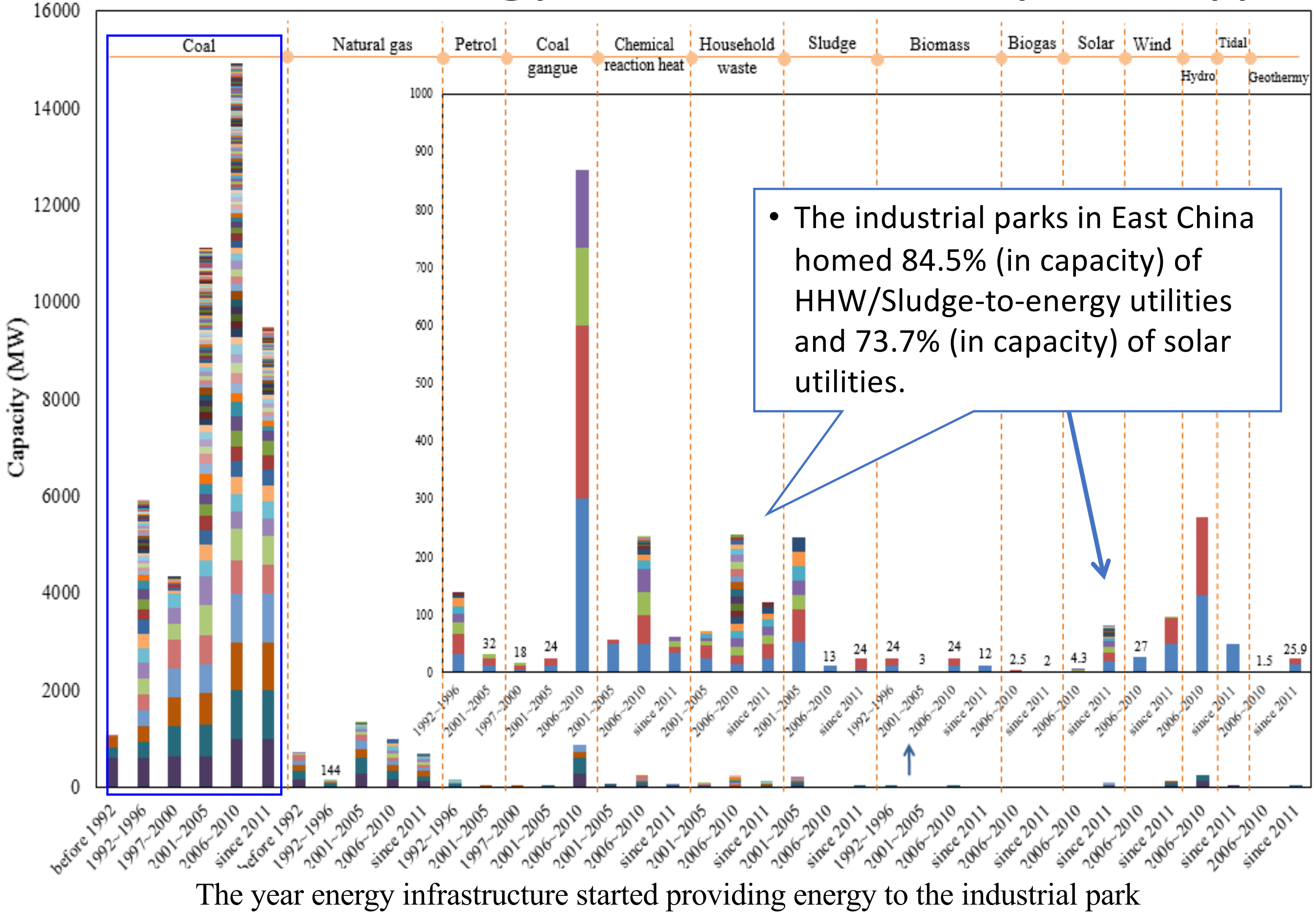
Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Journal of Industrial Ecology, 2018. 22(1), 106-120.

Connection between fuel, utilities and outputs



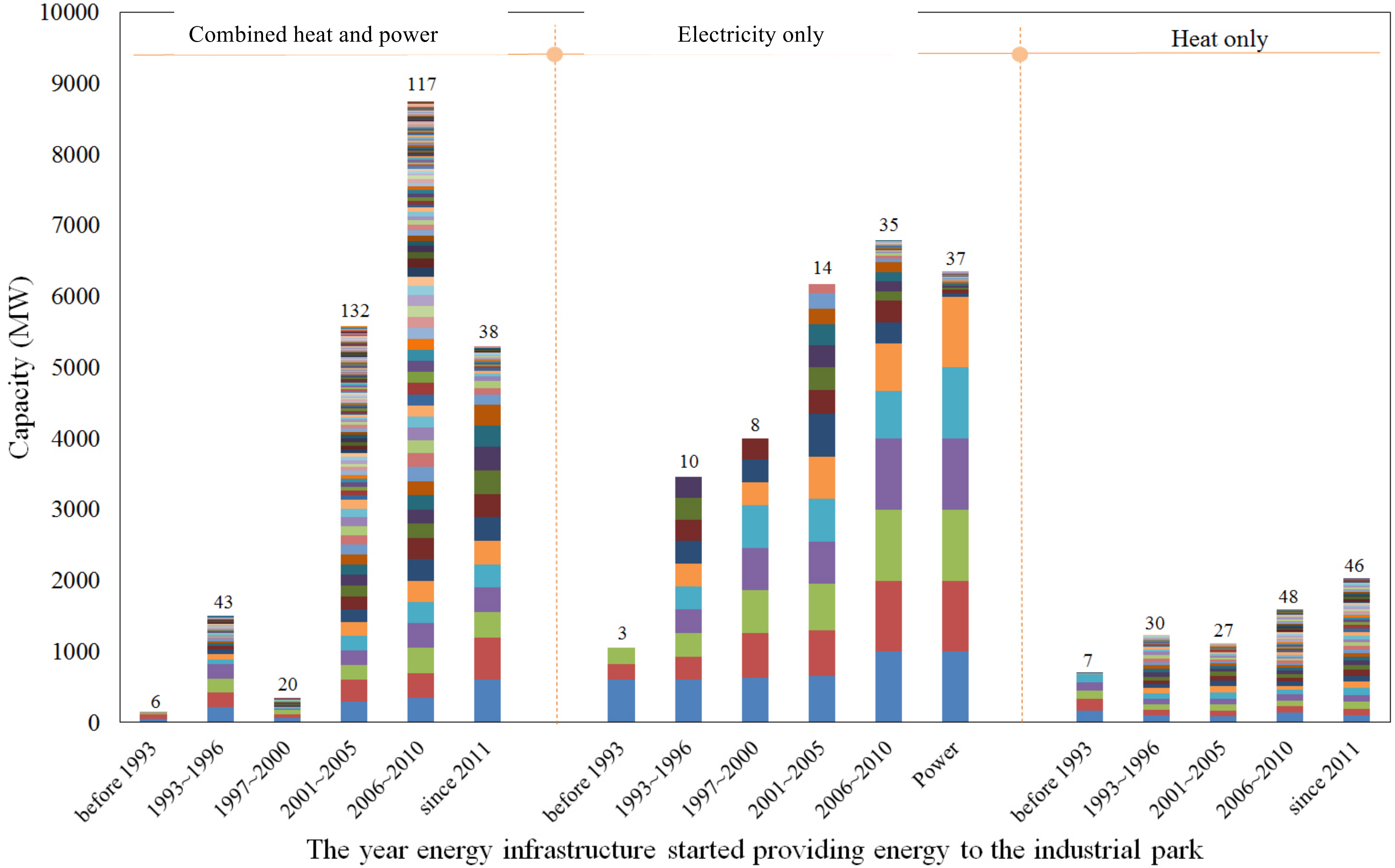
Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Journal of Industrial Ecology, 2018. 22(1), 106-120.

Evolution of energy infrastructure by fuel type

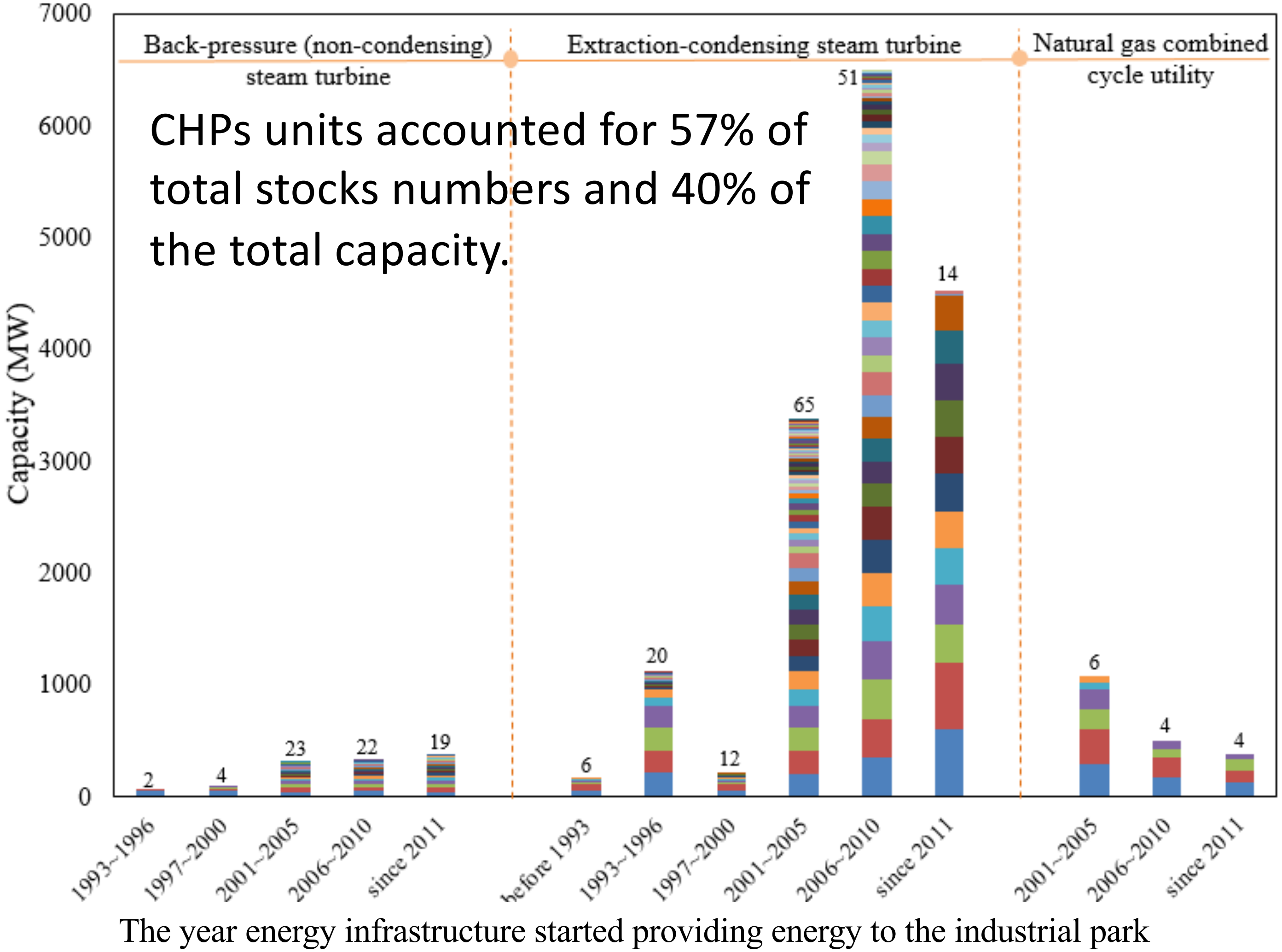


- The industrial parks in East China homed 84.5% (in capacity) of HHW/Sludge-to-energy utilities and 73.7% (in capacity) of solar utilities.

Evolution of energy infrastructure by outputs

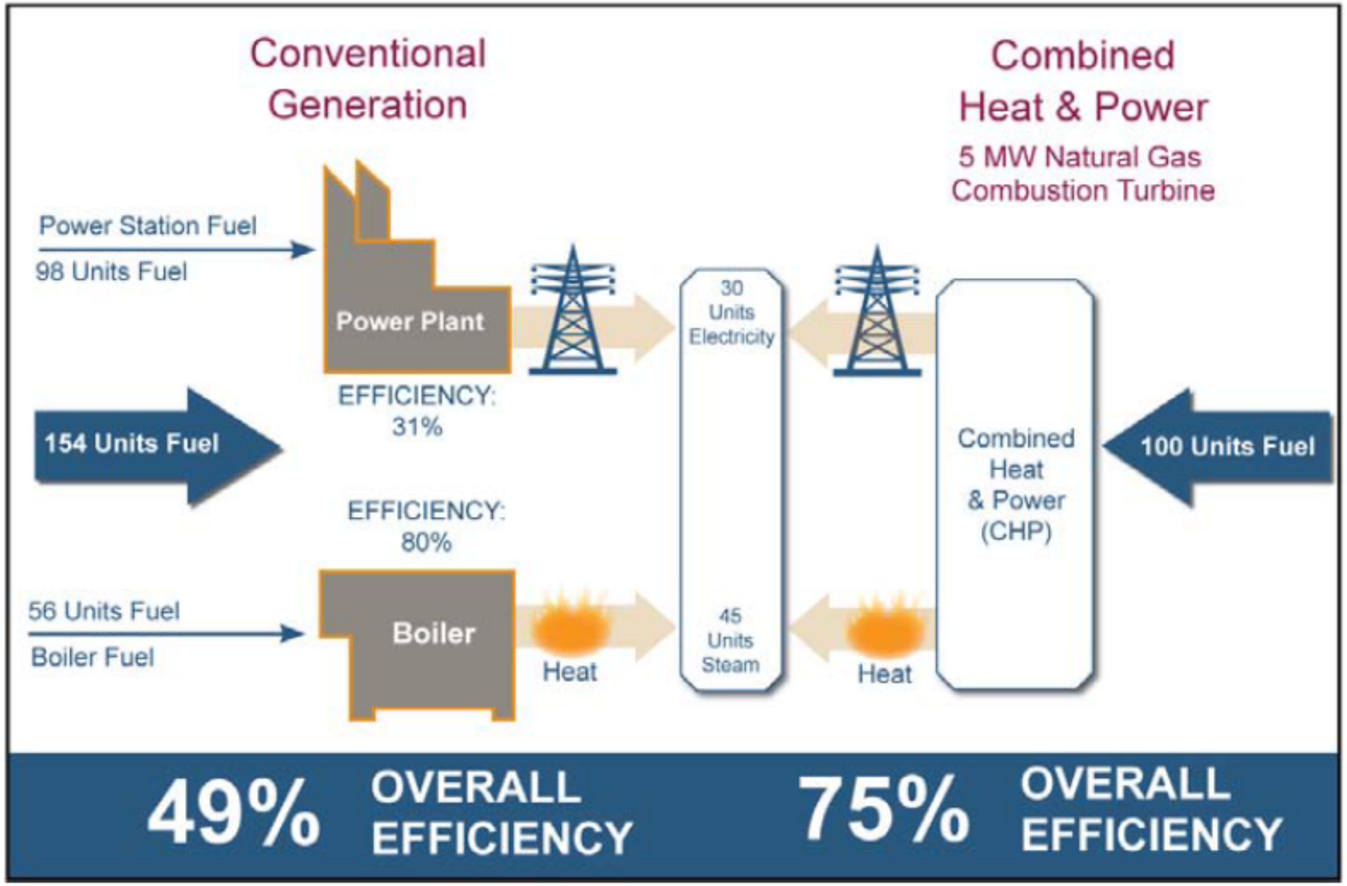


Technological evolution of CHP stocks



CHPs units accounted for 57% of total stocks numbers and 40% of the total capacity.

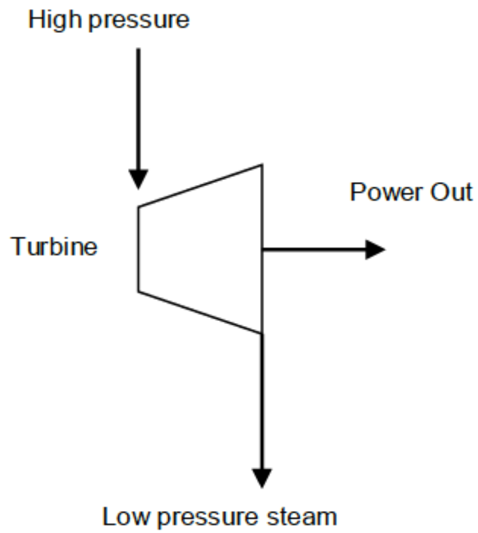
Comparison between CHP and conventional generation



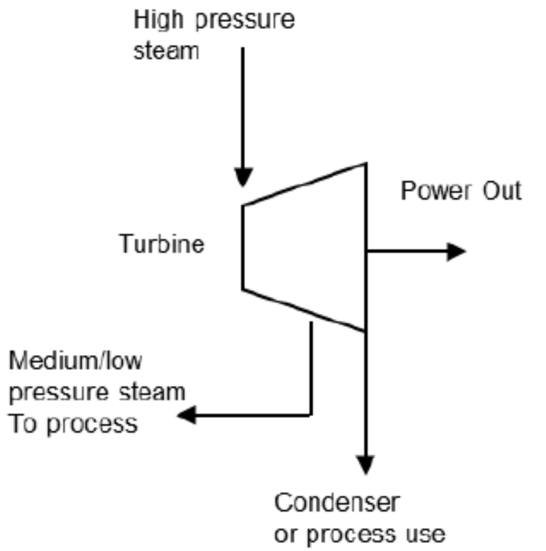
Note: Assumes national averages for grid electricity and incorporates electricity transmission losses.

Source: http://www.epa.gov/chp/documents/catalog_chptech_intro.pdf

Steam turbines used for CHP can be classified into two main types: non-condensing and extraction.



Non-Condensing (Back-pressure) Steam Turbine



Extraction Steam Turbine (also called extraction-condensing turbine)

Exhausting its entire flow of steam to the industrial process or facility steam mains at conditions close to the process heat requirements.

The extraction turbine has opening(s) in its casing for extraction of a portion of the steam at some intermediate pressure. The extracted steam may be used for process purposes in a CHP facility, or for feedwater heating as is the case in most utility power plants. The rest of the steam is condensed,

http://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf

Performance of energy utilities at different capacity scales

Utility capacity (MW)	Effective electricity efficiency	Coal consumption for electricity generation (gce/kWh)	GHG emissions (gCO_2e/kWh)
≥1000	0.442	278.17	786.32
[600, 1000)	0.415	296.14	837.12
[300, 600]	0.408	300.89	850.55
[200, 300]	0.401	306.67	866.89
[100, 200]	0.393	312.51	883.39
[6, 100]	0.353	347.89	983.4

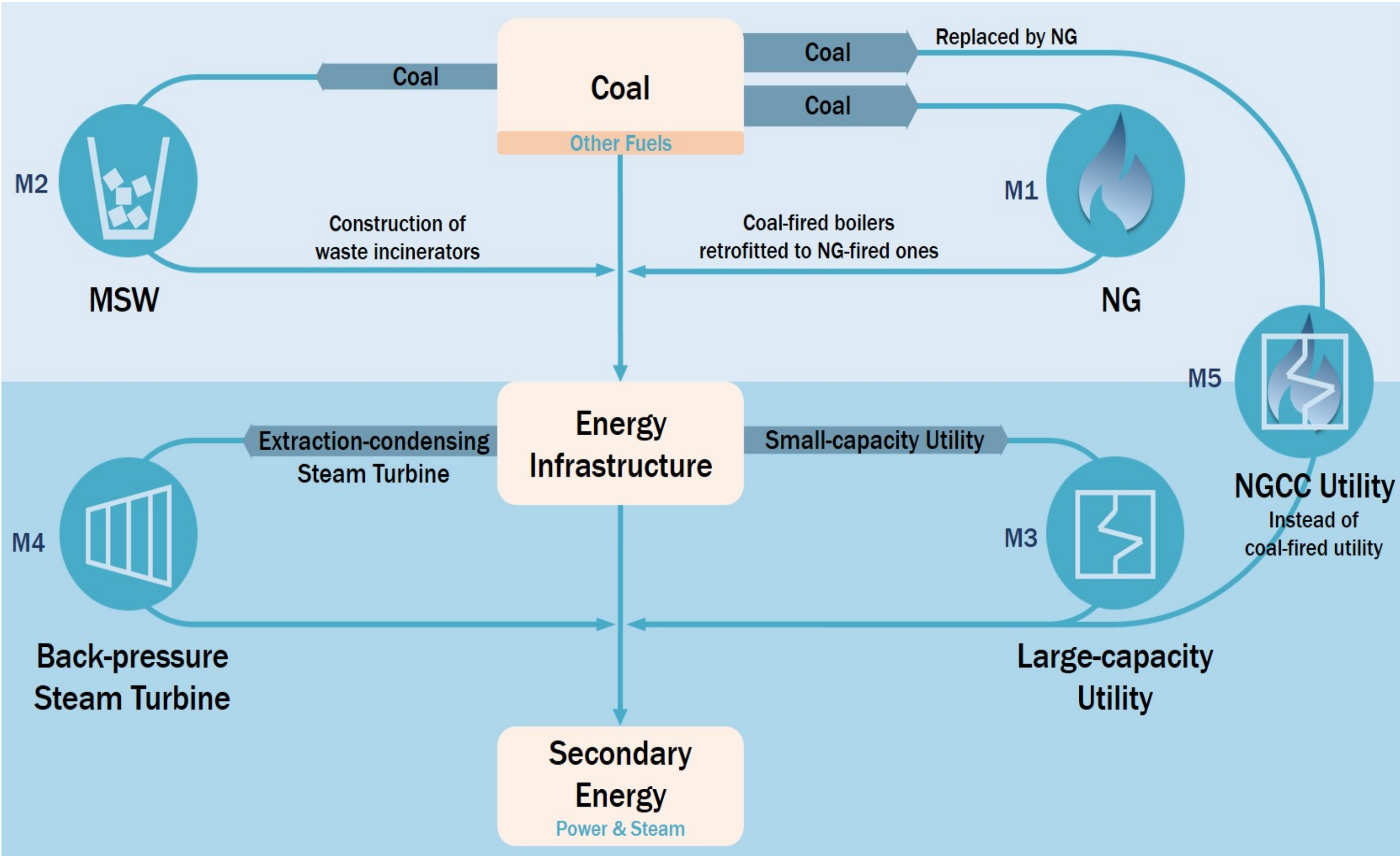
Source: Electricity Council, China. 2014. Statistical Data of Electricity Industry Development (2013).

Features of energy infrastructure development in EIPs

(1) Shifting from coal-fired utilities to NG-fired ones;
(2) Replacement of small utilities by large ones;
(3) Upgrading technologies;
(4) Multi-functionalization;
(5) Diversifying the fuel type with non-conventional fossil fuels; and
(6) Sharing energy infrastructure among industrial parks.

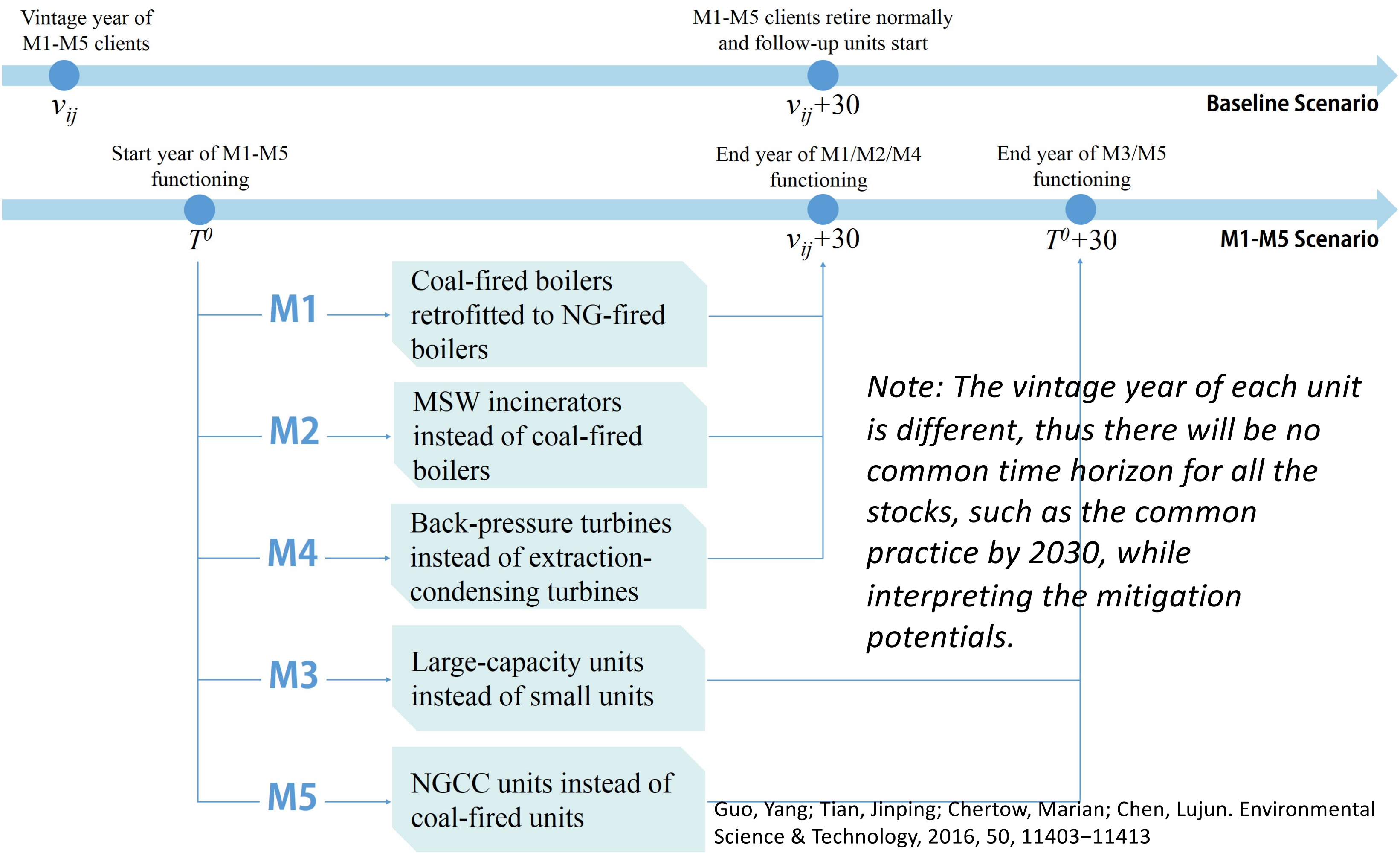
Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Journal of Industrial Ecology, 2018. 22(1), 106-120.

Five Measures to mitigate GHG emissions by Targeting Energy Infrastructure



Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Journal of Industrial Ecology, 2018. 22(1), 106-120.

Baseline scenario and M1-M5 scenarios in the vintage stock model



Note: The vintage year of each unit is different, thus there will be no common time horizon for all the stocks, such as the common practice by 2030, while interpreting the mitigation potentials.

Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Environmental Science & Technology, 2016, 50, 11403–11413

Mitigation Cost Modeling

The GHG mitigation cost involves six parts

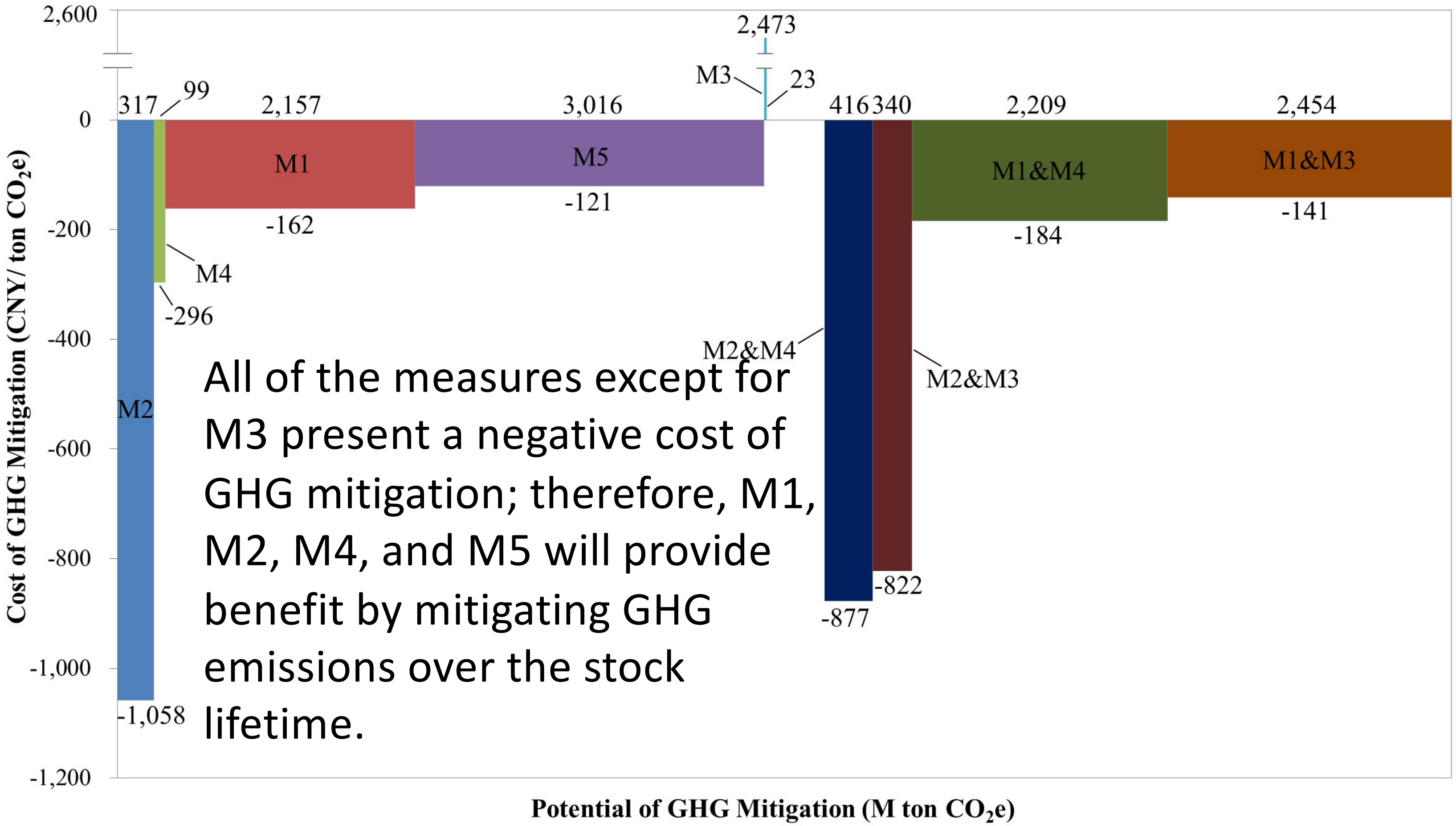
$$MitCos^{M1-5} = (TotReq^{M1-5} \times UniCos^{M1-5} + \Delta FueCos^{M1-5} - \Delta EleBen^{M1-5} - \Delta SteBen^{M1-5} + \Delta SupCleCos^{M1-5} + \Delta FolCos^{M1-5}) \div GHGMit^{M1-5}$$

- $TotReq^{M1-5} \times UniCos^{M1-5}$ → Equipment retrofitting cost
- $\Delta FueCos^{M1-5}$ → Fuel cot
- $\Delta EleBen^{M1-5}$ → Electricity sales revenues
- $\Delta SteBen^{M1-5}$ → Steam sale revenues
- $\Delta SupCleCos^{M1-5}$ → Costs of retrofitting coal-fired units to ultralow emission units
- $\Delta FolCos^{M1-5}$ → Costs of building follow-up units when old units retire normally
- $GHGMit^{M1-5}$ → GHG emission mitigation for the M1−M5 scenarios

Δ refers to the cost difference between M1 and M5 and their specific baseline scenarios

Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Environmental Science & Technology, 2016, 50, 11403−11413

Potential and cost of GHG mitigation measures for the energy infrastructure stocks in the Chinese EIPs

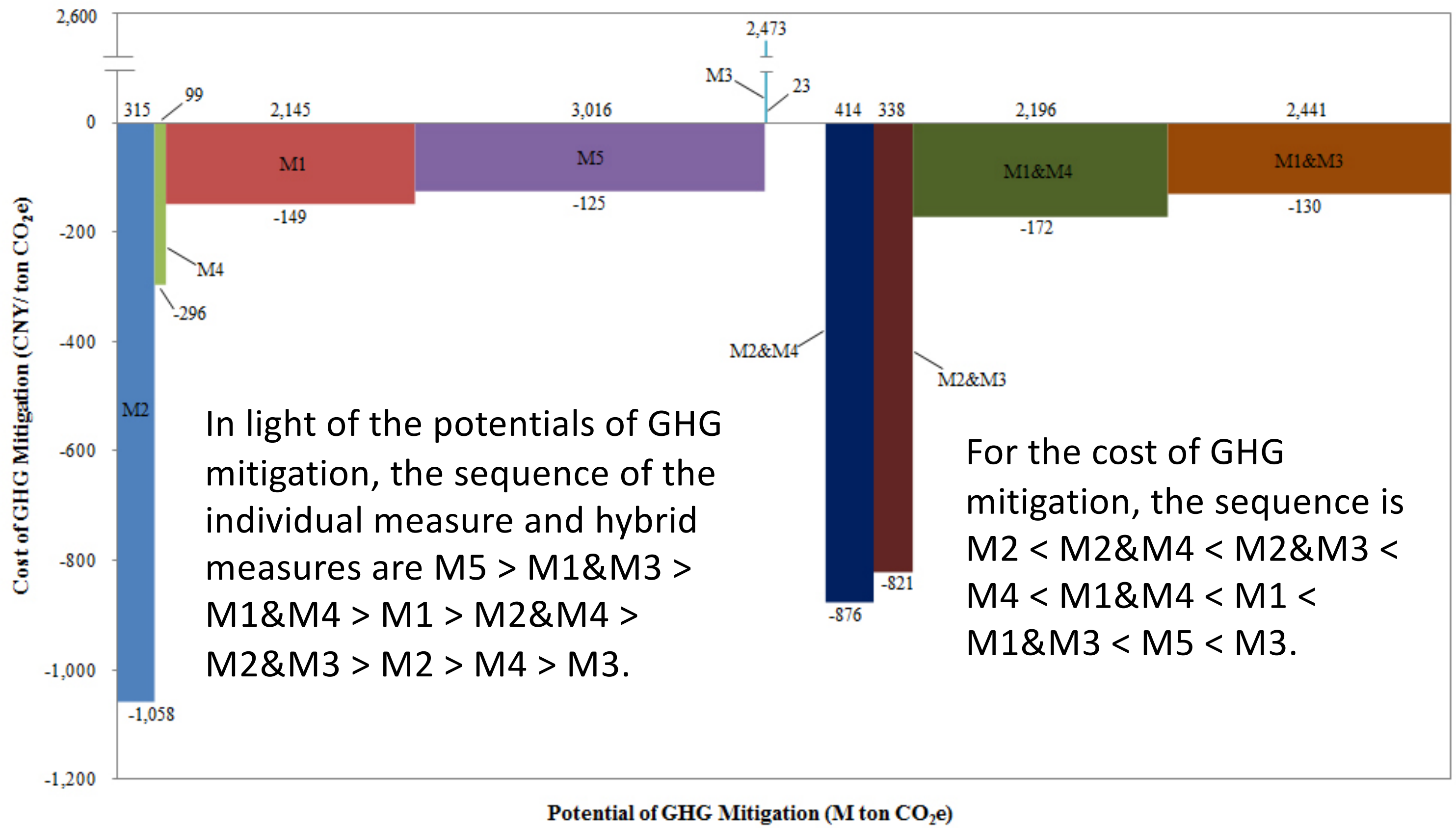


All of the measures except for M3 present a negative cost of GHG mitigation; therefore, M1, M2, M4, and M5 will provide benefit by mitigating GHG emissions over the stock lifetime.

EIP: Eco-industrial park

Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Environmental Science & Technology, 2016, 50, 11403−11413

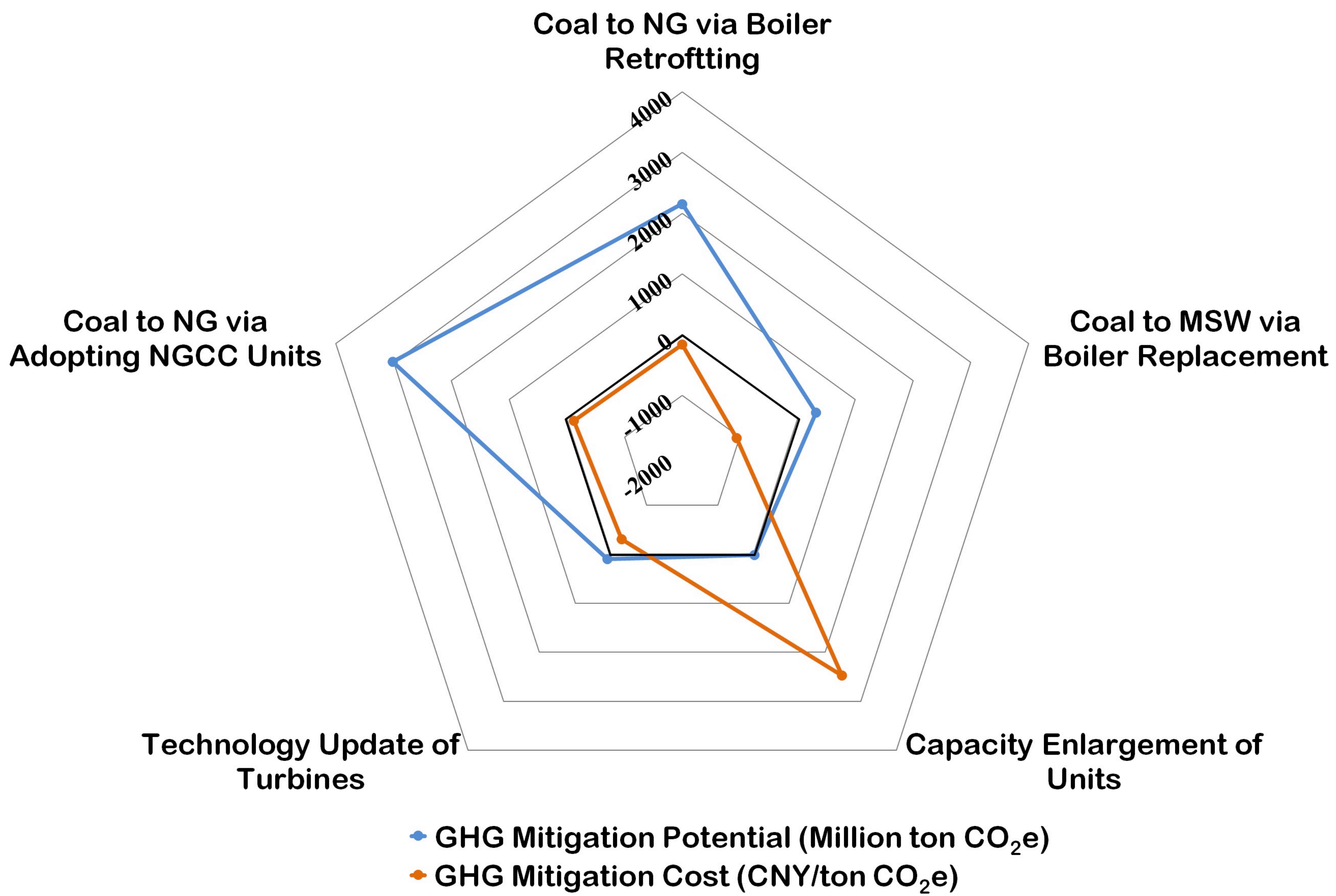
Potential and cost of GHG mitigation measures for the energy infrastructure stocks in the Chinese EIPs



In light of the potentials of GHG mitigation, the sequence of the individual measure and hybrid measures are M5 > M1&M3 > M1&M4 > M1 > M2&M4 > M2&M3 > M2 > M4 > M3.

For the cost of GHG mitigation, the sequence is M2 < M2&M4 < M2&M3 < M4 < M1&M4 < M1 < M1&M3 < M5 < M3.

Guo, Yang; **Tian, Jinping***; Chen, Lujun; Chertow, Marian. 2016. Assessment of Greenhouse Gas Mitigation Strategies in Chinese Industrial by Targeting Energy Infrastructure: a Vintage-stock Model Coupled with Cost-effectiveness Analysis。 In preparation.



Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Environmental Science & Technology, 2016, 50, 11403−11413

GHG mitigation potential, rate and cost sensitivity to variations in key model variables and parameters

Variable/ parameter		Two-end values	*GHGMit* sensitivity (%)					*MitRat* sensitivity (%)					*MitCos* sensitivity (%)				
			M1	M2	M3	M4	M5	M1	M2	M3	M4	M5	M1	M2	M3	M4	M5
(H/E)		0.19	-14.3	-15.2	0	0	-16.2	0.3	-0.7	18.2	17.0	-1.0	-18.9	0	0	0	-21.8
		11.71	82.4	87.6	0	0	93.8	-0.9	1.9	-47.0	-45.7	2.7	51.5	0	0	0	54.3
BE	coal/coal gangue-fired	70%	4.8	8.2	0	0	2.2	3.6	6.9	-1.2	-1.1	1.1	-15.1	4.6	0	0	-3.3
		75%	-4.7	-7.5	0	0	-2.1	-3.6	-6.5	1.1	1.1	-1.0	16.4	-4.9	0	0	3.2
	NG-fired	80%	-3.3	0.1	0	0	-1.0	-3.3	0.1	-0.1	-0.1	-1.1	19.8	0	0	0	8.7
		85%	3.1	-0.1	0	0	1.0	3.1	-0.1	0.1	0.1	1.0	-17.5	0	0	0	-8.1
	petrol-fired	84%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		91%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MSW/sludge -incinerated	63%	0	-21.9	0	0	0	0	-22.0	0	0	0	0	-20.3	0	0	0
		79%	0	22.0	0	0	0	0	22.0	00	0	0	0	13.1	0	0	0
EEE	extraction -condensing	29.6%	0.1	0.1	21.3	1.7	0.2	0	0	21.2	1.6	0.1	0.5	0	-19.7	0	-0.3
		55.1%	-0.1	-0.1	-1.4	-1.3	-0.2	0	0	-1.3	-1.2	-0.1	-0.5	0	0.8	0	0.3
	back-pressure	33.4%	0	0	470	0	18.8	0	-0.1	425	0	9.5	0.2	0	-92.5	0	-23.8
		75.8%	0	0	-462	0	-18.5	0	0.1	-495	0	-11.1	-0.2	0	*	0	34.1
	NGCC	40.2%	0	0.1	0	0	-14.3	-0.1	0	0	-0.1	-14.3	0	0	0	0	142
		65.4%	0	-0.1	0	0	19.0	0.1	0	0	0.1	19.1	0	0	0	0	-136
Annual working hours (hour/a)		3329	-23.1	-23.1	-23.1	-23.1	-23.1	0	0	0	0	0	-3.1	0	33.7	0.6	18.8
		5329	23.1	23.1	23.1	23.1	23.1	0	0	0	0	0	1.9	0	-21.1	-0.4	-11.7
Serviceable lifetime (a)		35	26.1	26.3	67.5	27.2	17.9	0	0.2	42.9	0.9	0.6	-0.2	-0.6	-45.2	-0.4	-11.8
		40	52.2	52.6	135.1	54.4	35.8	0	0.3	74.9	1.4	1.0	-0.3	-1.0	-64.5	-0.7	-20.4

Guo, Yang; Tian, Jinping; Chertow, Marian; Chen, Lujun. Environmental Science & Technology, 2016, 50, 11403−11413

Key findings on Greenhouse gas mitigation in Chinese eco-industrial parks by targeting energy infrastructure

- The first snapshot of the energy infrastructure stocks in almost all Chinese EIPs.
- Energy infrastructure using coal as their major fuel accounts for an average of 75.2% of direct GHG emissions in these parks.
- Five key measures is proposed to mitigate GHG emissions
- A vintage stock model to quantify the GHG mitigation potential and cost effectiveness
- Shifting coal-fired boilers to natural gas-fired boilers and replacing coal-fired units with natural gas combined cycle units present a substantial potential to mitigate GHGs (42%-46%) compared with the baseline scenario.

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