Information technology and systems in China's circular economy

Implications for sustainability

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Abstract

Purpose – The purpose of this paper is to focus on the developing circular economy (CE) policy within China and its relationship to China's information technology (IT) and IT products industry. It provides a framework to understand the role CE plays in sustainability at many levels within China.
Design/methodology/approach – This paper provides a review of the literature and practice in China various information sources including Chinese publications are used to further develop the framework and provide exemplary activities fitting within this framework.
Findings – If The CE program for IT, is to work, these needs to be co-operation at multiple levels of analysis. A proposed governmental policy can greatly influence sustainability in the IT industry.
Research limitations/implications – This review is based on various sources which may become dated as the CE and regulatory policy that influence IT advance. Understanding the historical perspective and potential future directions can help researchers identify important areas of investigation for future development in this field.
Practical implications – Practically, the framework can help policy makers understand how to structure a previously unstructured and broad policy. Managers at various organizational levels can become more clear on their organizational's IT role in a CE-like program.
Originality/value – This is the first comprehensive paper that seeks to integrate IT sustainability issues in China. It is one of the first to utilize the CE policy implications on any functional, industrial, and technological group.

Keywords Communications technologies, National economy, Ecology, Economic development, China

Paper type Research paper

1. Introduction

The Chinese information and information technology (IT) industry is composed of electronics and information products manufacturing, software R&D, telecommunications, internet and postal services. It currently ranked first among all national industries in China in terms of output, gross sales scale, as well as in contribution to national economic growth. The IT industry thus has the status of a first pillar industry and is an important force for the growth of China's national economy. In 2006, the amount of IT industry value-added contribution to the economy was over 1.56 trillion RBM yuan (approximately US$208 billion), or a 7.5 per cent share of China's gross domestic product (GDP) (Figure 1). China's IT industry surpasses Japan's and is just behind the US IT industry (CNBS, 2007).

IT industry growth, however, arrives with a corresponding deterioration of the environment, posing a major environmental challenge for the IT industry and the

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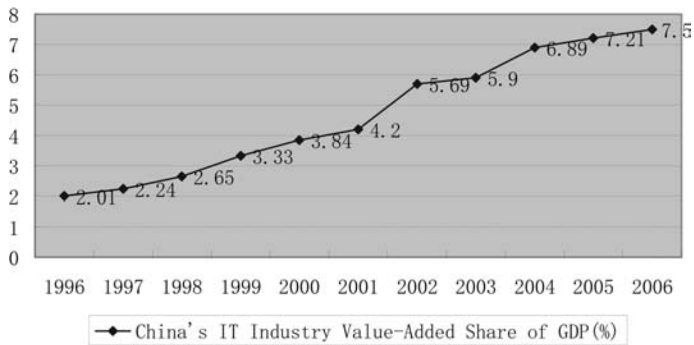


Source: CNBS (1997-2007)

Figure 1.
Proportion curve of value-added of China's IT industry among GDP

government. In this paper, we focus on China's circular economy (CE) regulatory plan and policy. We provide insights into how IT and IT infrastructure may enable this plan and policy, not just for the IT industry, but for Chinese enterprise overall.

2. IT and electronic waste management in China

2.1 Definition of electronic waste

E-waste includes IT and telecommunications items including computers, entertainment electronics, mobile phones and also supporting ancillary equipment that are no longer of use to the original consumer. E-waste is a significant secondary resource because of its suitability for direct reuse, refurbishment and material recycling of its constituent raw materials (including computer chips, plastics and precious metals).

The EU (and emergent China) waste electronic and electrical equipment (WEEE) directive defines the following IT and information systems related items and ancillary equipment as potential e-waste (under Annex A of EU Directive 2002/96/EC) (Yu *et al.*, 2007): IT and telecommunications equipment; consumer equipment; lighting equipment; toys, leisure and sports equipment; medical devices; and monitoring and control instruments.

2.2 Problems associated with electronic waste in China

E-waste is a valuable source of secondary raw materials when treated properly. Improper treatment makes it a major source of toxins and carcinogens (Cui and Forssberg, 2003). Shortened life cycles and low cost in the Chinese IT industry have resulted in a growing problem which require legal, technical, infrastructural and logistics systems. These all fit within the CE framework discussed below.

China's traditionally lower environmental standards (which have changed in the past few years) reflects electronic waste being sent for processing – in many cases illegally. Much of what occurs is due to informal networks of e-waste organizations who practice uncontrolled burning, disassembly and disposal. These activities cause occupational and broader environmental, safety and health problems, because much of this waste is recycled typically using manual and low-cost hand labor (Terazano *et al.*, 2004). While trade in waste is regulated and controlled by the Basel Convention, the rules have been side-lined in China.

E-waste is of concern largely due to the toxicity and carcinogenicity of some of the substances if processed improperly. These include lead, mercury, cadmium and polychlorinated biphenyls (PCBs) (Wong *et al.*, 2007). The non-sustainability of discarding electronics and computer technology also underscores the need to recycle – or perhaps more practically, reuse – electronic waste. However, to be able to achieve this, more formalized systems as recommended by CE are required. The major concerns are summarized by Collins (2007) in a report by the United Nations University. Inappropriate handling of systems may lead to:

- Emissions of highly toxic dioxins, furans and polycyclic aromatic hydrocarbons, caused by burning polyvinylchloride (PVC) plastic and wire insulation.
- Soil and water contamination from chemicals such as: brominated flame retardants (used in circuit boards and plastic computer cases, connectors and cables); PCBs (in transformers and capacitors); and lead, mercury, cadmium, zinc, chromium and other heavy metals (in monitors and other devices). Studies show rapidly increasing concentrations of these heavy metals in humans; in sufficient dosages, they can cause neuro-developmental disorders and possibly cancer.
- Waste of valuable resources that could be efficiently recovered for a new product life cycle.

In 2006, 75 per cent of German and Japanese households were equipped with a personal computer, compared with only 4.1 per cent in China. Also, according to OECD data (OECD, 2007), China overtook the USA in 2004 to become the world's leading exporter of information and communications technology (ICT) goods such as mobile phones, laptop computers and digital cameras (Figure 2). China exported US$180 billion worth of IT goods in 2004, compared with US exports in the same category valued at US$149 billion. In 2003, the USA led with exports of IT goods worth US$137 billion, followed by China with US$123 billion. China's share of total world trade in ICT goods, including both imports and exports, rose to US$329 billion in 2004, an almost ten-fold increase since 1996s amount of US$35 billion. By comparison, the US share stood at US$375 billion in 2004, up from US$230 billion in 1996.

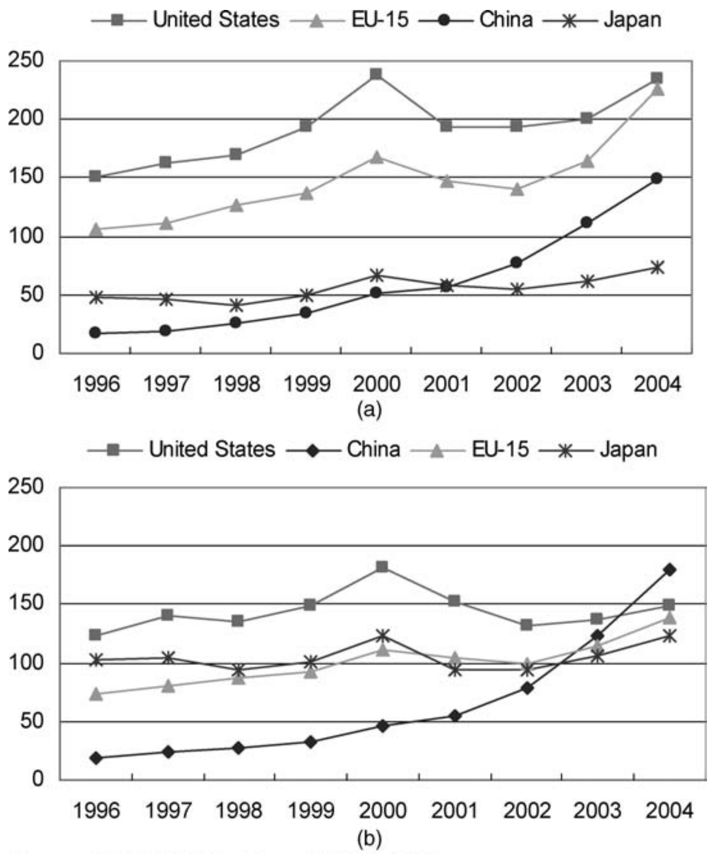
No country has ever experienced as large or as fast an increase in solid waste quantities as present-day China (World Bank, 2007). In 2004, China surpassed the USA as the world's largest waste generator, and by 2030 China's annual solid waste quantities will increase by another 150 per cent – growing from about 190,000,000 tons in 2004 to over 480,000,000 tons in 2030.

We make the case below that a CE, where a circular flow of material and resources occurs within China's industrial markets, thus conserving resources, may be a viable and valuable option for China in resolving its waste problem.

3. China's CE

CE was developed in China as a national strategy for reducing its economy's demand for natural resources as well as ecological damage. The importance of CE is described by Pan Yue, Deputy Minister, State Environmental Protection Administration (SEPA):

> China can no longer afford to follow the West's resource-hungry model of development and it should encourage its citizens to avoid adopting the developed world's consumer habits . . . It's important to make Chinese people not blatantly imitate Western consumer habits so as not to repeat the mistakes by the industrial development of the west over the past 300 years.



Source: OECD, ITS database (OECD, 2007)

Figure 2.
(a) Imports and (b) exports of ICT goods, billions of US dollars in current prices, 1996-2004 (USA, China, EU15, Japan)

3.1 Elaboration of the CE concept

China's CE policy helps both economic efficiency and sustainable development. It includes three aspects of an eco-economic system: optimal economic growth, good environment and harmony between human beings and nature. Research on CE within China includes: technical innovation, e.g. cleaner production, waste disposal and agile manufacturing; innovation for organization, e.g. green supply chain management and eco-industrial parks; and institutional innovation, e.g. institutional arrangement based on mechanism design theory (Nobel Prize Committee, 2007; Baliga and Maskin, 2002) and ecological modernization theory (EMT) (Chuanqi, 2007). These elements are summarized in Figure 3 which represents an overall framework for analyzing CE. Within each of these areas, there are significant information and IT implications for management. Each of these areas will be further defined as we discuss IT implications in the next section.

4. IT an integral cog of China's CE

4.1 Institutional innovation and IT in the CE

Our focus on institutional arrangements includes formal property rights, law and government policy (economic markets, legal), and also informal institutions such as

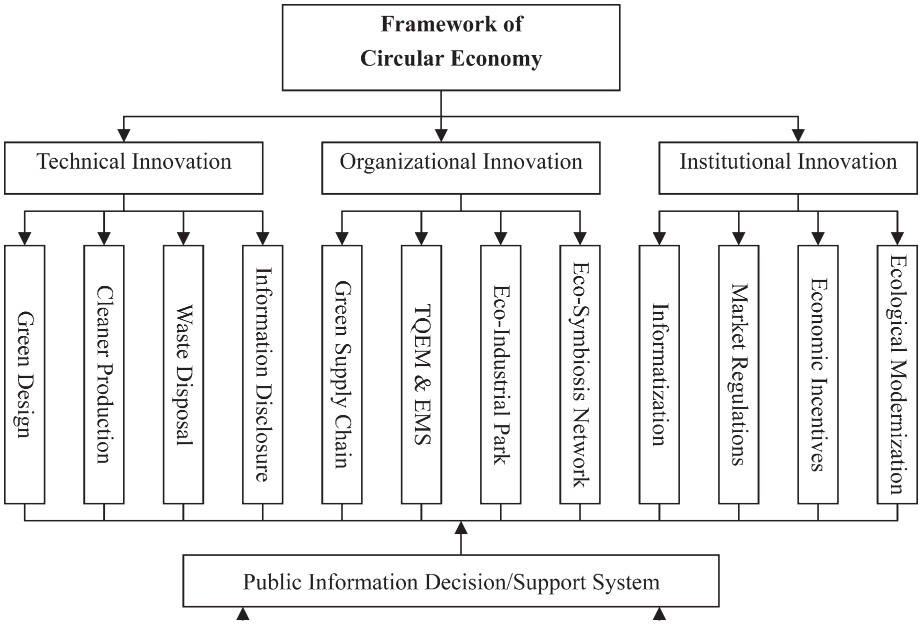


Figure 3.
CE framework

convention or customs (morale, social). There are four aspects of China CE institutional innovations which will influence the use, application, and production of IT within China:

(1) property rights development;

(2) market-based regulatory policy;

(3) economic incentive supported policy; and

(4) ecological modernization approaches.

4.1.1 Property rights institutional innovation and IT. Property rights refer to a bundle of rights covering the use, control, and transfer of assets, including land, natural resources, intellectual products, ecosystems (Scheiber, 1981). Property rights systems include mechanisms to resolve disputes, defend rights and administer or manage land resources.

An emission trading system is one property right that shifts policy measures to help achieve environmental objectives at potentially lower cost than the more traditional use of uniform standards on emissions sources (OECD, 2001) and also perhaps to encourage innovation. An ambitious emissions trading system, which requires additional governmental infrastructure, is the open-market trading system has been recommended by Chinese scholars (Yi, 2006; Zhu, 2007a, b).

Credible monitoring systems are essential to ensure the environmental integrity of emissions trading regimes. To develop such markets, the roles of IT, information systems and decision support technology need to be developed for the many parties that would be involved in the trading. These parties would include, at a minimum, private organizations governmental agencies, non-governmental organizations and financial institutes. Systems to support these multiple organizations and their roles in a trading system will also be required.

In addition, property rights policies may be developed through a permitting system. The allowance to pollute in different settings essentially becomes a property right for those organizations that have the permits. IT tools such as integrated decision support systems (DSS) for the development of circular economy are established in many regions in China. One such DSS is for the economic development of the region of Lanchang River, Yunnan Province (Tian *et al.*, 2007). The system is equipped with five large-scale databases related to geography, population, ecological environment, agriculture, tourism, transportation, water resources and natural disaster prevention. The system can provide decision support for policy-making in natural resource management, environmental protection and economic growth in the region of the Lanchang and Haihe Rivers, which would include a permitting mechanism to help manage pollution in river systems.

4.1.2 Market-based regulations institutional innovation and IT. A market economy evolves institutions, rules, and standards that further regulate the behavior of economic agents. Emissions trading is an example of a market-based mechanism, which sets prices on emissions, which can then be used as property.

Another example of a market based mechanism would be to use deposit and refund type programs (World Bank, 2007). This type of system may be regulated and implemented effectively for IT products. Computers, phones and various electronic accessories are all encompassed by the WEEE regulations from Europe that are influencing Chinese organizations (Hicks *et al.*, 2005). In China, a similar regulation called the "Management Methods for Controlling Pollution by Electronic Information Products" regulation took effect in March 2007. Part of these regulations require a significant extended producer responsibility for electronic and IT systems. These regulations may be managed and effectively implemented through deposit–refund market-based mechanism policies. To help address this type of situation, IT equipment from various countries may have specific tariffs and requirements that would encourage their take back from other countries, and also within China (Bhuie *et al.*, 2004).

4.1.3 Economic incentives institution innovation and IT. Economic incentives are defined broadly as instruments that use financial means to motivate polluters to reduce the health and environmental risks posed by their facilities, processes or products. These incentives provide monetary and near monetary rewards for polluting less and impose costs of various types for polluting more. Even though there are overlaps with market-based regulatory mechanisms and institutional innovations, there are economic incentives such as pollution charges and taxes, input or output taxes and various types of subsidies that may not fall within the realm of market based regulatory mechanisms. Economic incentives and constraints help internalize the external costs of socioeconomic activities.

The circular economy stresses the importance of taking material circulation and its supply–demand relationship into account as endogenic factors. It is expected that environmental costs and scarcity costs for the sustainable use of natural resources will be internalized into organizational costs, encouraging organizations to save resources and mitigate pollution – this is a central goal of the CE policy (Yong, 2007).

Many taxes and penalties (either as output or input taxes) may not necessarily target the IT equipment overall, but only the materials that are within this equipment. For example, lead, mercury and other toxic elements are pervasive in IT equipment, manufacturers may have to design and develop IT equipment with reduction or substitutes of these chemicals. As part of the taxing of inputs and outputs and extended producer responsibility, government and organizations will require the effective development of information auditing and tracking systems to trace materials as they flow through various product life cycle chains.

4.1.4 Ecological modernization. EMT explores the interaction between modernization and the natural environment (Fisher and Freudenburg, 2001). EMT encourages green industrialization, green urbanization and ecological modernization all advancing in a co-ordinated manner. Technological and ecological synergies are sought out with EMT and ecological modernization. IT and systems plays a key role.

Three major policy initiatives in China that have EMT implications include an informatization development strategy, development of high-tech industrial parks and development of national electronic information industrial parks.

China's State Informatization Development Strategy (2006-2020) sets forth China's goals for providing information infrastructure nationwide including promoting informatization of the national economy; popularizing e-government; establishing advanced internet culture; pushing ahead social informatization; popularizing information infrastructure; exploiting information resources more efficiently; improving information industry competition; building national information security system; improving people's ability in using IT and cultivating more talents in IT.

China views the development of high-tech industrial parks as a dominant force underlying its ability to build international competitiveness. One such example is The Pearl River Delta the Yangtze River Delta and Bohai Area where high-tech industrial parks' income from technology, industry and trade will continue to grow by an average of 30 per cent annually. It is expected that appropriate environmental technologies will be developed in these high-tech industrial centers and require supporting IT and systems.

In 2005, the ministry of information industry identified the first group of National Electronic Information Parks in Beijing Tianjin Qingdao, Shanghai, Suzhou, Hangzhou, Shenzhen, the coastal areas in Fujian and the Pearl River Delta. These parks are more specific for IT and systems development (instead of just general high-technology developments).

4.2 IT within CE organizational innovation

Organizational innovation items within CE each have IT and information systems implications. Some are quite pervasive and may need to include inter-organizational management systems; other to be at the transactional and operational level. We provide a number of examples.

4.2.1 Total quality environmental and environmental management systems. One of China's recent institutional innovations is the "Green Watch" program which is based on information disclosure and ratings of organizations on a color scale. These ratings are then disclosed to the public. As part of this rating scheme organizations are ranked on the adoption and effectiveness of their environmental management systems (EMS) (such as ISO 14000 certification) (Wang *et al.*, 2004). The world total of ISO 14000 certificates as of December 2005 was 111,162. China accounted for 12,683 certified locations, only behind Japan, (ISO, 2005). ISO 14000 and total quality environmental management programs and other EMS will require significant information systems to manage them (Tang *et al.*, 2007). Appropriate IT such as enterprise resource planning (ERP) systems will be needed to manage these integrate ISO-based systems that are heavily documentation, process, multifunctional and information oriented.

In China's construction industry, environmental impact analyses are required and are more greatly practiced by organizations than EMSs. An IT system integrating ISO-like EMSs with a generation of environmental impact analysis reports has been developed for this industry to help it get closer to ISO 14000 certification requirements (Chen *et al.*, 2004a, b). These systems are encouraged and required by a number of China's regulatory policies. Organizations also feel pressures from regulators as well as competitors (Zhu *et al.*, 2008). As part of this system, total quality environmental (TQEM) initiatives, such as continuous process improvement of environmental issues, empowerment and environmental management using data and information, are all dependent on operational and strategic information (Sarkis, 1999). Managing this information set across and between organizations is necessary.

4.2.2 Eco-industrial parks. Eco-industrial parks as an organizational innovation is occurring throughout China. The newly introduced industrialization practice in China has a strong element of IT in its design and is promoted by means of a new approach to information which is described as "informatization" (Ren, 2003). Informationization strategy focuses on promoting informatization in concert with industrial policy encouraging informationization in enterprises. Fang *et al.*, 2007, state that informationization provides a potentially powerful foundation for eco-industrial development. For example, as we have noted environmental information systems at the municipal level being built in some cities led by local environmental protection bureaus. Inter-organizational environmental information systems are also recommended for establishment within industrial parks and zones to provide integrated and reliable data. Such data would include eco-industrial park member surveys, detailed information about inputs and outputs of materials, environmental monitoring and other data. Life cycle analysis and material flow analysis tools and information will help eco-industrial parks guide the eco-industrial development. "Symbiotic synergies" such as exchange of by-products among organizations within eco-industrial parks would be aided (Fang *et al.*, 2007).

4.2.3 Eco-symbiosis. Eco-symbiosis is defined as an approach where systems work together and within larger systems in a sustainable manner. Eco-Industrial parks may be considered a specific type of eco-symbiosis. Synergistic and mutually beneficial systems may also exist in this environment. This aspect of CE can begin at the level of enterprises, then expand to industrial parks, then to cities and regions, thus enabling accumulation of experience to facilitate reasonable decision-making at each successive step (Nailing and Zhijun, 2007).

For example, eco-industrial parks within a larger community (city or province) working together in a broader system may have eco-symbiotic relationships at many levels, similar to an organism that has subsystems working together in a mutually beneficial manner (e.g. circulatory and respiratory systems in humans). Their interaction with each other and the eco-system should be mutual and adaptive in concert to improve environmental and economic circumstances. Open source and distributed systems that can communicate at many levels are needed to enable this situation. The internet, e-commerce and other relationships amongst different organizations that share knowledge, expertise and data will be needed. This type of system is probably the least developed of the organizational innovations that cross organizational boundaries. Adaptive and dynamic information systems that can evaluate and link these organizations at multiple levels, such as geographic information systems and mobile information (GISs) technologies are needed to manage this organizational innovation.

Systems that can manage waste exchanges that occur across and between organizations, a virtual eco-industrial symbiosis, will be needed. An example of such a webexchange type tool appears in China's construction industry and is called "Webfill" (Chen *et al.*, 2003). Webfill is an e-commerce platform to encourage the exchange of residual materials and construction waste for reuse and recycle among different construction sites and material regeneration manufacturers.

4.2.4 Green supply chain management. Green (Environmental) supply chain management is a broad group of organizational innovations that are part of an organization's larger set of inter-organizational value chain functions. Supply chain management includes managing resources (informational, knowledge, economic, material and labor) that flow to from and between organizations (Sarkis, 2006). In China, this innovation is still emerging (Zhu and Sarkis, 2004; Zhu *et al.*, 2005). While IT can green a supply chain through many different approaches, one of the most effective methods is through the substitution of information movement for movement of physical objects and materials (Sarkis *et al.*, 2002). This substitution allows for transportation and storage efficiencies, such that material and goods are not transported, produced or stored inappropriately. Part of the IT and information system requirements in this environment include the linkage of life cycle analysis, design for the environment and green purchasing systems within and across organizations. These technologies and systems do not appear to be currently in operation in Chinese organizations due to the lack of information and systems to support the activities across the supply chain.

4.3 IT within CE technical innovation

4.3.1 Green design. Green design (also referred to as "sustainable design", "eco-design" or "design for environment") is designing products and their processes to comply with the principles of ecological sustainability while minimizing economic costs. Green design can range from the smallest materials (e.g. nanotechnology) to the largest infrastructures (roads and buildings).

Green design's significance in CE arises because the focus of products life cycle should begin at its infancy. The best way to manage wastes is to prevent them and design them out of a product. Green design relies on a variety of tools, especially, IT-oriented tools life cycle analysis systems and various software tools to evaluate the "greenness" of various design choices. The Chinese ROHS regulation (defined earlier under institutional innovation) clearly signifies a regulatory force for information technology to be eco-designed (Yu *et al.*, 2007).

4.3.2 Cleaner production. Cleaner production refers to a philosophy of how goods and services are produced with minimal environmental impact under present technological and economic limits. It is a balanced technical (product and process) solution. Overall, it is the continuous application of an integrated preventive environmental strategy to processes, products and services to increase overall efficiency and reduce risks to humans and the environment. Cleaner production technical solutions overlap significantly with green design.

From a broad technological perspective, designs of new machinery and innovative technology to minimize the environmental burden of production are necessary as is IT to help in the monitoring, management and communication among these systems. From a more specific environmental perspective, there are a number of dimensions of cleaner production that require significant information and document control including (ChinaCP.org, 2007; Sarkis, 2001):

- EMS;
- eco-labeling (or environmental labeling);
- environmental accounting;

- environmental audits; and
- environmental indicators.

4.3.3 Waste disposal. Waste management is the collection, transport, processing, recycling or disposal of waste materials. Waste management information and IT issues for China are:

- information availability: lack of reliable and consistent waste quantity and cost data makes planning for waste management strategies extremely difficult;
- decision-making tools: lack of consistent policy and strategic planning toward technology selection, private sector involvement, cost recovery, inadequate public access and participation in the planning process; and
- institutional and arrangements: inadequate decentralization of collection and transfer services, inadequate municipal capacity for technology planning and private sector involvement, and inadequate clarity on mandates between government agencies, and inadequate delineation between central and local government responsibilities.

A number of general and specific IT and information systems requirements are provided for the first two categories above, and the supporting tools and information. For the third category, both regional, local and organization-wide systems can be developed. For example, the integration of GISs technology with efficient scheduling of waste management and disposal is an important aspect of waste management (Chang *et al.*, 1997) and manufacturing with "smart parts" using radio frequency identification technology will make it easier to track and manage these wastes through the system (Zhekun *et al.*, 2004).

4.3.4 Environmental information disclosure. Environmental information disclosure is a result of institutional innovations. This technical innovation is meant to integrate information and communication to various stakeholders with various environmental programs. Environmental information management is the most direct IT and information system dimension of CE. It can have a very broad definition and includes written, electronic, visual or audio information on:

- elements within the environment, e.g. air, atmosphere, water, soil, land, landscape and natural sites, biological diversity and its components;
- factors affecting the environment, e.g. substances, energy, noise, radiation or waste, including radioactive waste, emissions, discharges and other releases;
- measures (including administrative measures) and activities affecting or designed to protect the environment e.g. policies, legislation, plans, programmes, environmental agreements;
- reports on the implementation of environmental legislation;
- cost-benefit and other economic analyses of environmental measures and activities; and
- human health and safety and epidemiological information including the food chain information, human life conditions, cultural sites and built structures.

In April 2007, SEPA issued the decree on environmental information disclosure (DEID), which will be effective on 1 May 2008. This decree is the first formal regulation on information disclosure by a Chinese government agency. It is also China's first comprehensive governmental document to regulate environmental information disclosure. DEID forces enterprises and governments to reveal their important environmental information to the public and serves as a foundation for public participation in pollution control.

This specific technical solution requires the capabilities to effectively manage and disseminate this information. Information disclosure is a useful mechanism if all stakeholders within communities have easy access to this information. Thus, e-government systems, internet capabilities and other informational infrastructure requirements become necessary.

5. Conclusion and directions for future investigation and research

IT and its supporting systems will have both positive and negative profound influence on how various groups, countries, and organizations manage their environmental issues. China is noteworthy as one of the fastest growing countries in the development, application and production of IT and information systems. The implications of IT in the Chinese environmental situation include IT as a product and as management tool. The product itself can cause a large amount of environmental burden due to the waste and emissions that are generated from its production, use and disposal. The application of IT can be of great help in managing the environmental burden caused by IT and other products, materials and industries. Thus, in many ways, IT planning and management at all levels of analysis, individual, organizational, municipal, regional, national and global, is critical from an environmental perspective. China realizes this issue of industry's environmental burden and has introduced the concept of the CE to address these issues.

An important factor for developing the CE (and ecological modernization) is enhancement of the technological level to help achieve joint gains in economic and environmental performance. We reformulated the definition of CE into three major innovational categories: institutional, organizational and technological. While these innovation categories overlap, they jointly provide a comprehensive picture of CE projects and programs that the Chinese government has supported. Within this CE context, we have described in general and through specific examples how IT and information systems can be both a burden and a benefit to environmental situations.

We only touch upon some general issues that may require research related to IT relationships to the various CE innovations. However, this paper is one of the first to link the issues of IT to CE and to make further sense of this important social policy set forth in China. The paper also provides a springboard and framework for further study in this field.

For policy and macroeconomic research, we can investigate the most appropriate type of policy mechanisms in a country with shifting political winds. There are ample opportunities to initially predict the outcomes of various policy mechanisms based on previous experiences in other countries. For example, we might ask whether the most effective means of lowering emissions from IT usage and production come from developing market-based mechanisms or from economic incentives? Also, what form of institutional innovation will make a long-lasting cultural change in the way organizations and individuals use and apply IT? What type of decision technologies are needed to guide policy makers in developing permitting schemes?

A number of organizational innovation -level research issues emerge. It is expected that many of the initiatives in this category do not involve one organization, but a number of organizations as part of supply chains, as symbiotic partners or members of eco-industrial networks and parks. IT needs should be focused on developing and implementing inter-organizational systems to manage these relationships. In China, the integration of various policy mechanisms outside of CE, such as various information network policy stances, into the CE framework will need to be investigated within these multi-organizational realms. China needs to further support the development of these organizational initiatives and may be able to do so by providing external (foreign direct investments) that seek to enhance the CE organizational initiatives and technological development.

EMS and ISO 14000 implementation is one of the major organizational innovation initiatives in CE. Many, if not most, of the organizations involved in China's networks will be small and medium-sized enterprises. A model for integrated systems in China based on the Hackefors model in Sweden (Ammenberg and Hjelm, 2003), where 26 small and medium-sized enterprises have formed an environmental network and implemented a joint EMS according to ISO 14001, is potentially applicable in China (Chen *et al.*, 2004a, b). These types of inter-organizational EMS will require development for significant integration of information and documentation across organizations. Also, how, when and who will invest in these types of IT systems is a critical aspect to their implementation that must be addressed. Further, investigations of various implementation and project management models will be required. The issues are similar to those in virtual enterprise models within the IT literature. Evaluating how well IT will work in terms of effective implementation of ISO 14000 and other EMSs is an important area of potential study as are investigation of performance outcomes.

Most of the operational level research opportunities for IT and CE linkage are most likely to occur within the technology innovation category. These supporting technologies will prove valuable for the organizational and institutional innovation areas. The research in this area can be at hardware, control or planning tool levels. Development and application of life cycle analysis and design for environment tools and integrating them with existing IT such as ERP systems in the China and international context needs study. Cleaner production control technology many not only be focused on monitoring and control of materials and products manufacture, but also on the gathering and storage of data related to environmental performance that can feed environmental performance, auditing and management systems. New product designs using the latest IT for mobile and life cycle information capture will also be critical as management through closed-loop systems are encouraged. Wide area networks that help in the management of inventory (both traditional forward supply and other byproduct/waste inventory management) will be needed in broader eco-industrial system situations.

Social IT systems to incorporate and share information across broader sectors of society are other emergent areas of study within e-government, non-profit and community-based systems, especially in terms of information disclosure requirements. Research investigations can also include theoretical topics such as transaction cost investigations, technology acceptance, diffusion of technology and behavior-intent theoretical investigations as these CE technological innovations emerge.

This is one of the few and first papers to help establish a framework to help understand China's CE policy and effectively show its relationship to IT. Yet, the framework has limitations. As evidenced by the discussion, many factors are interrelated and a distinctive definition of these categories and factors does not exist. That is, literature may define some of the factors from differing perspectives. Different terminology, depending on the field of study and perspective, may provide different definitions of these practices. Also, as made clear with the various innovations discussion, the categories and factors are not all-encompassing and may cover multiple levels of analysis. We provide a comprehensive listing, but a broader more complete listing may evolve over time as CE matures. Thus, we look at the framework as an initial exploratory "sense-making" process for a relatively complex, dynamic and convoluted regulatory policy.

As we have seen, the CE concept is a broad-based effort within China that will be significantly influenced by IT capabilities and IT production, and also influence how IT is used and viewed. What is learned by China's grand experiment is something that may well prove valuable for developed and developing countries. For example, even in the USA there are still emergent activities on how information and the role of information and IT in environmental management at many governmental and institutional levels is still a necessary area of concern, even today. Europe is faced with similar peculiarities since such a system is broad enough to encompass various practices, cultures and regions within the diverse European Community. From a developing nation perspective, India is facing similar concerns on its growing economic prowess and faces many of the same sustainability issues as China. What makes India more interesting is that one of its major industries is the service oriented IT industry (growing through offshoring and outsourcing). This growth and maturity of India's IT infrastructure may mean that they can implement many of the same broad aspects of China's CE policy. Thus, implications exist for large and small nations throughout the world based on China's endeavors to provide an environmental policy that is geared to both economic growth and environmental well being.

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