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China's Transformation towards a Global Green System of Innovation

Introduction

China's economic strategy has been successful in maintaining high economic growth for over three decades and the country has become the world's second largest economy. However China has now also became the global top energy consumer and greenhouse gas (GHG) emitter. In early 2010 the Chinese Government joined the non-legally binding Copenhagen Accord demonstrating strong political will to be part of combatting climate change and the global efforts to prevent further anthropogenic ecological deterioration. China announced to the international community its intentions to voluntary reduce its emissions of carbon dioxide per unit of GDP (namely, its carbon intensity) by 40 to 45% to 20202 compared with 2005 levels. The country's national policies shifted from resource- and energy-intensive economic development models towards creating an energy efficient and environmentally friendly society. China's innovation policies and overall innovation capacity have positioned the country well to achieve such an ambitious move. Its investment in research and development (R&D) has steadily been increasing for decades and at 18% per annum, R&D growth has almost doubled the country's GPD growth rate in the last ten years (Wu forthcoming).

China's substantial economic progress was accompanied by dynamic developments in the area of science and technology. The country's R&D intensity (the ratio of R&D expenditure over GDP) rose from 0.9% in 2000 to 1.8% in 2011 (see Table 1). Although this is still lower than in the United States (2.8%) and Japan (3.4%), it is higher than in other fast developing economies, such as India (0.8%) and Brazil (1.1%) (National Statistical Bureau and Ministry of Science and Technology, 2011). China's 12th Five Year Plan and medium- to long-term development strategy propose a further increase in China's R&D intensity to 2.5% by 2020.

The sheer volume of R&D investment at present, estimated at US$ 198.9 billion (Batelle 2012)[1], is second only to USA with China recently overtaking Japan. The result of the expansion in R&D spending is rapid technological progress which is taking place in the country. In 2004 China became the world's leading exporter of ICT, including mobile phones, digital cameras and laptops (OECD 2005). Other examples include the development of bullet (high-speed) trains and advancement in clean energy technologies. China has also significantly increased its innovation capacity by a steady performance in commercialising R&D and developing technological markets. The number of domestic patents granted doubled between 2006 and 2010 followed by a further sharp increase in 2011 (see Figure 1). The value of the domestic technology market transactions, including commercial transfers, development, consultations and services associated with technology, also manifested a similar high growth (see Figure 1).

The fast economic development of the country however has produced significant environmental deterioration and the current environmental performance index by Yale University ranks China 116th out of 132 countries[2]. The more recent commitments to reduction in CO_2 intensity and a plan for transitioning towards a low-carbon economy (Guo et al. 2013) are expected to be achieved through further investments in R&D and the development of new technologies. China has started to transform itself and this will also have significant implications for the world and the global economy but how do its national efforts

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[1] Australia's gross expenditure on R&D are estimated to be US$ 21.8 billion in 2012 (Batelle 2012).
[2] Environmental Performance Index 2012 (http://epi.yale.edu/epi2012/rankings)

fit within the bigger global picture? China's top-down policies are very different to the free-market innovation mechanisms endorsed in many other parts of the world. If China has started to endorse a greener economy on a national level, is this enough? Does understanding innovation in China help shed light as to where the global economy is going, particularly given this country's size, impacts and political uniqueness?

Table 1 R&D Intensity (R&D expenditure as % of GPP) in China, 2000-2011

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
R&D (% GDP)	0.90	0.95	1.07	1.13	1.23	1.34	1.42	1.44	1.52	1.70	1.76	1.83

Sources: National Bureau of Statistics of China (NBSC, 2000-2011) and (NBSC, 2012)

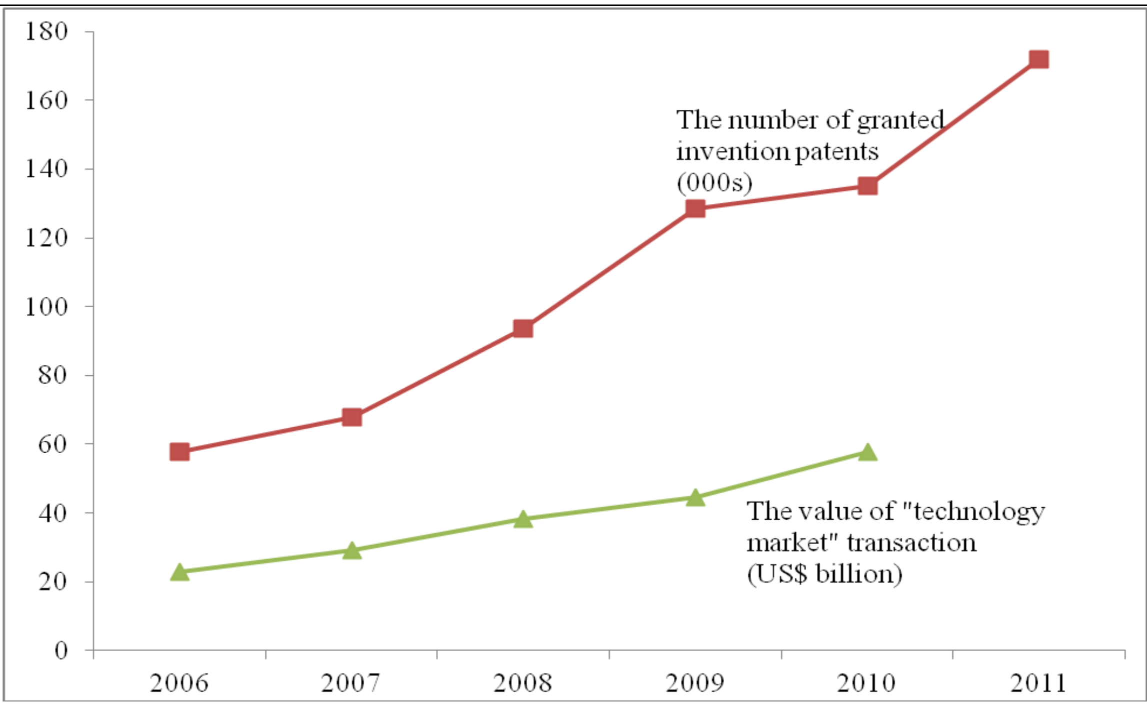

Figure 1. Invention Patents and Technology Markets

Source: National Bureau of Statistics of China (2011), *China Statistical Yearbook 2011*, and the National Bureau of Statistics and Ministry of Science and Technology (2011)

The remainder of the article analyses the main theoretical concept surrounding innovation policy, namely systems of innovation. We first present an overview of the research themes related to national systems of innovation and technological systems of innovation from the perspective of transformational change towards sustainability. We then articulate the case for a global green system of innovation as a way to avoid transformational system failures in a time when humanity's life on earth is existentially threatened by climate change. This is followed by an analysis of China's national system of innovation and its role within a global green system of innovation.

Systems of innovation

Since the 1970s, innovation has been a very strong area of policy research and advice at government and industry level with innovation policy “increasingly being informed from a perspective of a national innovation system (NIS)” (Dodgson et al. 2011: 1145) and in recent years, this approach is becoming dominant (Weber and Rohracher 2012). The need for innovation policy is justified by considerations related to market failure, namely that left without support the market will underinvest in research (Arrow 1962), may not be able to capture all positive knowledge and technology spill-overs if it does so (Jaffe et al. 2005) and valuable emerging opportunities may be lost (Mowery and Ziedonis 1998). Hence, the need for national systems of innovations which describe the interplay of institutions and the interactive processes that generate and diffuse knowledge (OECD 2005). They create national patterns of specialisation and unique characteristics, which tend to persist over prolonged periods of time making some countries better than others in the development and use of particular technologies. According to Scott-Kemmis (2004), there are significant differences between countries in the way they invest in R&D, education, offer support to industry, take risk or encourage cooperation. Despite many questions raised about the explanatory power of NIS (Shariff 2006) and whether it is possible to draw a line between local, national, global, sectoral and technological settings and influences, the concept continues to be extremely influential. Numerous analyses of NIS are being carried out on a regular basis in countries, such as UK (DIUS 2008) and Australia (DIISR 2011), and specific country profiles are produced by the OECD (2005). Dodgson et al. (2011) describe the broad policy approaches taken by the various NIS as being oriented towards the free-market (e.g. USA) or based on a coordinated logic (e.g. the Scandinavian and emerging Asian economies). They also identified an area in between these two approaches, namely a “complex-evolutionary” trajectory, and point out that no country can yet be located there.

The main characteristic of the free-market NIS is the encouragement of the entrepreneurial capitalist economy which generates a constant stream of radical and incremental innovations (Baumol 2002). Within a coordinated NIS, the national government plays a key role in facilitating technological competitiveness, social inclusion and equity and takes responsibility for the development of the country’s intellectual capital, tangible and intangible investments around new technologies, encouraging learning to occur across society and adopts an interventionist economic position to achieve long-term goals (Freeman 1992). The complex-evolutionary NIS recognises the complex nature of innovation which requires strong coordination logic but also conditions that encourage the entrepreneurship and risk taking characteristic for a strong free-market approach. Hence NIS should allow “dynamics of variation, selection and retention” (Nill and Kemp 2009: 669) acknowledging “that there are major problems facing any attempts by governments to implement detailed coordination strategies… in the face of the uncertain and unpredictable nature of innovation” (Dodgson et al 2011: 1148).

Dodgson et al. (2011: 1153) point out that innovation policy should “identify and address key factors that limit the ability of actors in the system to respond effectively, using a variety of public policy justifications and interventions”. Some of these may be within the conventional market failure approach but the most important ones are those which address system failures as they relate to the behaviour of the innovation systems, in other words “where the scope for innovation is limited by policy and institutional shortcomings” (DIISR 2009: 15). This can include, for example, the presence (or the lack) of policy measures that affect the nature, roles, behaviour and interactions between institutions. Against evidence that market failure analysis can be simplistic and often misleading, Dodgson et al. (2011) advocate that a move towards a complex-evolutionary NIS would require future innovation policy making to focus more on systems failure.

Despite its significance, the NIS approach (Lundvall 1992; Nelson 1993; Edquist 1997) focuses at the micro-dynamics between firms, e.g. "patterns of collaboration, organisation of value chains, behaviour of firms, knowledge flows between actors, collaboration of firms with universities, networks of innovators, etc. – and the framing and shaping of these interactions by institutions, policies and technologies" (Weber and Rohracher 2012: 1039). At a macro-level, indicators of NIS performance measure innovation per se, i.e. the ability to generate innovations without necessarily assessing how they transform a country's economy.

The body of research that examines the role of innovation in transforming society, namely technological innovation systems (TIS), including technological waves (Mansfield 1983) and technological trajectories (Freeman and Perez 1988), has taken a more historical and long-term perspective. According to Carlsson and Stankiewicz (1991), important features of TIS are that their boundaries may or may not coincide with national borders; and they are defined in terms of knowledge and competences and not just products and goods. The functions technological innovation systems play within society to build momentum for change have attracted further interest and they have been described as market-oriented activities (such as entrepreneurship and market development) but also knowledge development and diffusion as well as broader societal functions, namely guidance for the search, resources mobilisation, creation of legitimacy and counteracting resistance to change (Heckkert et al. 2007; Bergek at al. 2008). The focus of TIS is on the deeper socio-economic multi-level impacts of technology and the role of policy to support and build up momentum for these transformations (Weber and Rohracher 2012). From this point of view, Weber and Rohracher (2012) describe NIS as a way to counteract structural system failures, covering infrastructural, institutional, interaction/network and capabilities failures (Woolthuis et al. 2005) while TIS are needed to avoid transformational systems failures related to lack of or insufficient directionality, demand articulation, policy articulation and reflexivity.

In reality innovation systems can no longer be focused only on the supply side of innovation (namely providing a constantly increasing number of new products) and related economic priorities while ignoring the need for transformation in society's production and consumption trajectories and not taking responsibility for human and ecological wellbeing. Nowhere have the innovation systems failures (market, structural and transformational) been better manifested than in the area of environmental protection.

Climate change looms as one of the biggest environmental crises in the history of humanity (Gold 2004: 4) with anthropogenic greenhouse gases emissions causing global warming (IPCC 2007). Already the impacts of climate change are disruptive (Min et al. 2001; Pall et al. 2011; Dummer et al. 2011) and the next five years are likely to be the world's last real chance to combat climate change before climate disruption is projected to become irreversibly catastrophic (IEA 2011; The Climate Institute 2011). International negotiations to date have delivered very limited positive outcomes in arresting environmental deterioration, including climate change, resource depletion and increasing pollution. Against this complex background and the global nature of environmental pollution no NIS will be powerful enough to reverse environmental degradation. However a global TIS that aims to achieve a transformational change across the globe has a much higher chance to succeed. The need for a fundamental change in the current technological systems is unprecedented as never before has humanity been subjected to impetus that it cannot control (Marinova et al. 2012).

Market failures (information symmetries, spillovers, asymmetries of knowing, externalisation of costs, exploitation of public and collaborative goods) are endemic to any market system and there will always be risk associated with innovation activities (Dodgson et al. 2011). Furthermore, structural system failures (insufficient infrastructure, low return on private investment, inadequate regulations and standards, network failures and lack of appropriate competences and skills) are also likely to continue to manifest as individual countries explore what works against vested interests and locked-in institutional inertia. Such failures have characterised all previous technological waves and are similarly affecting the current technological transformations within individual countries and global society. However the new technological innovations will have to come within a completely different set of circumstances that have never played a decisive role in the past (Marinova et al. 2012). They put a high prerogative on the avoidance of transformational system failures as:

(1) The trigger for transformation is no longer anthropocentric (namely, improving the quality of human life), but is related to sustainability (namely, improving and maintaining the health of the planet and all its species);
(2) In the past innovation was shaped predominantly by market forces and the competitive aspirations to reap the maximum benefits from new products, processes, services, organisational and marketing ideas (OECD 2005); nowadays climate change (and associated phenomena, such as increases in temperature, extreme weather events, variations in precipitation, sea level rise, melting of the sea ice coverage, release of methane stored in permafrost among others) emerges as the new constraint and defining feature of innovation in order to protect the living conditions on the planet;
(3) Until now there was not apparent immediate urgency for the introduction of new technologies while the imperatives of climate change and the short window of opportunity it leaves humanity to come up with drastic changes lead to unprecedented urgency for technological transformation;
(4) The impacts of the these innovations need to be perceived and assessed within a global framework, rather than the discrete disjointed and fragmentary approaches used before;
(5) There is need for a global knowledge system that supports new technologies based around integrated (rather than distributed as in the past) systems of information, management, policy coordination, demand articulation and reflexivity.

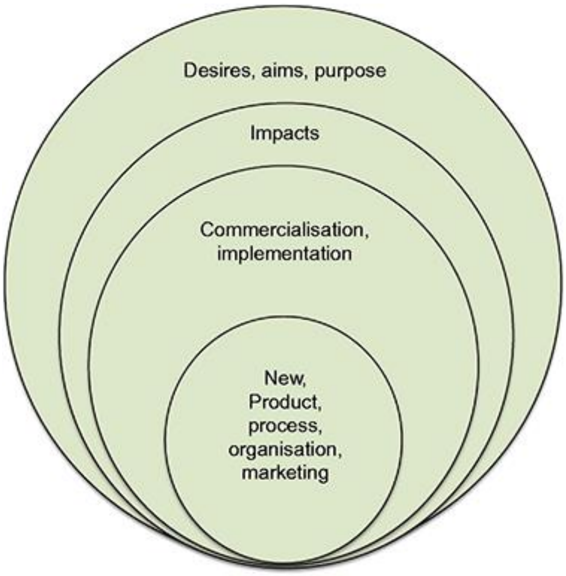

Figure 2. Innovation
Source: Marinova et al. 2012

Innovation has long been understood as the commercialisation or implementation of new technology (e.g. Rogers 1962; Rothwell and Zegveld 1981; von Hippel 1988). However, this has changed in more recent times with technology users playing a much more prominent role. Tuomi (2002), for example argues that with the advent of the Internet and social media, innovation has shifted towards creating meaning within existing social practices. Impact analysis and assessment have also emerged as a strong area aiming to understand the potential societal (TAMI 2004), social (Becker and Vanclay 2003) and environmental consequences (Holder 2005) of the adoption of particular new technologies. Hence users and communities where new technologies are adopted are gradually becoming an important, and in many cases, the determining factor in the innovation process shaping it according to their desires, aims and purposes. This means that innovation is no longer just about competition, it is about doing things differently and transforming social practices with particular goals in sight. Figure 2 describes graphically this new understanding of innovation. At its core is the new technical idea which can be a new product, new process, organisational change or new way of marketing. However, for innovation to occur, it needs to satisfy three further types of considerations: (1) existing demand as represented by potential commercialisation and implementation; (2) favourable impact assessments; and (3) achievement of particular broader aims. For example, in the case of the current climate change challenges new technology plays a crucial role in breaking up the dependence on fossil fuels (broader aim) by developing more environmentally sustainable products and ways of production, including food production, and living (new products), in response to a growing evidence of social demands, concerns and consumer preferences (commercialisation and implementation) supported by strong scientific evidence about human-induced ecological deterioration and need to reduce the human ecological footprint (impacts).

The Natural Edge Project (Hargroves and Smith 2005) describes this wave of new technologies as one determined by sustainable technologies, such as renewable energy, biomimicry, green chemistry and green nanotechnology. According to Nisbet (2011), there is a strong need to merge the innovation network (motivated by energy insecurity) and the green network (motivated by climate change) for which he coined the new term grinn. Altenberg and Pegels (2012: 5) describe the new technological paradigm as Sustainability-oriented

Innovation System (SoIS) which puts “high demands on governance, because governments need to disrupt unsustainable technological pathways and encourage alternative technologies long before they reach the stage of commercial viability”. All this puts a lot of emphasis on governments and policy makers in order to avoid transformational system failures (lack of shared vision, understanding of user demands, concerns and aims, policy coordination at the local, national, regional and global level, ability to monitor, reflexivity and adaptation within a framework of uncertainty) associated with the new technologies.

The transition to green technologies requires a massive effort (Geels et al. 2008). Although many countries, such as the European Union, South Korea, China and Australia, are gradually taking measures to reduce GHG emissions and promote green investment, these are still uncoordinated efforts in a globalised world economy that has been responsible for globalised detrimental ecological problems. The only way to avoid globalised transformational system failures is through the emergence of a Global Green System of Innovation (GGSI), namely a synergy between a sustainability-based technological innovation system and sustainability-oriented national innovation systems. Within such a GGSI, each country will have a distinctive role and there are already many signs that China is emerging as a very influential global player.

Global green system of innovation

Irrespective as to where it is developed, the novelty criterion for innovation can be applied at the level of the firm (minimum requirement), a particular market, new to the world, or radical (disruptive) to prior knowledge and practices (OECD 2005). A major defining feature of the GGSI is that it requires disruptive innovation that breaks away from tradition, inertia and existing vested interests and moves away from established technological trajectories. Altenburg and Pegels (2012: 6) emphasise that the management of the green transformation will be confronted with particularly serious market failures, including the market failure of non-appropriability: “as the social benefits of science, technology and innovation tend to exceed privately appropriable benefits, the services concerned are frequently undersupplied”. Another concern is the time required for the new technologies to become commercially competitive, particularly within markets fraught with coordination and information failures. Geels et al. (2008) stress that the socio-technical transition towards green technologies involves multiple actors and social groups (not only firms or consumers/markets) who offer multi-dimensional and multi-disciplinary insights, not just the input from science and engineering but also from economics, management studies, sociology, science and technology studies, political science and cultural studies. A GGSI is about disrupting the basis of society and economic activities, as we know them and directing them on a more sustainable path which brings hope for all living species and the planet itself. Some refer to this as an innovation journey (van de Ven et al. 1999); however it is a journey that all of the humanity has to take simultaneously and which it cannot afford to fail.

Figure 3 is a graphic representation of the building blocks of a Global Green System of Innovation. The central block represents the desired global innovation outcome, namely a clustering of green innovations as a result of green values dominating within society. In order to achieve this outcome, there are four required blocks: people who have green skills and talent to come up with the new ideas; entrepreneurial innovative business and access to capital to facilitate the implementation of their green ideas; easy information flows and exchange around green ideas; and further R&D and appropriate education that stimulate green innovations. The change towards green innovation is occurring within a global economy that will have to provide the supporting frameworks which include: proper infrastructure and networks for what are likely to be highly diverse and distributed (rather than centralised) technological solutions; community visioning and long-term perspectives (in contrast to the short-term politically driven imperatives); adaptive governance and global institutional alignment that stimulate and facilitate green innovation; and integration of sustainability within all processes of globalisation (in other words, mainstreaming sustainability.)

Using the classification of the transformational system failures provided by Weber and Rohracher (2012), we describe how GGSI (see Figure 3) can assist in building momentum for green innovations through coordinated global activities:

(1) Demand articulation – refers to availability of space and mechanisms for understanding user needs and signals from the broader public. There is ample evidence about green consumerism, green values and green skills but all of these are currently at the periphery of mainstream economic activities. The main outcome, the top of the innovation pyramid should be *a clustering of green innovations* in order to respond to green values within society. Each individual NIS should be aiming to deliver green innovations while GGSI will set the standard of not encouraging innovation just for the sake of it, but to achieve shared green values. Failing to do so, humanity will continue to go down the precipice of environmental deterioration be it at an economically efficient and effective way. The main function of a GGSI is to assist in articulating the global demand for green innovation and rejection of technologies with heavy ecological footprints.

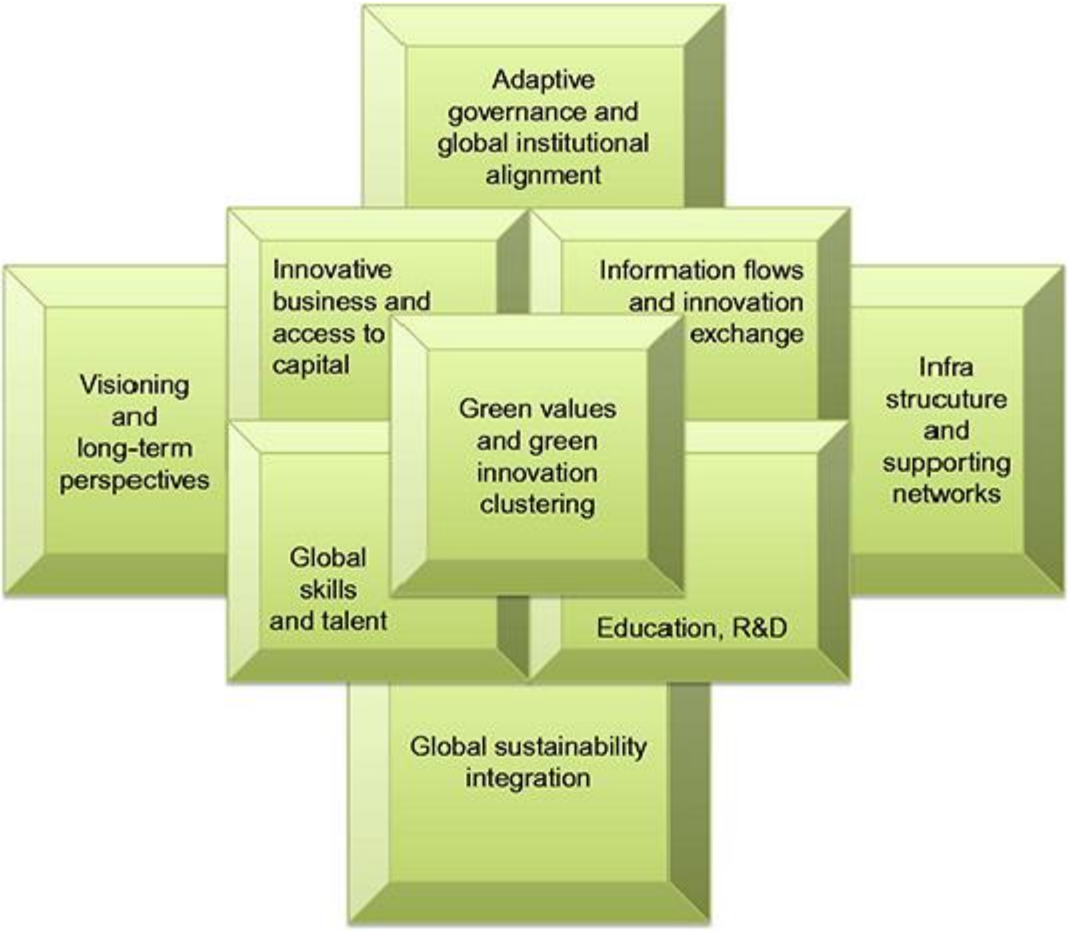

Figure 3. Building blocks of a Global Green System of Innovation
Source: Marinova et al. 2012

(2) Directionality – refers to a shared vision regarding the sustainability goal and direction of the social transformation. The GGSI will need to deliver systematic changes that shape society through investing in sustainability-related *education and R&D* which should be able to stay abreast with the urgency and complexity of the required changes and understanding of the global phenomena. Open source availability of data and research outcomes should be the norm and a sustainability lens should be part of education and training at all levels. The global pool of *sustainability skills and talent* should be in a position to generate a new global green economy where many of the current jobs will be replaced with exciting new opportunities which will be geared by community *visioning and long-term perspectives* instead of short-term interests dictated by global industry and global politics. This will require the setting up of proper international standards and regulations in order to assist a directional shift to sustainability.

(3) Policy coordination – refers to horizontal (research technology and innovation policies on the one hand and sectoral/industry policy on the other), vertical (decision making versus implementation), temporal (timing of interventions) and any other aspects of coordination of the concerted efforts for a social transformation. Encouraging *innovative businesses and access to capital* is an important function of the GGSI, as is the coordination assistance for the provision

of appropriate national *infrastructure and networks* supported through individual NIS. This function needs to be performed based on evolutionary *adaptive governance* which allows for proper alignment of powerful global institutions, such as the UN or the World Bank.

(4) Reflexivity – refers to the propensity of the GGSI to be able to monitor, anticipate and involve individual countries in processes of self-governance while keeping the channels of communication open. *Information flows and innovation exchange* are critical for monitoring progress as it relates to the healing of the natural and social environment. The *global sustainability integration* block is essential in not allowing humanity to be locked into a small limited number of possible technological solutions and choices and offer adaptive policy portfolios and options.

There are signs that such a GGSI has started to emerge with the OECD countries signing the Declaration on Green Growth in 2009 and the UNEP's Report on the Global Green New Deal (UNEP 2009) following the global financial crises. In 2011, the OECD officially released its Green Growth Strategy, which is about "fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. It is also about fostering investment and innovation which will underpin sustained growth and give rise to new economic opportunities" (OECD 2011: 4). The Strategy also includes specific recommendations, tools and indicators for measuring the progress. In a similar vein the 2012 OECD Economic Outlook stresses the need for green growth and policies with a longer time horizon that find ways to ensure environmental and social sustainability (OECD 2012).

Business attitudes are also changing. According to a survey of 1,000 senior business executives from 12 countries (GE Global Innovation Barometer 2011), innovation will help "green" the world: 90% believe innovation to be the main lever for greener national economies and 85% are confident that innovation will improve environmental quality. There is also strong research evidence that green innovation contributes to competitive advantage (Chen et al. 2006). Green innovation is also becoming a significant area of research (Schiederig et al. 2011) with 88% of the publications clustering in the areas of business, humanities and social sciences.

More work however is needed in order to avoid transformational system failures. The globalisation of the world economy has also changed innovation which has now become faster, multidisciplinary, collaborative, democratised and also globalised. A determining factor to achieve a GGSI that can shift the globe away from its current existentially threatening trajectory is for the global community to adopt a vision for a sustainable world that will translate into changes in values and everyday practices as well as in a surge of human inventiveness activities. The worldwide economy, together with science and technology, needs to reform itself into a new society where national innovation systems are geared towards supporting a global green system of innovation.

China's innovation system

In the last ten years China has developed a very ambitious national innovation system targeted to become a world leader. Since 2000, China is ranked second in terms of total number of researchers which in 2009 exceeded 1.15 million[3]. The majority of them, namely 61.5%, are employed in business enterprises (with the government and higher education sectors accounting for further 19% and 19.5% respectively)[4]. This significantly facilitates innovation and the commercialisation of new inventions. Through encouraging university education from undergraduate to postdoctoral studies, China has developed strong human resources capacity for science and technology.

Domestic and foreign investment in new technologies and manufacturing capabilities in China have dramatically transformed its economy. Many innovative Chinese firms also "developed a global brand and expanded their operations abroad, in some cases with a view to tapping into foreign pools of knowledge through mergers and acquisitions and the establishment of overseas R&D" (OECD 2008: 17). Sun et al. (2012) identify knowledge spillovers and technology diffusion as a key pattern of high-tech industry special transferring in China. Research output in terms of scientific publications and patents has also grown at an unprecedented rate (OECD 2008). Despite regional disparities between Chinese provinces and cities, the country has many major "innovative islands", incubators, science and technology parks (OECD 2008) as well as industry parks dedicated to clean energy (Mastny 2010). Located mainly in the eastern half of the country, they have proven capable of generating spillovers and innovative clusters.

China's international presence is felt strongly in the area of innovation. The State Intellectual Property Office of China in 2011 received a quarter of the world's patent applications[5] and Chinese inventors are increasingly being represented in the US Patent and Trademark Office[6]. Research cooperation with other countries is also strongly encouraged. For example, China is Australia's 3rd most important research partner and 6th highest partner in publications (DIISR 2011). Zhou et al. (2012) observe that China is becoming selective in establishing technological standard alliances as they play an important role in enhancing the partners' independent innovation capacity.

As the world's second largest economy, China is expected to become a world technology leader and the World Bank (2012) predicts that China will develop into a modern and creative high-income society within decades. By that time Wu (2012) projects China's economic power, fuelled by its R&D sector, to also overtake the United States in becoming the world's largest economy.

For any outside observer, this phenomenal growth is stunning; however Chinese innovation policy documents emphasise the need "for a shift in the growth trajectory with stronger emphasis on 'endogenous innovation' and 'harmonious development'" (Gu and Lundvall 2006: 1). According to Gu and Lundvall (2006), production capital and intellectual capital are easy to be reproduced, while a key element of China's development and innovation policies should be avoiding the degradation of the natural environment and stimulation the formation of social capital. In other words, China's national innovation system is now charged with facilitating a major social transformation.

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[3] http://stats.uis.unesco.org/unesco/TableViewer/document.aspx?ReportId=198&IF_Language=eng

[4] For Australia the respective shares for business enterprises, government, higher education and private non-profit organisations were 30%, 9%, 58% and 3%. This share is about 30%.

[5] http://english.sipo.gov.cn/news/iprspecial/201211/t20121114_770467.html

[6] The share of US patents by Chinese inventors reached 3% in 2010, a ten-fold increased from the humble 0.3% in 2000 (according to data extracted from http://patft.uspto.gov/).

Over the past decade, and particularly during 2006–2010, the period covered by the 11th Five-Year Plan, China prioritised green development and the creation of green jobs in the country's leading economic sectors (Pan et al. 2011). The 12th Five-Year Plan sets a new green GDP growth target of 7% and outlines National Strategic Emerging Industries, including 7 strategic innovation driven new energy industries and 20 projects focused on innovation, energy saving and environment protection technology China State Council (2012). Measures of energy saving and emission reduction have been undertaken to promote green manufacturing (Li et al. 2010), including the employment of innovative technology, optimisation of the production process and use of energy efficient equipment (Cao et al., 2011). China has become the world's largest investor in renewable energy and in 2010, 50% of all solar panels and wind turbines worldwide were manufactured there (Pew, 2011). In addition, as the world's largest solar photovoltaic manufacturer, China's solar PV manufacturing capacity doubled between 2009 and 2010, is very much export oriented (see Figure 4) and now provides 53% of the global capacity (Varnas et al. 2012). These phenomenal changes are regarded by some as a science and technology revolution (Zhang and Zheng 2009). From compact fluorescent light bulbs and solar water heaters to PV cells and wind turbines, China has set a new clean energy pace for the rest of the globe to follow (Mastny 2010).

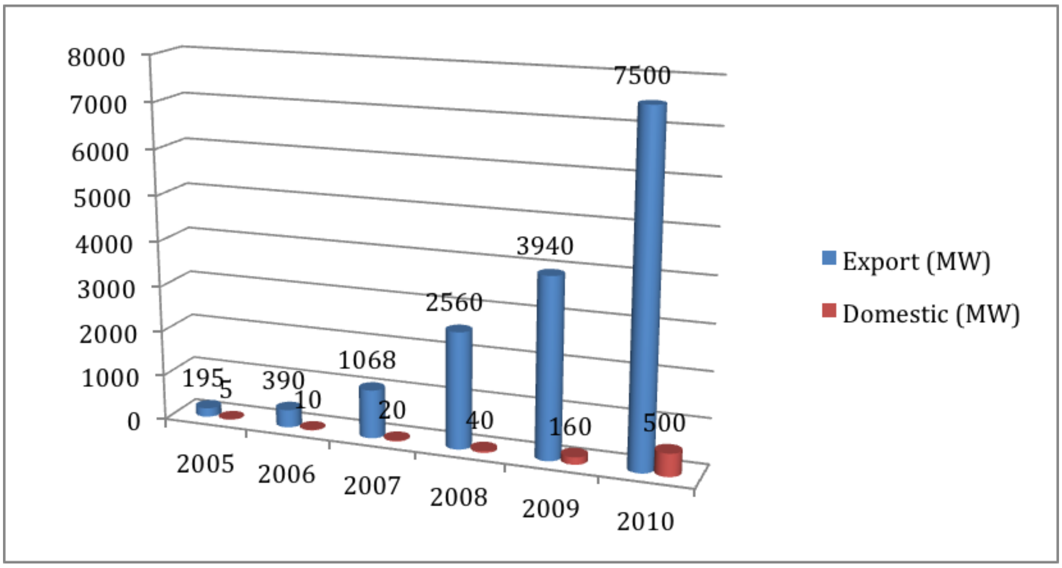

Figure 4. Chinese solar PV domestic installations and export
Source of data: Liu and Goldstein (2012)

The considerable achievements in the R&D sector in terms of investment, capacity building and outcomes combined with its large size are positioning the country extremely well within a global green system of innovation. China's NIS is easily characterised as based on coordinated logic and away from the free-market economy (Dodgson et al. 2011). With a sound government backing, this has managed to avoid market failures associated with innovation asymmetries and knowledge spillovers but has failed in avoiding the externalisations of costs, as demonstrated in the heavy pollution and other environmental problems it has created, as well as in preserving the commons, including the global commons. The NIS is now in a process of complex-evolutionary transformation aimed at avoiding structural system failures by developing sound physical and knowledge infrastructures, putting in place environmental regulations and developing favourable conditions for the implementation of clean technologies, developing green capabilities and supporting networks and interactions across organisations. This is a major move that supports a sustainability orientation of technology development.

There are numerous examples of green technology outcomes facilitated by China's NIS. Established in 2000, the Qingdao Kindman Green Tech Group is now conducting R&D activities through a network of government and academic research institutes located in Beijing, Suzhou, Shanghai and Tianjin in China and also with the United States and Germany (Kindman Green Tech 2012). Through these collaborations, its relatively small R&D team of around 20 people has been able to deliver numerous green innovations related to environmental technologies, new materials, such as reflective films, green outdoor products and green household appliances, such as solar cookers and solar cups. The company operates worldwide and its annual sales are more than US$100 million (TradeKey 2012). Another example is the Peako Biomass Energy Group comprising four companies operating in Hong Kong, Jiangxi and Guangdong. The Jiangxi company has a R&D centre, fabrication workshop and training facilities to test prototypes and develop patented innovations in using agricultural waste and residues, such as rice husk, saw dust, wood chips, nut shells and forest wastes for fuel and energy generation (Jiangxi Peako 2012; Jiangxi Peako Biomass Energy 2012). Further examples of green jobs generated in high-tech sectors are presented in Table 2.

Table 2 Generated average annual green jobs

	2006-2010	2011-2020
Solar photovoltaics (PV)		
– direct jobs	2,700	6,680
– indirect jobs	6,500	16,370
Wind power		
– direct jobs	40,000	34,000
High Speed Rail		
– direct jobs		230,000
– indirect jobs		400,000
Hybrid and electric vehicles		
– direct jobs		1,200,000

Source: Pan et al. (2011)

Table 3 compares several defining elements of NIS and GGSI and positions them within the Chinese context. While NIS encourages a steady supply of innovations (in some cases there may be a deliberate effort in picking winners), a GGSI is only concerned with technologies that can reduce the ecological footprint and transform the economy away from dependence on fossil fuels, GHG and waste generation as well as heavy use of natural resources. China's NIS encourages the positioning of the country as a leader in many green technologies, such as solar and wind energy. According to Liu and Goldstein (2012), "as the decade of the 2000s progressed, environmental goals played an increasing role alongside export promotion in motivating and shaping" Chinese policies in relation to renewable energy technologies.

What is particularly interesting is that the country is simultaneously inward and outward looking. Its current 12th Five-Year plan aims to achieve a more balanced and integrated harmonious society that allows for millions of people to be lifted out of poverty but also for resources to be used in a better way. The government strongly encourages international collaboration and the building of international networks and linkages in the area of education, research and business opportunities. Some warn that the challenge for China is to ensure that the quality of its R&D is not compromised due to the expansion of market activities (Wu forthcoming). However, fast commercialisation as the strength of its NIS perfectly fits the GGSI requirements.

Renewable energy and energy efficiency in China are attracting not only a lot of research and policy attention as a strong example of technological transformation under the imperatives of climate change (e.g. Mastny 2010; Pew 2011; Pan et al. 2011; Liu and Goldstein 2012) but are also becoming an area of investment and risk sharing supported by global financial institutions, such as the World Bank Group (IFC 2012). China's NIS is an example of a government-led effort to align the interests of society, including future generations, with those of industry and international community to achieve a transformative system change.

Table 3 Comparison between National Innovation System (NIS) and Global Green System of Innovation (GGSI)

	NIS	GGSI	China's NIS
Types of innovations	Encourages steady supply of innovations	Encourages specifically green innovations	Encourages China's leading position in many green innovations, such as PVs, wind energy and high-speed trains
Aim	Aims at providing a competitive edge	Aims to transform the world economy	Aims at achieving a more harmonious society
Values	Facilitates skill development and entrepreneurship	Seeks reduction in GHG, biodiversity conservation and natural resource preservation	Strives for improving people's quality of life
Focus	Human-centred	Planet-centred	Government-lead
Timeframe	It is essential to achieve and maintain high performance	It is essential to achieve urgent change in direction of performance	Specific clear goals are set within the 12th Five-Year Plan
Resource use	Efficiency and specialisation are essential	Interconnectivity and diversity of solutions are essential	Explores all opportunities for achieving high performance
Knowledge and information	Facilitates knowledge creation	Facilitates information sharing, knowledge exchange	Improves education, seeks and encourages global collaboration

		and collaborative efforts	and network opportunities
Coordination	National government and national legislations	International agreements	National government in response to global and domestic priorities

In its essence, China's NIS is very much attuned with a GGSI. The country is inevitably and increasingly becoming not only an integrated but substantial part of the global system of knowledge creation, diffusion and use (OECD 2008). Its policy shifts towards sustainability are facilitating a decarbonising and environmentally friendly economy. Hence, China's NIS is already supporting sustainability oriented innovations and is ready to transition towards a global green system of innovation (GGSI). However as GGSI is only in its infancy, there are only a few examples as this can work. The Clean Development Mechanism (CDM) is therefore used to analyse China's transformation towards a GGSI.

The country's political and economic stability has attracted the lion's share and growing numbers of CDM projects (see Figure 5a and 5b)[7], namely 51.3% of the projects (UNFCCC 2012a) and 64.5% of the certified emission reductions of the total host parties (UNFCCC 2012b) as of November 2012. As an innovative mechanism, CDM plays an important role connecting developed and developing countries through technology diffusion to reduce GHG emissions (van Putten 2009). Jia et al. (2012) show that implemented CDM projects help China reduce its emission intensities of carbon dioxide, sulphur dioxide and industrial dust. Thus CDM is an important factor for mitigating and adapting to climate change as well as in stimulating scientific and technological progress (Ye and Jian 2011).

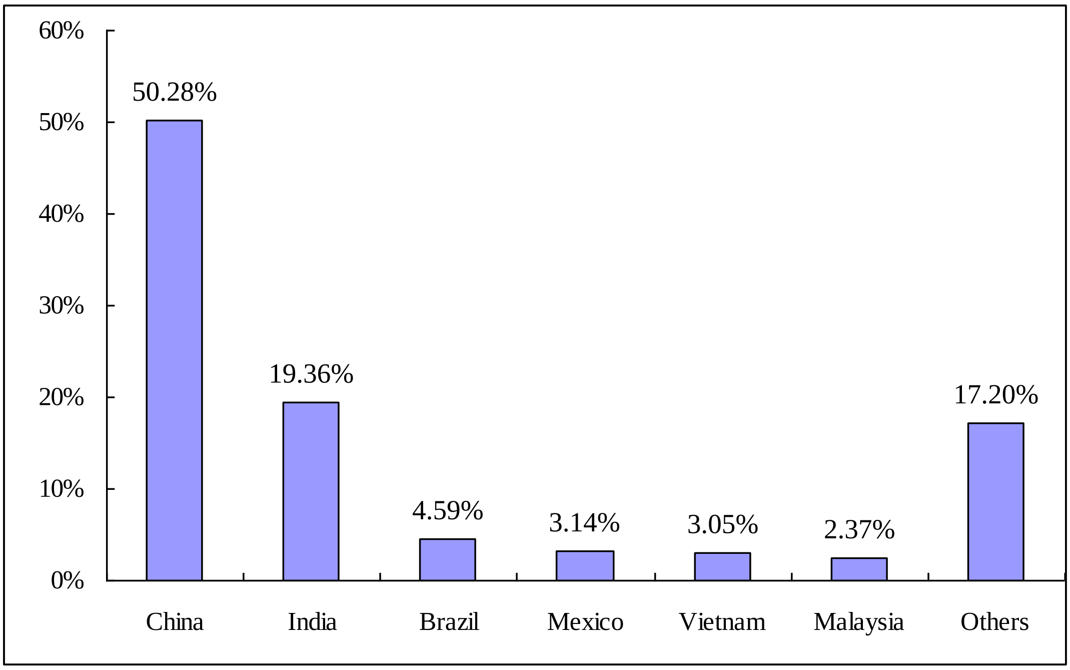

Figure 5a. Registered CDM projects by host country
Source of data: http://cdm.ccchina.gov.cn/web/NewsInfo.asp?NewsId=6022

[7] http://cdm.unfccc.int/

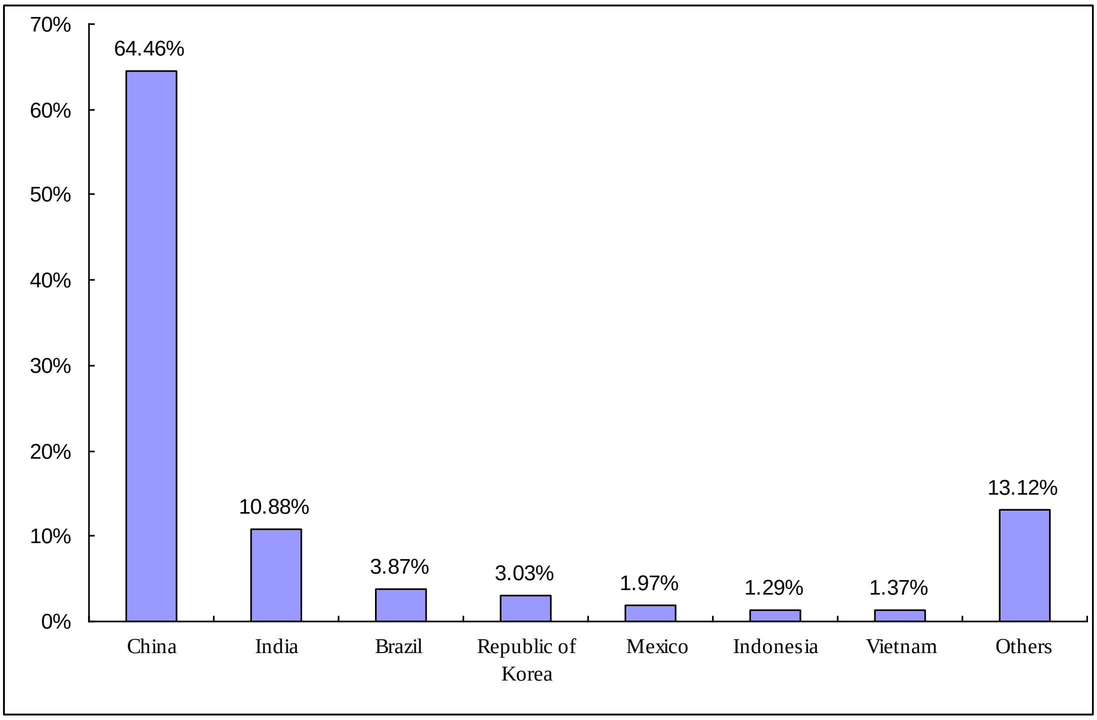

Figure 5b. Registered CERs by host country
Source of data: http://cdm.ccchina.gov.cn/web/NewsInfo.asp?NewsId=6022

What is of interest from a GGSI perspective however is how the clean development mechanism assists in avoiding transformational system failures.

(1) Demand articulation – CDM has been a very powerful way to articulate the global demand for clean technologies that allow developing countries to reduce their fossil fuel dependency and has resulted in clustering of green technologies stimulating further spillovers and diffusion through China's significant investment in renewable energy, including photovoltaic and wind energy. The global cooperation was based on shared understanding of what are the values between any new technologies;

(2) Directionality – education and technology, both within China and in the developed countries which provide the technologies, have played an essential role in allowing the successful operation of CDM. In comparison with other emerging economies China was better placed to avoid any failure and to keep abreast with the urgency and complexity of the projects. The long-term visioning and positioning of the country in this market was part of the political decision making despite any uncertainties associated with the post-Kyoto future of the mechanism. The international standards and CER accounting although somewhat cumbersome also allows for directional failures to be avoided;

(3) Policy coordination – the policy coordination is well achieved at a national and regional level within China as well as at an international level through the Designated Operational Entity and the Designated National Authority (Jia et al. 2012). China's success is building on providing good support to potential investors through access to innovative businesses and to capital as well as with having the required national infrastructure and supportive networks. The rigidity

of the rules of the mechanism however do not allow for adaptive governance and in some cases this was manifested with delays, multiple layers of bureaucracy and overall complexity of governance;

(4) Reflexivity – even with some commitment for the post-Kyoto future of CDM, in many ways it is an example of a transformative system failure. There is a lot of uncertainty as to what the new CDM will look like. For example, it is not clear how CDM links and interacts with other national emission trading schemes. Despite some presence and transparency of information about implemented projects, this is quite segmented and does not allow for proper information flow and innovation exchanges. Schmid (2012) also points out that the detail of the transferred technology through the CDM should be clearer, such as where the parts of the technology are produced; whether it is patented and how the assessment of technology transfer is conducted.

Overall, CDM is a good example of a global green innovation mechanism but there is need for further improvements in its efficiency and governance. CDM projects in a country can act as a significant stimulus to low-carbon development (Huang and Barker 2012). China is willing to contribute to the global green system of innovation through timely formulating relevant policies on climate change and successfully hosting CDM projects activities.

Conclusion

As one of the most R&D intensive developing countries, China has been catching up with developed countries for decades in economic development. Consequently it has become an important global player with many of its products incorporating green energy innovations (Wu 2011). According to Pan et al. (2011), the Chinese green technology industries are globally competitive because of preferential government policies and further investment in R&D will strengthen their position. The country's economy is also transforming balancing intellectual and capital growth with environmental considerations. China is committed to building energy efficient and environmentally friendly society which can be achieved through upgrading its industrial structure, inspiring and protecting innovation and transformation towards a global green system of innovation (Ye and Jian 2011).

The policy analysis through the lenses of innovation systems shows that there is need for national innovation systems to be attuned towards sustainable technologies within a framework of a global green system of innovation. The success of this transformation for China will depend not only on government actions but also on society adopting "the concept and practice of green living" (Pan et al. 2011: 27).

China is committed to cooperate with the international community through R&D investment and innovation for tackling the challenges of climate change and avoid transformational system failures. It is well positioned for playing a major role in the global green system of innovation. The innovation system concept is ultimately about people – "the knowledge, technology, infrastructure and cultures they have created or adopted, who they work with, and what new ideas they are experimenting with" (DIISR 2011: iii). People's voices are most loudly heard when they are directly affected by pollution, droughts, floods or other climate related calamities, but they also have an active role to play in gearing the world towards a green economy. A global green system of innovation will not put a stop to competitiveness and/or collaboration. It is however a realignment of priorities and making a change on a new path of innovation activities. Most importantly, for the global green innovation system to become a reality, every nation and every researcher has to clearly articulate the need for transformation, direct its activities in coordination with other players and be able to reflect on what are the best ways to demonstrate that we all share the same concerns and love for the planet Earth.

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