Institutional Drivers for Deciding on Sustainable Technologies in China

Von der Fakultät für Gesellschaftswissenschaften der Universität Duisburg-Essen
zur Erlangung des akademischen Grades

Dr. phil.

genehmigte Dissertation

von

Aristova, Julia

aus

Komsomolsk am Amur

1. Gutachter: Prof. Dr. Christiansen, Flemming
2. Gutachter: Prof. Dr. Eaton, Sarah

Tag der Disputation: 22. März 2023

Table of Contents

I. Introduction

1.1. Geothermal Heat Pumps: Towards Understanding Theories of Sustainability

Led by China's National 11th Five-Year Plan (2006 - 2011), which calls for energy efficiency, reduction of carbon emissions and development of renewable energy sources, Chinese local governments hit the road towards a low carbon future. In 2007, Shenyang City invested 10 billion yuan in geothermal heat pump (GHP) projects - an energy-efficient technology for space heating and cooling based on renewable energy - surpassing the former leader in GHP application Beijing. Shenyang started from almost zero, rising to 15 million m^2 of GHP heated area in 2007 and reaching nearly 60 million m^2 by 2010 and 330 million in 2014 (K. Zheng, Mo, and Chen 2015). Such sharp growth with no preexisting infrastructure appears administratively and ideologically contradictory. It raises questions about the logic behind the decision-making and sustainability of technological innovation.

In the Chinese political economy context, the Shenyang government's decision to invest in GHP appears inconsistent. GHP policy is associated with high technological, investment and reputational risks, which local governments in China tend to avoid due to intense administrative failure costs. At the installation stage in Shenyang, there was no guarantee that the technology performs well in the long-term perspective. It was high-rise buildings or large areas that were equipped with GHP, while the previous worldwide experience with GHP use was limited to private homes of relatively small size. Moreover, the GHP policy brought no direct economic benefits to the city bureaucrats that initiated the pilot project. The GHP return on investment period takes a minimum of six years, whereas the city mayor's office term is limited to four years with an inevitable redisposition after the end of the term. Thus, the GHP policy brought no direct economic benefits to the local government. The logic behind policy decision-making poses a puzzle.

Besides, Shenyang’s case challenges the idea of sustainability. Sustainability is by definition oriented towards environmentally, socially, and economically desirable goals, i.e. sustainable outcomes. Achieving these goals is commonly associated with technological innovation. Yet, radical technological innovation is intrinsically uncertain and prone to failure. Is radical innovation in the name of sustainability justifiable despite high failure risks and potentially negative environmental consequences? What makes an innovation and related policies sustainable - the intention or the outcome? The radicality of the GHP pilot project in Shenyang points to the ideological stance that sustainability effort predominates sustainable outcomes.

Existing literature on GHP implementation in Shenyang fails to look into the rationale behind the policy or to examine it as an individual case of China’s general approach to sustainability. The majority of the related academic papers address technical aspects of the GHP. Largely published between 2011-2016, that is in a post-installation period, those works analyse and evaluate technology performance. The keen interest of engineers is additional evidence of the GHP project's experimental novelty. The few socio-technical papers rely on secondary data to calculate economic profitability and focus on policy recommendations.

Solving the administrative and ideological puzzles of the sharp GHP growth in Shenyang requires a critical examination of the interconnection between sustainability, technological innovation and China’s planning processes, corroborated by firsthand evidence from Shenyang. A thorough examination of how sustainability is defined aids in understanding development goals and expectations. Analysis of the role of technological innovation in the sustainability processes can clarify if the implementation of a high-risk radical innovation is necessary for achieving sustainability and if it can be considered sustainable just by its potential. China's socioeconomic development is driven by planning. Therefore, further examination of how sustainability is interpreted and integrated into China's planning processes sheds light on the internal dynamics and logic behind decision-making related to sustainable innovation. Shenyang's pilot project represents an opportunity to observe China's political decision-making process in all its institutional complexity. It provides readers with practical knowledge about the sustainability processes in China.

The discussion starts with the definition of sustainability as a general background and ideological guide to a socio-technical transformation aimed at finding a balance between economic growth and climate action.

1.1.1. Definition of Sustainability

Sustainability is, in a certain sense, a superstar concept of modern times. Brought to the fore by the Club of Rome in the 1960s, it was, with the Brundtland Report in the late 1980s, made the central point on the UN agenda and has remained so ever since (Du Pisani 2006). Sustainability was the organising factor for Agenda 21 in the 1990s leading up to the Millennium Goals and the relatively recent Paris Agreement on Climate Change in 2016 (Falkner 2016; Lafferty and Eckerberg 2013; Sachs 2012). Despite initial and ongoing critique and resistance, it is now known and accepted as desirable by most across the industry, transport, agriculture, energy, tourism, education sector, etc. Sustainability has been hailed as *a new philosophy* (Basiago 1995) and *a shared vision of the future* (White 2013).

The conceptual elusiveness of sustainability has given rise to criticism yet guaranteed its endurance (Johnston et al. 2007; Solow R 1993). The Brundtland Commission in 1987 defined sustainable development as “development which meets the needs of the present, without compromising the ability of future generations to meet their own needs,” yet left open such questions as which systems are to be sustained, for how long, and how their sustainability is to be assessed (Costanza and Patten 1995), and allowed for a great sector-specific, spatial and temporal variation in interpretation and approaches (Seghezzo 2009).

Thus, sustainability is understood differently across disciplines. Biologists understand *sustainability* as a functional interaction between human and natural systems (Kawall 2004). Sociologists speak of the *sustainability* of individuals and communities concerning environmental equity (Longo et al. 2021). Urban planners think of *sustainability* as the intersection between human systems, the built and natural environment, and livable urban space (Childers et al. 2014). Environmental ethicists understand *sustainability* as a part of the discourse on nature’s agency and human interference (Becker 2011; Biedenweg, Monroe, and Oxarart 2013; Shearman 1990). Economists see *sustainability* as an adjustment of the modern production system to the limits of the natural capital (Basiago 1995; Spangenberg 2005).

Despite these differences in interpretation, a set of general assumptions are embedded in the concept of sustainability (B. J. Brown et al. 1987; Caradonna 2016). First, sustainability treats human society, the economy and the natural environment as interconnected. This is commonly envisioned as a Venn diagram or concentric circles (Fig.1) (Caradonna 2016; Lozano 2008). In the Venn diagram, the overlap of the three circles of economy, environment and society indicates sustainability as the intersection of these three dimensions (Todorov and Marinova 2011).

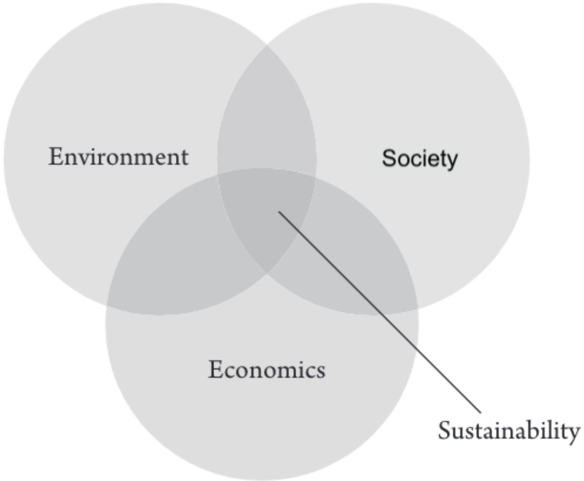

Figure 1.

The model of concentric circles, where the outer ring represents the environment, the middle one society, and the inner one economy, visualises an integrational perspective (Fig. 2) (Goodland 1995). Those circles represent environmental, social and economic sustainability, which are conceptually different. Environmental sustainability stresses scarcity. It applies that humanity must learn to live within the limitations of the biophysical environment (Obach, Dobkowski, and Wallimann 2003). Social sustainability envisions equitable, diverse communities characterised by connected systematic community participation, strong civil society, and good quality of life (Eizenberg and Jabareen 2017; McKenzie 2004). Economic sustainability suggests devolving on consumer interest rather than capital, and instead of focusing on money, it is supposed to embrace the other forms of capital - natural, social and human (Anand and Sen 2000).

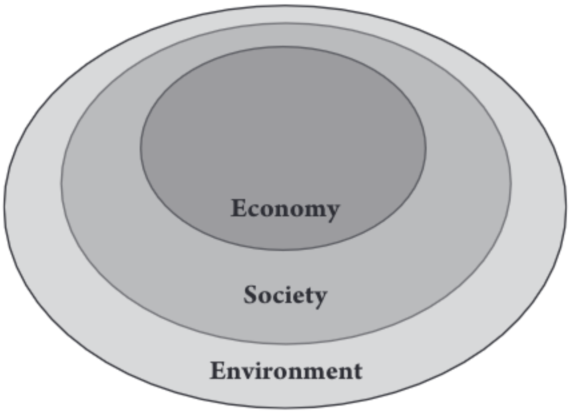

Figure 2.

The second underlying principle of sustainability implies that resources are scarce and limited. If a society does not respect ecological limits, it will face collapse (Moore 2017; Walker 1979). It demands control and improvement of the quality of the environment and ecosystems.

Third, a society's continued existence requires wise long-term planning (Gonzalez, Thompson, and Loreau 2017; Wheeler 2000). This, among others, includes transforming energy production and use, maintaining the stock of biological resources and the productivity of agricultural systems. Finally, it is believed that this can only be achieved through localisation and decentralisation (Guha and Chakrabarti 2019). It emphasises small-scale and self-reliance (Caradonna 2016).

Furthermore, participation and agency are central to the sustainability transition (Farla et al. 2012; L. B. Fischer and Newig 2016). The success of sustainability as a concept lies in its ability to engage in dialogue, even with those who might lack imagination, interest or moral standards to care for the long-term future (Ratner 2004). While from a broad view, sustainability claims that the survival of humankind is at stake, it also clearly addresses the survival of the cultural foundations of the social order of modern societies (Soini and Dessein 2016). Effective engagement may, therefore, not just be motivated by the care for future generations but rather by fear of uncontrollable changes in everyday life. In this sense, modern society attempts to learn to overcome the limits of the cultural model of early modernity (Eder 1996).

Besides, sustainability urges for and offers control, which despite privacy concerns, appeals to and pleases modern people (Lyon 2004). Surveillance, i.e. control over information and social dimensions, is, according to Giddens (1990), an institutionalised aspect of modernity and is thus associated with rationality, predictability and safety. Solutions offered within the sustainability framework call for control over the economy scale, distribution and allocation of resources, greenhouse gas emissions, population growth, environmental costs, etc. (Goodland 1995; Pezzey 1992).

Sustainability is widely perceived as a desirable social goal (Costanza and Patten 1995). Despite social desirability, realising sustainability is complex and challenging (Tonelli, Evans, and Taticchi 2013). First, there is an issue with the assessment needed to direct and, if necessary, correct the process, for sustainability can only be assessed after the fact (Costanza and Patten 1995). A system can only be known to be sustainable after there has been time to observe if the prediction made regarding the benefits of transformation holds (Bond, Morrison-Saunders, and Pope 2012; Singh et al. 2012). The second challenge is the incredible levels of uncertainty in terms of outcomes and timescale (S. R. Dovers and Handmer 1992). The process is driven by expectations rather than clear-cut definitions and goals.

Third, sustainability requires profound institutional change, new types of citizenship and governance (Orr 2002). Sustainability may occur only when formal and informal institutions, systems and relationships actively support its realisation (McKenzie, 2004). As Jamieson (1998) points out, moral reorientation becomes pivotal. This inevitably meets resistance from embedded institutions and systems.

Fourth, promoting sustainability raises moral and ethical issues (Bandura 2007; Man Li et al. 2021). It requires managing the sensitive field of population control and quality of life (Johnston et al. 2007). In the case of technology transfer as an environmental solution, it may cause growing dependence and exploitation of poorer nations (Swilling and Annecke 2012).

Finally, another severe limitation inherent in the sustainability discourse is that, like any other concept, it highlights some concerns while masking others (J. D. Marshall and Toffel 2005). Sustainability is primarily an economistic and anthropocentric notion (Jamieson, 1998). It has the potential to sustain an unjust *status quo* by shifting the economic and environmental burden of the ecological problems to less advantaged communities. Besides, insisting on globally shared common interests blurs existing conflicts of interest at national and international levels (Marcuse 1988). However, even among unequal nations, unprecedented global cooperation is essential for effectively realising sustainability (Pezzey 1992).

After more than forty years have elapsed since the concept of sustainability entered the political and social realms, the question is not whether sustainability is right, wrong or vague. It is more about making it work despite its challenges.

1.1.2. Achieving Sustainability

Like democracy and justice, sustainability is a moral ideal, desirable yet challenging due to its universality (O'Riordan 2013). Achieving sustainability is commonly referred to as a *transition to sustainability*, which suggests gradual system transformation. The system is the whole complexity of human material and non-material socio-economic reality. This complexity is partially reflected in the following challenging processes and conditions and creates the overall context for the transition to sustainability (Kates and Parris 2003).

First, peace and security are needed to realise sustainability (Sharifi et al. 2021). Warfare, crime, corruption, social unrest and conflict are direct threats to it. They cause deaths, destruction of infrastructure, economic decline, overuse of resources, neglect of environmental issues, etc. Although formal warfare has decreased since the 1990s, the unrest caused by violence and conflict persists (Marc 2016). The number of refugees has escalated from 19,5 million in 2014 to 26,3 million in 2020. The forcibly displaced population doubled in 5 years and accounted for 80 million in 2020 (UNHCR 2020). This does not affect all regions in the same way, the Global South being more unstable and therefore economically, socially and environmentally more vulnerable (Ibid.)

Second, trends in population and urbanisation are central to sustainability (A. A. Bartlett 1994; Jarzebski et al. 2021). Sustainability's primary goal is to meet the needs of all people. Therefore, the size and location of populations are critical. Population growth, a primary concern in the early stages of environmental research, has slowed down due to lower fertility rates. However, all projected demographic shift continues to occur in developing countries (Alkaher and Carmi 2019; McNabb 2019). The level of urbanisation continues to increase, adding to the challenges of urban supply of water, food, energy, housing, health services, and waste management. According to the United Nations, sixty-eight per cent of the world population is set to live in urban areas by 2050 (Beermann 2014). Currently growing the fastest in China, India and Nigeria, cities will have to accommodate 2.5 billion more people (Avis 2019).

Third, the population's welfare is an ultimate sustainability goal (Grum and Kobal Grum 2020; Long and Ji 2019). Therefore, trends in affluence, poverty, well-being and health are essential. The well-being of the world population measured by per capita GDP has grown 8-fold since 1820 (Bossel 1999), continues to improve, and the number of people living below the poverty line has decreased (Lakner et al. 2022). However, the rich and poor gap grows (Cole 2018). Income inequality increases between and within countries (Zucman 2019). Sustainability calls for harmonising the rich's and poor's needs (Caradonna 2016).

Fourth, although growing affluence is directly connected to increasing production and consumption, ever-speeding production volumes and obsessive consumption pose a terminal threat to the environment (Dauvergne 2010). So-called *social metabolism*, the amount of energy and matter used, has to decrease markedly to meet sustainability expectations (Haberl et al. 2011). Although, an unexpected and sharp turn in consumer behaviour happened due to the Covid19 pandemic (Constantin, Saxon, and Yu 2020). Consequently, consumers worldwide spend less on everything except grocery items. Nonetheless, the most populous China and India kept their spending habits.

Fifth, sustainability as a concern for humankind and the world goes hand in hand with globalisation (Borghesi and Vercelli 2003), changes in governance (Rosenau 2017), institutions (Connor and Dovers 2004) and values (Leiserowitz, Kates, and Parris 2006; Millar et al. 2012) accompanying it. Globalisation deepens interconnectedness, clearly reflected in enormous cross-border flows of people, goods and information (Hobden 2021). While promoting globally shared values, specifically post-materialist values (Tibbs 2011) beneficial for sustainability, globalisation also facilitates disadvantageous outcomes like rapid transmission of infectious diseases and environmental harm (Huynen, Martens, and Hilderink 2005; Zimmermann et al.

2020). Forms of governance, furthermore, change due to the power shift from the national level upwards to transnational organisations and institutions and downwards to the local level (Boas, Biermann, and Kanie 2016).

Last but not least, global environmental change has been underway for the past 10,000 years, but most of that change has occurred over the previous half-century (Turner et al. 1997). Rapid environmental changes put temporal pressure on the transition to sustainability (Bornemann and Strassheim 2019). Besides, the consequences of climate change are experienced more harshly by poorer nations regarding water and air pollution (Ayala-Orozco et al. 2018). These issues are transboundary and require collaborative solutions (Skoulikaris and Zafirakou 2019).

All the above trends give rise to challenges for the transition to sustainability, which requires solutions beyond conventional development (Raskin et al. 1996). To overcome the complexity of factors imposed on achieving sustainability, O'Riordan and Voisey (1998) conceptualise it as three domains characterised by interlocking and interconnected relationships, namely the technology and economy domain, legal and institutional domain, and cultural and civil society domain.

The technology and economy domain is a primary driver (Ferreira, Fernandes, and Ferreira 2020; Goerner, Lietaer, and Ulanowicz 2009). It aims to shift human activity to eco-efficiency by creating wealth for fewer materials and energy resources, moving past neo-classical economies of growth obsession, incorporating environmental costs through green accounting, and introducing sustainable technological innovations.

The transformation of economies meets strong resistance from embedded interests (Pardo Del Val and Martínez Fuentes 2003). Achieving sustainability means overcoming this resistance. The tendency of systems to defeat the policies designed to improve them is known as *policy resistance* (Ford, Ford, and D'Amelio 2008; Oreg 2003). The system dynamics approach suggests overcoming policy resistance by mapping out the system's structure responsible for policy resistance to identify high leverage points that support sustainability transitions (de Gooyert et al. 2016).

Technology plays an essential role in fulfilling societal functions, including transportation, communication, housing and feeding, in a sustainable way (Callon 2012). However, artefacts by themselves have no power (Angus 1980). Sustainable technologies may fulfil their functions only supported by human agency and social institutions (Elzen, Geels, and Green 2004). There is a need for the political will to explore and foster socio-technical change (Wilkinson, Hill, and Gollan 2001).

The legal and institutional domain reflects inclusion in strategic planning for natural resources, regulations and agreements, global-local linkages and vision-building (Leon-Soriano, Muñoz-Torres, and Chalmeta-Rosaleñ 2010; Werbach 2011). Policies and politics are crucial elements of sustainability transitions (Dernbach 2011). Transition pathways unfold due to the continuous struggles of actors over policy goals and instruments (Lindberg, Markard, and Andersen 2019). In its very essence, sustainability is a process of learning by doing (Elzen, Geels, and Green 2004). In transition management, it is described as a cyclic process of vision-building that includes taking action, evaluating the response to this and subsequently taking new action. Enabling social and institutional learning is critical for sustainability (H. Johnson and Wilson 1999; Steele 2011).

The cultural and civil society domain covers the ethical issues of intrinsic rights for critical natural recourses, civil rights for vulnerable populations, empowerment for enterprise and direct democracy (Ward 2008). It would require internalising sustainability values and reconsidering human-nature relations (Ives et al. 2017; Rees 2010). There is a need for public support without getting politicised (Abbott 2012). The sustainability goals should not be associated with a specific political party. Otherwise, it jeopardises the transition process (Saha 2009).

Considering sustainability's prerequisites and characteristics, the Chinese political economy is a suitable environment for exploring and achieving sustainability, not without some challenges, however. Sustainability requires agency, political stability, long-term planning, decentralisation, learning by doing and control. These are all characteristics of the current political system in China. Besides, the CCP, as an integral part of the governance system, has a monopoly over ideology and the construction and reconstruction of values. China has had a positive experience in institutional transformation, such as shifting to a market economy.

However, the economic restructuring for sustainability demands unprecedented efforts. Market reforms followed a catching-up trajectory. A new economic growth model has no references. It also meets resistance from the local governments unwilling or unable to internalise cost to nature. Nevertheless, China has managed to overcome challenges and is transitioning toward sustainability. It will be deeper analysed in Chapter III.

1.1.3. Sustainability and Technological Innovation

Transition to sustainability means changes, in other words, innovation. Typically any system, whether human psyche, organisation or institution, would resist innovation due to internal determination to maintain its structural integrity and avoid extinction (Watson 1971).

However, what prolongs a system's existence and functioning is the adaptive capacity that allows it to change with the conditions of the external environment (Engle 2011). The negative examples are easy to observe from the past experiences in the natural realm distinction of species since the Ice Age or, in the socio-political realm, the collapse of the Soviet Union due to its deficient policies. The Chinese Communist Party is an impressive example of organisational adaptability that navigates through internal and external challenges (Heilmann and Perry 2020).

In the case of sustainability, the existing socio-economic regime feels threatened and resists change (Smink, Hekkert, and Negro 2015). The regime is represented by institutions like capitalism or national bureaucratic mechanisms and by personal preferences and lifestyles. It means that resistance to innovation is not localised but rather scattered across levels. The positive side of regime resistance is that its locus is identifiable and predictable, and the negative one is that it is exceptionally sturdy (Geels 2014).

Nonetheless, innovation for sustainability continues unabated, so entrepreneurs of human or institutional agencies continue to support innovation (Hargreaves, Longhurst, and Seyfang 2013). Identifying them, learning about their motivation, and multiplying their impact is critical for achieving sustainability.

Despite the complexity of the socio-economic system that has to transform to continue its existence, the variety of sustainability challenges, and the diversity of domains that needs to become sustainable, there is only a limited number of innovation types identified within the framework of innovation studies. This could be a good start to approach the "what to do" question.

Innovations may have different forms and procedures (Kemp 2010). First are product and service innovations (Clausen and Fichter 2019). Second, process innovations modify how processes are run (Baptista 1999). Third, organisational innovation is related to innovative ways of organising work, management and finance flow, for instance, business model innovation (Laforet 2011). Fourth, presentational innovation is found in design and marketing (Gupta et al. 2016). Fifth is system innovation, which is new technology systems (Elzen, Geels, and Green 2004). Any of those innovations can be sustainable, but only a sum of them can lead to sustainability (Fiksel 2006).

It is remarkable, albeit logical, that initially, starting with Marx, great hopes were associated with technological innovation capable of fixing all environmental issues. Even the first department of the American Sociological Association to research the environment was Environment and Technology section. In the trinity of economy, society and environment, technology is an institution, a tool, for shifting the nexus of internalities and externalities (van den Bergh 2010).

Profit is based on externalising costs. The production process costs resources and earns resources. The conventional capitalist firm pays for raw materials and labour and sells the products on the market. The "capitalist" pays for the "reproduction" of the work in the forms of the worker as a person (food, housing, remuneration, health insurance, pension contribution) but not for the "production" of future workers (creches, schools, training) and the running of broader sets of social and cultural services: he externalises these costs to society. He also externalises the cost of pollution and using natural resources to society and/or the environment. The Chinese danwei internalised many social costs of the workers. However, the planning system externalised the cost of industrial development and fed the industrial workforce to agriculture/the people's communes.

The main problem for industrialised societies in the classical forms is that they externalise the cost of environmental resources to nature. They, therefore, destroy resources and make it harder for future generations to use environmental resources. Rich countries and large global corporations externalise costs to society and nature in the global south. The hukou in China and internationally, the holding of national passports and residence permits are examples of externalising social costs through institutions of entitlement. Integrating technology into a socio-economic system is a tool for internalising costs to the environment for building socially proper sustainable systems.

However, technologies aimed at easing environmental pressures failed to meet expectations. First, any technology, regardless of its benefits, is powerless without agents' support. Second, Kemp (2010) states that no sustainable technologies exist because any technology coproduces environmentally harmful products. Therefore, only wise long-term decision-making and compound action of governments, communities, professionals and a set of institutional drivers can make technology work for sustainability.

1.1.4. Geothermal Heat Pumps

Space heating is essential in cold and severely cold areas and often becomes the primary source of air pollution (Xiao et al. 2015). In China, coal is the most common fuel for heating due to its affordability. Coal-based boilers lead to heavy air pollution and adverse health impact (J. Zhang and Smith 2007). Thus, heating costs are externalised by the government to the environment and health of the population. Sustainable heating technology reduces emissions, internalising costs to nature. The geothermal heat pump is one of that technologies.

The trend of the geothermal heat pump (GHP) application is a good demonstration of the sustainability efforts: it has environmental and economic benefits, is recognised by specialists, and shows implementation growth if supported by policies, but without broad support, it fades away.

Geothermal heat pumps experienced their global installation peak around the 2010s. It is still called promising and has been technically improved since. However, the growth is relatively slow, there is a decline in project numbers, and the technology is still marginal. It is also reflected in the number of academic publications on GHP. There has been a decline in papers focusing on socio-economic aspects of the technology since 2015, with only a few technical researches on GHP published recently. It is, to some extent, a sign of technology leaving the socio-political agenda. Like sustainability in general, GHP has potential, but it requires institutional settings and agencies to realise that potential.

A geothermal heat pump (also known as a ground source heat pump) is an energy-efficient technology for space heating and cooling based on renewable energy. The concept of heat pumps has existed since the 19th century. Commercial applications began in the 1950s with water-source heat pumps (Self, Reddy, and Rosen 2013). It can serve new constructions or retrofits of existing buildings. The system operates on electricity. It directly heats the space or warms up the water for central heating. Usually, GHPs have warranties of 20–25 years, but there are systems installed over 30 years ago which are still in operation (Huttrer 1997).

GHP relies on ground sources for heat extraction, including soil, groundwater and surface water (Yang et al. 2010). GHPs exploit the relatively constant temperature in the ground, which is warmer than the ambient air during winter and cooler in summer. If an excessive temperature difference exists, heat pump systems fail to operate. GHP's great advantage is that it can be used for heat extraction anywhere where soil and the ground temperature is between 5 °C and 30 °C, which are common worldwide.

GHP system consists of three main parts: geothermal heat pump, earth connection and interior heat distribution system (Bi et al. 2009). Earth connection (or ground loop heat exchanger) enables the extraction of low-temperature thermal energy from the ground via a heat exchanger loop for use in the heat pump unit. It comprises the construction of pipes that transfer fluid between the heat pump unit and the ground. The working fluid within the pipes is usually a refrigerant. Heat pumps transport heat to the building and modifies the temperature to that required for practical use. They operate on the vapour-compression refrigeration cycle. The internal heat distribution system moves heat throughout the space.

GHP is up to six times more efficient than traditional heating technologies (Cui et al. 2019), with the value defined by the earth connection setups, system sizes, earth characteristics, installation depths, local climate and other characteristics (Self et al. 2013). The source of electricity production determines the system’s carbon footprint.

GHP is being improved by adaptation to greener electricity sources like gas (Sáez Blázquez et al. 2019) and photovoltaic (Kavian et al. 2020); development of the thermal response test (Sanner et al. 2003), which allows assessing the thermal characteristics of the local underground before instalment; implementing grouting material with an enhanced thermal conductivity as working fluid (Sanner et al. 2003).

Specialists in GHP technology see the benefits of implementing the technology for the environment, economy and customers (Cui et al. 2019; Huttrer 1997). They include lower operating costs, no outdoor units, longer service life and higher comfort to customers, lower environmental imprint, and creation of jobs. However, obstacles to GHP promotion remain similar from the 90s till now: high initial investment costs (due to drilling and trenching) compared to other heating options, lack of policymaker and consumer knowledge and trust in GHP, and lack of policy support (P. J. Hughes 2008; Ramos-Escudero et al. 2021; Self, Reddy, and Rosen 2013).

1.1.5. Hypothesis

Led by China's National 11th Five-Year Plan (2006-2011), which calls for energy efficiency, reduction of carbon emissions and development of renewable energy sources, Chinese local governments hit the road towards a low carbon future. In 2007, Shenyang City invested 10 billion yuan in geothermal heat pump (GHP) projects, surpassing the former leader in GHP application Beijing.

Beijing has been implementing GHP since the early 2000s at a steady pace, with annual growth of about 2 million m^2 of GHP application area — reaching 17 million m^2 in 2012. Shenyang started from almost zero, rising to 15 million m^2 in 2007 and reaching nearly 60 million m^2 by

2010 and 330 million in 2014 (K. Zheng, Mo, and Chen 2015). Such sharp growth with no preexisting infrastructure raises the question of innovation sustainability and the logic behind decision-making[1].

This thesis argues that according to the internal logic of China's political economy, the geothermal heat pump pilot project in Shenyang between 2006-2016 was a necessary and sufficient contribution to the city's sustainable development. This has three interlinked reasons:

(1) The pilot project was necessary and sufficient because GHP implementation in Shenyang reshaped the city's image, impacted city livability and, most importantly, legitimised the CCP rule at the local and national levels. Whether the criteria *necessary and sufficient* are internal to the process or relatively objective is to be explored.

(2) Central CCP leaders, aware of the environmental issues since the 1970s, were able to counter local government's resistance because they imposed planning targets that forced local governments to realise the necessity and inevitability of dealing with environmental issues and to integrate environmental targets sufficient to be approved by the central government.

(3) Sustainable innovation reaffirmed CCP rule because the promotion of sustainable economic and social development (planning) is considered integral to the rationale of the ruling party itself.

The thesis is structured as follows. Chapter I discusses sustainability and its integration into China's political economy, the role of technological innovation in the transition towards

[1] The paper published by Geng et al. in 2013 specifically addresses the GHP initiative in Shenyang (Geng et al. 2013). It takes, however, different approach by reporting on Shenyang's GHP-related policy documents and providing policy recommendations to the local government.

sustainability, social acceptance and environmental impact in the decision-making process. Chapter II explains the research methodology. Chapter III is dedicated to the case study, analyses national and local institutional framework, and introduces specific GHP projects and their outcomes. Chapter IV summarises the findings.

1.2 Sustainability and Chinese Planning: Integration in China's Socialist Political Economy

1.2.1. Role of Planning in the Chinese Political Economy

Despite China's drastic shift from a planned to a market economy, central planning still plays a pivotal role in the Chinese political economy. Since the People's Republic's establishment in 1949 and till the beginning of the Reforms of Opening in 1978, China maintained a planned economy. This type of economic system was borrowed from the Soviet Union. In a planned, or command, economy, the state controls economic activity by setting production goals, allocating recourses and managing prices (Mcmillan and Naughton 1992). Unlike in market economies, where market forces like a business offer and citizens' demand organise economic activity, often driven by the persuasion of personal or organisational profit, a planned economy is driven by social and national interests and ultimately aims at social equality. The state controls the economy through long-term and short-term policy planning and setting detailed objectives. Implementation, evaluation and control over the realisation of plans rely on central and local bureaucratic systems.

Given that the state broadly owns any resource, control over production and prices is manageable under a planned economy. However, disconnection from consumers' demand, lack of competition, and artificial costs make the economic system a cumbersome and ineffective structure that fails to produce conditions for increasing the social wealth it initially aims at. The socioeconomic crisis in China by the end of the 1970s jeopardised the very existence of the Communist Party (Yongnian Zheng 2009).

In 1978 the Chinese government initiated a historic transition to a market economy. It, first of all, meant decentralisation of economic policymaking and, as the title of a highly influential work by Barry Naughton suggests, “growing out of plan” (Naughton 2014). The introduction of the free market started with agricultural production and gradually spread over other economic sectors in the following decade. Although the economic transition was prompted by abandoning some core planning features like the direct allocation of resources or state control over prices, central planning remained at the heart of China’s development (Y. Liu and Zhou 2021).

The development planning has been transformed along with the economic reforms to guarantee the central government and the CCP power to excise overall state control (Heilmann and Melton 2013). In the new era, central planning and fiscal and monetary policy became vital control mechanisms.

The current planning system took shape through two significant shifts in the early 90s and 2000s (Zhao 2015). The first reorientation and reorganisation of the planning system were launched by the Central Committee in 1993, marking the abolishment of Soviet-style planning. The system has been completely modified, or rather reinvented, in terms of function, content, process, and methods (Heilmann and Melton 2013). The primary part of planning became coordination and balancing economic activity. Previously planning used to substitute markets; since 1993 market had to be taken as a foundation by planners. Now Chinese administrators had to design with and for markets, taking into account major domestic and global trends and incorporating them into governmental programs. Instead of setting innumerable targets, planners had to focus on macroeconomic strategies and refrain from issuing orders to departments and local governments. Same year combining planning with experimentation was officially proposed. On the one hand, central planning assures stable policy objectives; on the other, it allows for flexibility for local governments to adapt and innovate (Kanbur and Zhang 2005).

The second wave of changes in the planning system came in 2006 with the 11th Five-Year Plan (L. Liu, Zhang, and Bi 2012). Against the backdrop of the fast developing economy and China becoming a global economic leader, there was a need to reinforce party influence over administrative action, foremost in environmental protection and land management (Tian, 2010). First, since 2003 five-year plans have been referred to in Chinese as 规划 *guihua*, rather than the former 计划 *jihua*, while the official translation into English remains the same - "plan". It is, therefore, somewhat of a message to the national audience. The relabeling reflects the changing function of the Plan in Chinese policy-making and the abandonment of Soviet-type planning. Now instead of dictating specific objectives, the Plan offers guidelines. 规划 *guihua* also has a temporal connotation to it that differs it from 计划 *jihua* (Huang 2013). *Guihua* has the meaning of *longevity,* which might not only refer to the Plan itself but also extends to the CCP guidance.

Second, the 11th (2006– 2010) and 12th Five-Year Plans (2011–2015) introduced novel types of binding targets 约束性指标, for example, newly introduced by the 11th Five-Year plan binding target of a 20 per cent reduction in energy intensity.

Third, to ensure the local government's compliance with set targets, those binding targets were incorporated into local officials' performance evaluations. Performance evaluation as an instrument of control is not novel to Chinese politics (Y. Chen, Li, and Zhou 2005). However, local officials used to challenging economic growth targets, population control, and social stability tend to ignore environmental protection and energy efficiency issues as they limit economic growth (Mingxing Liu, Song, and Tao 2006). Increased priority given to the unpopular environmental targets by the central government forced it to find solutions to avoid poor implementation. Thus, the plan-cadre nexus enacts person-based policy accountability instead of law-based and bureaucracy-based accountability in performance.

Fourth, to align local and national objectives, new types of contractual planning were developed between central ministries and provincial governments (Heilmann and Melton 2013). Particularistic contracting has been common in China since the 1980s, mainly in authorisation for developing special economic zones or government-sponsored regional programs. Launching macro-regional cross-provincial plans became a step forward in harmonising central and regional development plans. The major challenge with these plans is coordinating multiple agencies and government levels. Therefore, they are designed to arrange responsibilities and organise investment flows and administrative action among all actors involved. Joint programs differ in duration, objectives, and funding sources (Tang and Shapira 2011). For example, Northeast Revitalization Program 东北地区振兴规划 adopted in 2007 with a duration period till 2020 aimed at restructuring the former heavy industry-dominated economy of the region, then the Pearl River Delta Program 珠江三角洲地区改革发展规划纲要 (2008–2020) aimed at administrative reorganisation and financial reform. While central funding plays a crucial role in some programs, in other cases with wealthier regions, the central authorisation for action or reform is more critical (B. Lv, Liu, and Li 2020). Thus, the Chinese planning system combines imperative, contractual, and indicative coordination features. In a way, a plan is a contract between local and national governments. Local governments agree to follow the plan in exchange for attaining and staying in power. The outcome of their work, in turn, legitimises the national government and the CCP rule.

1.2.2. Five-year Planning Cycle

Analysis of the planning cycle sheds light on the arrangement of multiple layers of bureaucracies and jurisdictions and their incentives. It helps to explain the Chinese policy-making process, including its successes and struggles.

The five-year plan remains the prime development program issued by the Chinese government once in five years (Wan et al. 2022). Despite all the dramatic events and abrupt changes, the People's Republic of China has gone through since its founding in 1949, the Plans were issued consequently without a break till the current 14^{th} five-year plan (2021-2025). It signifies the Plan's excellent internal continuity and external adaptivity (Yulian Zheng, Walker, and Chen 2013).

The planning cycle of a five-year plan starts two and a half years before its commencement when the State Council instructs the National Development and Reform Commission (NDRC) to initiate the drafting of the next five-year plan (Heilmann and Melton 2013). NDRC requests public and research contributions to the Plan's agenda. Two years before the finalisation of the Plan, Politburo and the Central Financial and Economic Affairs Commission (between 1989-2018, known as Central Finance and Economics Leading Small Group) identify the main challenges and objectives for the coming period. One year before the Plan finalisation, research reports are received by the NDRC and CFEAC.

The year before the Plan commencement, drafting five-year plan guidelines 建议 *jianyi* (the CCP document) begins. The drafting group led by the premier consists of about fifty experts in economics and policy-making, including regional representatives. After approval of the party core group of the State Council, draft guidelines, circulated by the General Bureau of Party

Center, go through another round of consultations with the party and non-party units. At this stage, the CCP General Secretary holds consultation meetings and party top leaders tour across regions to collect opinions on the draft. By October of the preceding year, all new input gets incorporated into the Guidelines, and the same month the Central Committee Plenum has to approve the five-year plan guidelines, and it becomes public.

In the following couple of months, on the orders of the State Council, the party plan guidelines are transformed into more detailed government documents by the NDRC with additional input from various units.

Usually, after the Chinese Spring Festival, the State Council holds several meetings on final revisions. In March National People's Congress has to approve the five-year plan outline 纲要 *gangyao*. Midyear, the NDRC holds a national conference to discuss the Plan implementation and special program plans. After two years, the NDRC initiates midterm evaluation, and a new planning cycle begins (Heilmann and Melton 2013).

Five-year plan cycle is desynchronised with the party and government power transfer (C. C. Fan 2006). New leadership takes office in the middle of a five-year plan implementation to ensure continuity in national development. For example, Xi Jinping assumed office as President in 2013 in the midterm of the 12th five-year plan (2011-2015).

In the Chinese language discourse five-year plan drafting procedure based on its characteristics is referred to as *scientific* (F. Wu 2015). At least formally, the planning process does fit this description. It is systemic, methodologically clear, and involves collecting, interpreting, and evaluating a vast amount of data from various experts, organisations, research units, think tanks, practitioners, individuals, etc. Saying that the planning process is scientific justifies its results and claims them properly and correctly. A fair share of the prognosis of future conditions and challenges is needed for the Plan's drafting. Therefore, despite the scientific approach to planning, significant uncertainties are still integral. In a way, a five-year plan is a meticulous experiment design that makes an attempt to predict and direct an experiment but is unable to control it fully.

The five-year plan contains quantified indicators, which are economic (economic growth, industrial structure), environmental (resource management, energy use), social (population size, urbanisation, rural income), etc. Indicators might be *obligatory*, that have to be achieved, and *anticipated*, that are desirable but not binding (P. Zhang 2021).

The proportion of indicators of different types varies from period to period. Thus the total share of economic indicators in five-year plans has been significantly decreasing from 60.7% in the 6th five-year plan (1981-1985) to 12.5% in the 12th five-year plan (2011-2015) (Hu 2013). At the same time, the proportion of environmental indicators has increased from 3% to 42.9%.

Drafting of local five-year plans follows a similar to the national five-year plans procedure. Each planning cycle begins with a midterm evaluation. The following drafting work involves ample human and institutional resources (G. Xie et al. 2021). However, research shows that at the provincial level, the role of government departments in drafting five-year plans significantly outweighs the input from experts and the public (Meng 2014).

1.2.3. Planning for Sustainability

Sustainability, as understood in the UN processes, are at the core of the Chinese efforts (Yu et al. 2020). China joined the UN security council in 1971/2 and started asserting itself in this area (Pye et al. 1999). After attending the Stockholm Conference on the Human Environment in 1972, which resulted in the United Nations Environmental Program (UNEP), a small leadership group of top leaders and scientific advisors was arranged to engage with this policy (Gilley 2012). Qu

Geping, who later became China’s first environmental chief of the newly established Bureau of Environmental Protection in 1987, was among the conference delegates (Boxer, Qu, and Lee 1985).

Qu Geping was not professionally trained in any environment-related field. He obtained his university degree in Literature and Art (China Vitae 2003). However, his participation in the conference and what he learned about environmental issues and ecological crises during the conference meetings, according to his own words, profoundly impacted his several decades-long professional pursuits. In the 70s and 80s, he was publishing and consulting the central government, making spreading awareness about environmental issues and integrating environmental protection into national policies his goal. His vision included three simple guiding principles: pollution prevention, the *polluter pays* principle and stronger environmental regulations (Qu Geping 1982). Between 1987 and 1993, he served as the first leader of the Bureau of Environmental Protection, the establishment of which was also part of his efforts. In 1994, he served as a senior consultant to the World Environment Foundation. From 1998 to 2003, Qu was a member of the Standing Committee of the 9th NPC and chairman of the 9th NPC Environment and Resources Protection Committee.

Qu’s persistent contribution to environmental protection is recognised both in China, including the State Council special award and top grade prize for scientific progress, and internationally, among other things, by the gold medal award from the UN Environment Program in 1987, the Dutch Order of the Golden Ark in 1996, and WWF's highest award the Duke of Edinburgh Conservation Medal in 2001 (World Wide Fund For Nature 2001).

The summary of Qu Geping’s professional experience shows that the UN's interpretation of sustainability is at the heart of China’s sustainability vision. Qu Geping is one of the founders of environmental protection agencies in China, a principal figure in shaping national strategies; a high-rank official acknowledged by the international community; his vision and work started with the UN conference and continuously developed through international collaboration.

Moreover, Professor Ma Shijun, an outstanding Chinese scientist in biology and ecology, a member of the Chinese Academy of Sciences, once an advisor on the State Council Environmental Protection Commission, and a committee member of UNEP and FAO, became a co-author of the Brundtland Report (Brundtland 1987; Kang and Li 2011). Professor Ma Shijun put great efforts into raising public awareness about environmental problems spreading the knowledge by travelling across China and convincing decision-makers about the urgency of the issues and the need for adequate policies, promoting the idea of sustainable development. He argued that it was not only science and technology but also the consciousness of ecology by the public that could resolve the country's environmental crisis (Kang and Li 2011). It is remarkable how, already in the 80s, he would refer to the ecological condition of China as a *crisis*.

Furthermore, Chen Yun, one of the founders and leaders of China's socialist economic construction (D. Zhang 2016), pointed out the importance of environmental issues as early as 1979 (Cao 2016). Available archives, documents, letters, and public speeches help recreate Chen Yun's vision for addressing environmental issues (X. Li 2007).

Chen Yun stressed the necessity for pollution prevention through proportional development and long-term planning. In a letter to the Central Committee in 1979, Chen Yun wrote that the development of the steel industry should be balanced with the development of other socio-economic dimensions such as agriculture, light industry, transportation, culture, education, health, urban housing construction, and *environmental protection* (Duan 2013). Pollution should be included in policy design, meaning the system should internalise costs to nature through planning (Jianming Chen 2020).

In 1983 in a reaction to an internal report on acid rains in Shanghai, Chen Yun said that the management fee should be a priority; otherwise, the consequences would be endless 治理费要放在前面,否则后患无穷 (Cao 2016).

The same year, Chen Yun attended the working conference of the Central Committee of the CCP. In his speech, he pointed out that the prevention and control of environmental pollution are crucial. Deng Xiaoping agreed with Chen Yun's subsequent remarks in his following speech (D. Zhang 2016).

In a letter to Li Peng in 1988, he wrote that controlling pollution and protecting the environment is a significant national policy which should be taken as a fundamental matter. This should be done by publicising environmental concerns and investing in environmental protection (Cao 2016).

In 1990, Chen Yun approved and forwarded Jiang Zemin, Li Peng and Song Jian the article *China's Water Resources Problems and Solutions,* jointly written by Zhang Guangdou, a professor at Tsinghua University and a water conservancy expert, and Chen Zhikai, a professor of the Institute of Water Resources of the Chinese Academy of Sciences. Chen Yun commented that the water pollution problem should have been understood strategically. Leading departments at all levels, especially economic, scientific, and technological, should treat planned water use, water conservation, sewage treatment, and developing new water sources as necessary as food and energy and include them in long-term plans. Chen Yun referred to the water resource *crisis* (Jianming Chen 2020).

The above demonstrates that the urgency of the environmental issues was understood and articulated among the top Chinese leaders, and the Chinese government was aware of the forefront of international research on ecological issues and their consequences (Maohong 2004). However, for decades the costs of environmental damage were externalised to society and nature. Only in 2006, following the amendment of the 11th five-year plan, the expenses were officially internalised, and the *polluter pays principle* finally came into effect (L. Liu, Zhang, and Bi 2012). In 1978 China amended its constitution to include the protection of the environment as one of the society's fundamental commitments (Byrne et al. 1994). Still, it took about 30 years before environmental indicators in five-year plans became obligatory. If, already in the 70s ecological situation in China was defined by experts as a *crisis*, why did it take so long before environmental protection policies became a priority in the planning?

It is misleading to think that the government was ignorant and passive about environmental issues before the 11th five-year plan, which triggered an array of national and regional mid-term and long-term plans, sector-specific programs and intense legislative work, creating an impression that hardly any attention was paid to ecological problems before that (L. Liu, Zhang, and Bi 2012). There was preparatory work in progress.

First, environmental protection work was gradually institutionalised through the establishment of administrative agencies, which were reorganised over time, gaining increasingly more independence, power, recourses and influence. In 1973 the State Council held the first National conference on environmental protection (K. Zhang and Wen 2008). The small leadership group organised afterwards became China's representative in UNEP. The following year the

Environmental Protection Leadership Group 国务院环境保护领导小组 was officially established (Jahiel 1998). Its responsibilities were broad and hardly feasible for a newly arranged unit. They include formulating guidelines, policies and regulations; examining and approving the national environmental protection plan; organisation, coordinating and supervising the ecological work of regions and departments.

In 1982 in the process of institutional reform of the State Council, some agencies were reorganised, including the Environmental Protection Leadership Group. The State Construction Commission 国家建委, the State Administration of Urban Construction 国家城建总局, the State Administration of Construction and Engineering 建工总局, the State Bureau of Surveying and Mapping 国家测绘局, and the Environmental Protection Leadership Group were merged to form the Ministry of Urban and Rural Construction and Environmental Protection 城乡建设环境保护部, which has an Environmental Protection Bureau 环境保护局 (Jahiel 1998). There was a lobby for granting the environmental protection agency ministerial status, but it failed to gain enough support (Child, Lu, and Tsai 2007). The failure can be explained by institutional resistance and the absence of external normative and cognitive pressures. In the USA, the development of the environmental protection system and consequent institutional change was pushed by the rise of NGOs and a changing public opinion. The normative and cognitive shift in society preceded institutional change and encouraged it. By contrast, in China, the development of the environmental protection system was a result of external events exercising pressure on the government. The state system itself initiated the institutional change in the absence of a normative and cognitive system. Thus, the internal impulse was not enough for effective lobbying at that moment. So, the Environmental Protection Bureau’s position in the governmental structure was lowered.

Nonetheless, in 1984 the Environmental Protection Commission 国务院环境保护委员会 was established and chaired by the Vice Premier (Z. Xie 2020). Its office was set up in the Environmental Protection Bureau. Later the same year, the Environmental Protection Bureau was renamed the State Environmental Protection Bureau 国家环境保护局 but remained under the leadership of the Ministry of Urban and Rural Construction and Environmental Protection. This looks like an attempt to provide more structural importance and institutional support to the environmental protection work. Although translated into English, both units, the Environmental Protection Commission and the State Environmental Protection Bureau, had similar responsibilities: planning, coordination, supervision and guidance. The word choice in Chinese demonstrates the considerable political authority of the former: "研究审定", "提出规划要求", "领导", "组织协调" vs "规划", "协调", "监督", "指导" (Ministry of Ecology and Environment 2018).

In 1988 the State Environmental Protection Bureau finally received vice-ministerial status (Y. Zhang 2018). The growing attention to environmental issues in the 1980s was most likely, among others, triggered by such environmental disasters as the Bhopal gas tragedy in India in 1984 and the Chornobyl nuclear accident in USSR in 1986. In the course of further institutional reform, the Ministry of Urban and Rural Construction and Environmental Protection was reorganised, following which the State Environmental Protection Bureau came under the direct authority of the State Council (Jahiel 1998). While its responsibilities remain the same, it grew considerably, reaching over 300 staff and several departments, including the Department of Planning, Department of Policies and Regulations, Department of Pollution Management, Department of Development Supervision, Department of Nature Protection, Department of Science and Technology Standards, Department of Publicity and Education, Department of Administrative System and Personnel and Foreign Affairs Office.

In 1993 the responsibilities of the Bureau were specified with new rhetoric coming into the picture. Previously the central concept was environmental protection 环境保护. Newly introduced was a distinction between the living environment 生活环境 and ecological environment 生态环境 and the function of not only protecting but also improving them (Hou, Chen, and Long 2022). Besides, the Bureau was expected to supervise law enforcement, prevent and eliminate pollution, and promote the sustainable, harmonious and healthy development of the economy and society. Such detailed elaboration compared to the previous general formulations of functions is remarkable, as it shows that the state's environmental development vision and strategy take shape. The new language defines how issues should be considered and dealt with (Xue and Liou 2012).

In 1998 the State Environmental Protection Bureau was renamed the State Environmental Protection Administration (SEPA) 国家环境保护总局 and upgraded to the ministerial level (Yuan, Bi, and Moriguichi 2006). The structure of the agency remained similar. However, the Nuclear Safety and Radiation Environment Management Department (National Nuclear Safety Administration) 核安全与辐射环境管理司（国家核安全局）was transferred under the jurisdiction of the SEPA giving it additional political weight. The SEPA kept its functions, including promoting economic and social sustainability.

In 2008 the SEPA became the Ministry of Environmental Protection 环境保护部, a constituent department of the State Council (Bai et al. 2016). After yet another decade, the agency was renamed the Ministry of Ecology and Environment (MEE) 生态环境部 (Tian et al. 2020). This institutional reform brought a significant rearrangement of responsibilities, reflected in the new name. The MEE stopped being responsible for environmental protection but received new functions of policy-making, supervision and control over law enforcement (J. Wang 2018). The responsibilities of the former SEPA were reassigned to respective ministries. As a result, the National Development and Reform Commission is to address climate change and emission reduction; the Ministry of Land and Resources is responsible for supervising and preventing groundwater pollution; the Ministry of Agriculture handles supervision and control of agricultural nonpoint source pollution, etc. This redistribution of functions erects the internalisation of environmental costs. The Ministries were forced to intergrade the ecological impact of their activities as a fundamental consideration. The MEE received the authority of law enforcement in pollution prevention, environmental protection, nuclear and radiation safety, but also policy-making and planning, coordination of investigation and handling of major ecological accidents, settlement of cross-regional environmental pollution disputes, control over the implementation of emission reduction targets, establishing of environmental monitoring systems.

Discussion of the evolution the MEE went through over time is relevant as it shows the growing lobby for environmental policies that eventually ended up as mandatory indicators in the 11th five-year plan and initially marginalised powerless agencies becoming law enforcement bodies.

The second argument demonstrating continuous work and the growing weight of environmental considerations in China is the gradually increasing proportion of the environmental indicators in five-year plans. Environmental indicators are those stated in the "Resouces and Environment" Chapter of the five-year plan, for example, *Main Pollutant Contents Discharged in Wastewater by Region, Disposal and Reuse of Industrial Solid Wastes by Main City, Ambient Air Quality by Main City, etc.* The relative proportion grew from 3% of the total number of indicators in the 6th five-year plan to 3.6 % in the 7th five-year plan, 7.7% in the 8th five-year plan, and 11.8% in the

9th five-year plan (Hu 2013). In the 10th five-year plan (2001-2005), the proportion jumped to 20%. It increased to 27.2% in the 11th five-year plan and reached 33.3% in the 12th five-year plan.

Third, China's global environmental agenda became an entry point into the world's political leadership (Heggelund and Backer 2007). Leaving this path would negatively affect economic development and international cooperation (Esty and Dua 1997). On the one hand, China's participation in the UN initiatives was instrumental. It assisted in elevating China's international status and building trust with partners (Ding 2010). China's delegation to the UN Conference on Environment and Development, also known as the Rio de Janeiro Earth Summit, in 1992 was led by Premier Li Peng. The conference took place one year after the collapse of the USSR, which became a crucial moment in world history and politics, a moment of reshaping and redistribution of global power. The Earth Summit afforded Li Peng a valuable opportunity to meet world leaders, including U.S. President George Bush, British Prime Minister John Major, etc. (Khooshie, Lal, and Panjabi 1993).

On the other hand, China took its commitments earnestly. Each commitment and ratification of environmental conventions, such as ratification of the UNFCCC in 1993, signing of the Kyoto Protocol in 1998, committing to the Copenhagen UNCCC accord in 2009, and submission of Intended Nationally Determined Contribution in 2015 (L. Li and Taeihagh 2020), was a further step forward in sustainable planning and development. Breaking those early commitments in the 90s could seriously jeopardise China's yet vulnerable reputation and growing participation in the world economy.

China's commitment to the UN conventions resulted in national long-term development programs. China's *National Agenda 21 - White Paper on China's Population, Environment, and Development in the 21st Century* was approved by State Council in 1994 in the aftermath of the

Earth Summit (G. Zhang 2011). It marked the beginning of sustainable development processes in China (K. Zhang and Wen 2008). The formulation and implementation of China's Agenda 21 were coordinated by a small leadership group co-chaired by the deputy minister of the State Science and Technology Commission and a deputy minister of the State Planning Commission. Agenda's 21 strategic guidelines were integrated into the 9th five-year plan (1996-2000) (Risheng 2012). In 2003 the NDRC promulgated the *Program of Action for Sustainable Development in China in the Early 21st Century* as a compilation of more detailed measures for achieving sustainability goals (Schienke 2012). In 2007 as mandated under the UNFCCC, the Government of China formulated *China's National Climate Change Programme* (Lewis 2007).

In other words, China's path to announcing its target to cut carbon dioxide emissions by 40–45 per cent per unit GDP compared with 2005 levels at the 2009 Copenhagen Climate Change Conference came from a continuous effort (N. Wang and Chang 2014).

Thus, externalising the environmental costs to society and nature for almost 30 years, despite the Chinese government's awareness of the ecological problems in the country, was a matter of priority. Taking into account the initial state of China's economy at the beginning of the Reforms of Opening, the government's main concern was meeting the population's basic needs by providing them with food, income and work opportunities (Schnitzer 2000). In the first 20 years of the economic reforms, China achieved tremendous success in poverty alleviation (Mingyue Liu et al. 2020). Economic growth was the national and regional priority (S. Fan and Chan-Kang 2005). This fired back once the national government turned towards sustainable development, as it met with non-compliance from local governments (Lo 2015). Partially, the reluctance of the local officials to submit to the environmental goals is caused by the specifics of regional financing and taxation in China (van der Kamp, Lorentzen, and Mattingly 2017). Local governments bare large proportions of their budgets and have to rely on their revenues.

Internalising environmental costs would mean increasing their financial burden for them; that is why for as long as it was possible, they tried to ignore or avoid committing to any environmental indicators. This consequently postponed the beginning of China's active action for sustainability. The CCP has made sustainability integral to its planning regime. Meeting economic growth targets is not enough, for the development must be presented as sustainable innovation.

This research addresses the decision-making process behind the sudden growth of the GHP application in Shenyang in 2006. Shenyang's GHP policy appears as a direct and logical outcome of the 11th five-year plan's requirement to reduce energy intensity by 20%, increase the share of non-fossil fuel consumption to 10%, and reduce SO2 and NOx emissions by 10% (L. Li and Taeihagh 2020). Indeed, GHP contributes to energy efficiency, uses renewable energy and ticks the box of technological innovation promotion. However, in terms of probability, it is instead a distant echo than a direct result of the national five-year plan because city-level policy written in the local five-year plan materialises as a product of a cascade of decisions and interests that goes through a myriad of agencies and institutions, that opens ways to some possibilities and rejects many others. Building sustainability lies at the intersection of the interests and responsibilities of at least three national agencies: NDRC, MoHURD, MEE, and local government agencies.

1.2.4. Tiao-kuai System

China's governance system has a fragmented structure, which is referred to as *tiaotiao kuaikuai* 条条块块 (Kostka and Hobbs 2012). The tiao/kuai administrative structure describes the internal division of power within the Chinese Party-state (Thornton 2013). Vertical bureaucratic relationships linking central to local organisations are called *lines* (tiao). At the same time, horizontal bodies coordinating action within given geographic areas are known as *pieces* (kuai), resulting in a crosshatch of political authority characterised as fragmented authoritarianism

(Mertha 2005). The vertical nexus is functional and represents the central government ministries and their branches. The horizontal nexus is geographic and includes agencies at the local level (provincial, municipal).

The *tiao/kuai* agencies are structurally disconnected.[2] Jurisdictional conflicts and inefficient interagency communication exacerbate systems' weaknesses (Fuller 2019). Such fragmentation results from the central government's strategy to prevent localism (federalism) while giving local governments enough administrative and economic independence to mobilise local initiatives, which is necessary for national development goals (Mertha 2005).

Sustainability requires a complex approach and governmental agencies' cooperation, which is challenging in the context of the *tiaokuai* system. Thus, interagency government data sharing presents a particularly complex social-technical phenomenon (L. Chen, Lai, and Zhou 2020) caused by technological, political, data ownership, and territory challenges.

For example, there is a case study of the conflict between the National Energy Administration (NEA) and other central departments such as the Ministry of Housing and Urban-Rural Development (MOHURD) (Liu & Xu, 2018). In 2009, China started with two national PV generation pilot projects: MOHURD's Solar Roof program and NEA's Golden Sun program. Although the central government attempted to integrate two programs into one, they were split apart again due to rivalry, differences in development ideas, and poor coordination between the two departments. Thus, interviewed civil servants from provincial and local NEA branches noted that they were unfamiliar with MOHURD's Solar Roof program.

[2] Intreviewee 3

Fragmentation creates space for non-compliance. For example, the National Energy Saving and Emission Reduction Programme, aimed at achieving energy efficiency goals, had a difficult start at the provincial level in 2006 (Kostka and Hobbs 2012).

Establishing small leading groups for implementing a specific project is a common way to overcome fragmentation. Local governments organise leading groups that incorporate agencies' representatives to improve integration and coordination among departments, eliminate interdepartmental competition and promote central government policies (Tsai and Liao 2020). Cross-system leading groups integrate departments from different systems.

1.3 Sustainability, Planning and Technological Change: Institutional Rationales

1.3.1. Is Innovation Necessary?

Environmental impact results from and positively correlates with economic growth and population size (Anser et al. 2020). National economies depend on economic growth as an instrument for wealth creation to meet citizens' needs in sustaining livelihood, housing, health care, education and leisure activities. Economic growth is achieved through industrialisation and increased consumption (Acheampong et al. 2021). Industrialisation leads to intense use of energy, raw materials, water, and inevitable wastes and unwanted secondary by-products (Kiely 2005). Economic growth allows for improving living standards (Acemoglu 2012). Pushed by information technologies that publicise the details of peoples' lifestyles, laypeople orient themselves not towards tv advertisements, which used to be a benchmark for living standards, but rather towards celebrities and their standards of living (Kim, Shoenberger, and Sun 2021). Such lifestyle transparency of wealthier socio-economic strata encourages the larger population to strive to improve their ability to consume and normalises ever-high standards of living and consumption. The growing population size adds to the pressure of economic growth (Fraser 2020).

Environmental impact can be considered a function of the number of people, resource use per person, and environmental impact per resource unit (Beder 1994). This function offers three variables for manipulation: population size, consumption levels and technological advancement. The decreasing ecological impact would mean excising control over population growth, slowing economic growth, or promoting technological innovation (Leopold et al. 1971). The Rio Summit in 1992 showed governments' reluctance to compromise economic growth, stop boosting consumption or implement population growth-related policies, leaving technological innovation as the only solution to reduce the environmental impact of energy use (Beder 1994).

Technological optimism, which nourishes the idea of combining economic growth with the improvement of the environment, rests on two premises (Nelson and Winter 1977). First, that technological advance has been a powerful instrument of human progress in the past. The assumption that innovation leads to societal progress is inherited from the Enlightenment and its belief in science providing a better quality of life (Vollenbroek 2002). This belief was reinforced during the Industrial Revolution when technology and technological innovation became a driving force for economic growth (Carlaw and Lipsey 2003). Therefore, the assumption that technological innovation can help solve environmental issues and lead to sustainability seems reasonable. The second premise that we know how to use this instrument to create wealth and guarantee the well-being of current and future generations is, however, less solid.

There are limits and risks to pursuing sustainability through science and technology (Huesemann 2003). First, our level of intervention within complex biological ecosystems lacks the level of understanding (Funtowicz, Ravetz, and O'Connor 1998). Science-based innovation contributed to industrialisation and economic growth but turned out to be destructive to the environment (Grupp 1992).

Second, innovation is inherently stochastic (Blok 2021). Its design must encompass environmental and institutional complexity and variety to minimise negative consequences (Nelson and Winter 1977). Environmental implications of technologies arise from their success rather than inadequacies (Commoner, 1972). Plastic is durable because it is made to be stable. The designers of technology never intended pollution caused by it. Therefore, technological innovation for sustainability has to be designed with complexity and uncertainty that goes beyond the pure function of high efficiency and low carbon imprint (Jalonen 2011). Engineers and policy-makers must consider short-term and long-term side effects and second-hand consequences.

Third, more scientific knowledge applied to innovations does not necessarily lead to a more sustainable economic process (Funtowicz, Ravetz, and O'Connor 1998). The task of science should be facilitating the social resolution of the problem, including participation and mutual learning among stakeholders, such as scientists, policy-makers and the general public, rather than providing a technological fix (Oelschlaeger 1979). New quality assurance processes are needed for science and policy sustainability based on comprehensive societal and ethical reflections.

Fifth, implementing sustainable technologies requires fundamentally restructuring the economic and industrial systems (Kern and Smith 2008). Sustainable technologies use less water, energy and raw materials and produce less waste (Weaver et al. 2017). By definition, they function on renewable resources. Current economies are, however, embedded in fossil-dependent infrastructure. The transition to more sustainable options is a massive paradigm shift (Bagheri and Hjorth 2007).

Besides, improvements in eco-efficiency alone do not guarantee a reduction in the total environmental impact of economic growth, in its traditional understanding, at the expense of intense resource use and encouraged consumption to continue (Van Ewijk and Van Wijnbergen 1995). The environmental burden per unit of gross national product must be reduced considerably (Vollenbroek 2002). There is a need to redefinition economic activity and re-formation the classical and neo-classical concepts of wealth and productivity (Stahel 1997). China made a rhetorical shift from economic growth to economic development, stating that economic development is not equal to economic growth (Van den Berg 2016). GDP traditionally measures financial success. With novel ecological, economic, and social values at play, a clean environment might become more important than the ability to consume and (re)distribute benefits of technological progress and innovation among most people before accumulating personal wealth (Gregson 2010).

Finally, commercially driven innovation and technology transfer can heighten socio-economic stratification and worsen the disadvantaged population's conditions (Funtowicz, Ravetz, and O’Connor 1998).

Despite the limitations and risks, leading economies have already chosen the technocratic approach to achieve sustainability as a development paradigm that requires radical and systemic innovations (Jensen et al. 2019). From a national government’s perspective, this necessity has national and international rationales (Mebratu 1998). At the national level, technological innovation responds to the challenges of climate change, environmental degradation, energy safety, growing urban population (McMichael, Butler, and Folke 2003).

From the international perspective, there are strong economic reasons to engage with technological innovation, especially in the high-tech and renewable energy sectors (O'Connor and Rice 2013). The global economic context has changed to multi-polar, and traditional international competitiveness rules are no longer working (Arkhipov and Yeletsky 2015). This creates excellent opportunities for newcomers to benefit from such changes (Boons et al. 2013). Failing to engage with technological innovation and smart specialisation means undermining development (Siudek and Zawojska 2014). Sustainable innovations create new global markets and local smart specialisation, giving a long-term development perspective and a stable context for policymaking (Geissdoerfer et al. 2017).

1.3.2. Causal Agents and Mechanisms of Innovation and Transition

Once a national government sets sustainability as a development path and a social target and chooses technological change as an instrument, the question arises of how to facilitate this innovation (Omri 2020).

Innovation is the first commercialisation of an idea (Fagerberg, 2003). In essence, something that is intended to make a profit. Therefore, innovation is inseparable from the market and economic system. However, *sustainable* innovation is not necessarily profitable in the short run. It means that neo-classical economic theories have limited explanatory power regarding the nature of sustainable innovation (Mulder and van den Bergh 2001).

Theoretically, any innovation is driven by a causal agent and mechanism (Dawid 2006). Social sciences offer a range of conceptualisations regarding innovation processes and their driving force (Geels 2010).

Neo-classical economics looks at innovation from the perspective of resource allocation in competition with other ends (den Butter and Hofkes 2006). Based on rational choice theory describes cause agents as self-interested individuals who use their instrumental rationality to maximise their preferences. Agents choose between alternatives relying on cost-benefit calculations, their knowledge about the options and the consequences of their choice (Livermore 2014). Strategy precedes implementation and results from data collection, analysis and selection of the best option. Implementation is a managerial process driven by tasks, incentives and control (Mulder, De Groot, and Hofkes 2001).

Transitions are adjustments in the economic structures caused by changing prices of production factors (labour and capital in neo-classical theory, knowledge in endogenous growth theories, and natural resources in environmental economics) and output. Rising production costs force firms to invest in innovation to reduce the price of production factors (Gilbert 2009).

From a neo-classical perspective, environmental issues are caused by market failure to internalise costs to nature (Owen 2006). Transitioning to sustainability means market conditions must change through the government introducing environmental taxes and subsidies (Fullerton and Metcalf 1998). This, in turn, will lead to price changes, investment in R&D and sustainable transformation of economic structures (Butter and Hofkes 2006).

In contrast to neo-classical economics, the endogenous growth theory developed by Romer treats *internal* factors as drivers for growth (Romer 1994). It is focused on human capital and knowledge flow. Marx has argued that what made the industrial revolution a revolution was not the use of machinery but rather the stage where machinery was used to produce machinery (MacKenzie 1984). Similarly, radical transformation of the economy is only possible when knowledge is systematically used to create knowledge. Technological development is then seen as a public good and invites government participation, which is no longer led purely by the free market's invisible hand (Callon 1994).

The evolution theory stresses the role of an agent and learning by doing. A causal agent is a population of diverse agents, and transformation is an incremental adaptation through trial and error (Witt 2016). Evolutionary economics studies firms, innovation and market competition through the lenses of the behavioural theory of the firm (Nelson and Winter 1982). Boundedly rational actors use routine and organisational procedures in day-to-day problem-solving. Firms are adaptive agents reacting to changes and engaging in innovation.

Nevertheless, their innovation is led by firm routine, operations and resource allocation practices. Therefore in problem-solving, they do not explore the whole range of alternatives but rather satisfy and stop searching when finding a satisfactory solution. Innovations, as a result, tend to be incremental (Metcalfe 1994).

Techno-economic paradigm (TEP), based on the evolution theory, explains the institutional change due to the subsystems' conflict (Connor and Dovers 2004). It differentiates between the following subsystems: science, technology, economy, politics and culture. Co-functioning of the subsystems provides stability and constrains innovation. However, maladjustments between subsystem dynamics lead to economic crises and create a window of opportunity for innovation and new TEP (Perez 2009).

From a structuralist perspective, causal actors are part of social groups that share a belief system, symbolic meanings and cultural categories that guide their behaviour. The neo-institutional sociological theory states that firms seek social legitimacy through conformity to cognitive frameworks and belief systems to gain profit through public acceptance and political protection (Suchman 1995). This links organisational behaviour to a broader social context and belief system. Accordingly, change is a strategic response to institutional pressures (Greenwood and Hinings 1996). Strains occur with a shift in belief systems, ideas, ideologies and discourses. Such concepts as "green", "sustainable development", "ecological footprint", "carbon trading", and "environmental impact assessment" entered societal discourse for decades (Connor and Dovers 2004). However, they lack the connotation of urgency, which is needed for radical sustainable innovation to be perceived as feasible and desirable (Geels 2010).

In the constructivist paradigm, actors are creative and continuously engaged in sense-making (Bell 2011). The process of interpretation, which takes place before action, happens in ongoing interaction and learning. Cognitions and performances are constantly produced and modified. From this perspective, a transition occurs in the context of uncertainty. The social construction of technology explains that actors attribute different meanings to new technologies (Bijker 1995), which leads to debates, conflicts and uncertainty that prevents innovation from roll-out (Bijker 2009). Once vision converges, there is an opportunity for transition. According to transition management, this can be achieved through stakeholder learning practices and societal debates. Accordingly, sustainability transition is hindered by a lack of shared vision (Strommen and Lincoln 1992).

In conflict and power theory, causal actors are collective actors with conflicting interests (Cheney, Nheu, and Vecellio 2004). Dominant actors use power to protect their interests and keep the status quo. Transition happens at the moment when dominant actors lose their leading position. The energy sector is a classic example, where interest groups profiting from fossil energy recourses severely oppose the development of alternative energy (Shafiee and Topal 2009).

1.3.3. Characteristics of Innovation

Innovation possesses inherent characteristics that must be considered to analyse, understand and stimulate the transition to sustainability. First, the innovation process is uncertain (Lundvall 1998). Characterised by ongoing innovation and total uncertainty, the institutional setting will determine how the economic agents behave. Lundvall (1998) proposes four kinds of institutions as necessary in the context of learning and innovation: long-term agents (some technologies can be implemented only by actors that operate with a long-term perspective), trust (presence of trust decreases transaction costs and increases productivity), communicative rationality (innovation systems with a kind of rationality where collective goals drive people) and authority (age and seniority, control over financial resources, merit in terms of training and skills, besides authority are necessary for effective learning). The way these institutions are expressed defines the innovation process (Lundvall 1998).

Second, innovation is rooted in interactive learning processes (Lundvall 1992). Pure markets run by short-term oriented individualist rational men do not allow for learning and innovation and come to stagnation (Lundvall 1998). Innovation systems develop by introducing knowledge into the economy and society at large. It requires active learning by individuals and organisations taking part in innovation processes of different kinds. Institutions define the rate and direction of innovation, how people relate to each other, and how they learn and use their knowledge (Lu, Tsang, and Peng 2008).

The extreme division of specialisation among policy institutions and policy analysts encouraged by bureaucracy has become a significant practical problem (Lundvall et al. 2002). If innovation is learning and learning is interaction, the interaction between agents is crucial for successful innovation. However, specialisation is essential to bureaucracy, which leads to a communication gap between agencies horizontally and vertically. A uniting analytical concept, such as sustainability, helps to overcome these problems.

Third, innovation is not linear; it is not applied science (Kline and Rosenberg 2009). Apart from scientific and technological research, essential parts of the knowledge base are tacit and emanate from routine-based learning-by-doing, -using and -interacting and not only from research activities related to science and technology (Parrilli and Alcalde Heras 2016). In fact, in many settings, the experience of users, not science, is deemed the most critical source of innovation (von Hippel 1976).

Fourth, invention and innovation is a continuous lengthy process involving many interrelated innovations (Dougherty and Dunne 2011). It requires complementary inventions and technical and non-technical innovations to succeed at the innovation stage. The systemic approach is necessary for approaching technological change through industrial dynamics, technology policy and firm strategy. In response to this, several system approaches have emerged, including the national systems of innovation approach (Chang and Chen 2004; Edquist 2010; Lundvall 1992), the technological systems approach (Carlsson and Stankiewicz 1991; A. C. Hughes and Hughes 2011; Joerges 2019), regional systems of innovation (Cooke, Uranga, and Etxebarria 1998; Doloreux 2002; Howells 2009; Uyarra and Flanagan 2013), sectoral systems of innovation (D. Li et al. 2021; Malerba 2005; Schrempf, Kaplan, and Schroeder 2013), the sociotechnical systems approach (Carayon 2006; Dwyer 2011; Van Der Zwaan 1975) and the network approach (Cho, wang, and Lee 2012; Oerlemans, Meeus, and Boekema 1998).

Multi-level perspective (MLP), inspired by actor-network theory and evolutionary theory, aims to describe a socio-technical process of a technological innovation making (or failing to make) its way from a niche development into wide societal use (Geels 2012). The advantage of MLP is encompassing the complexity of the context, including the overall nation and global “landscape”, local established socio-technical “regime”, and seeking a window of opportunity innovation “niches”. The socio-technical regime is an interaction of market, policy, industry, science, technology, and culture.

However, sustainability cannot be achieved by the proliferation of just one technology. The complex nature of innovation speaks for the system perspective approach rather than focusing exclusively on individual inventions/innovations. While analysing and learning about one type of innovation, it is essential to keep the innovative processes in the whole sector, region and state in the framework. In the case of GHP, it means studying dynamics and transformation in the heating sector and the overall regional and national context of sustainable development.

Lastly, innovation is an organisational phenomenon (Fagerberg 2003). In contrast to economics, which treats innovation from the allocation of resources, sociology, organisational science, management, and business studies conceptualise innovation as learning in organised settings (groups, firms, networks) (Cohen and Levinthal 1989). In the Chinese context, sector or firm focus is too narrow to provide the whole picture (Xiwei and Xiangdong 2007), as the state’s role is central to the innovation process. Despite globalisation and localisation, nation-states and national innovation systems remain essential research domains (Freeman 1995; Patel and Pavitt 1994; Soete, Verspagen, and Weel 2010). As long as nation-states exist as political entities with agendas related to innovation, it is helpful to work with national systems as analytical objects (Lundvall et al. 2002). National institutions are the key agents of sustainable innovation (S. Dovers 2004).

1.3.4. National Innovation Systems

In light of the characteristics of sustainable innovation, the national innovation system theory appears to attend to all of the aspects mentioned above of innovation. The national innovation system (or national system of innovation) approach emerged in the middle 1980s (Freeman 1995) to characterise the systemic interdependencies within a given country and explain variation in economic growth between primarily developed countries. It approaches economic structure and institutions as interdependent dimensions of the innovation system (Lundvall et al. 2002).

The national innovation system (NIS) focuses on the interaction between the elements of the innovation system, including technology and knowledge flow, actors and institutions. Christopher Freeman (1987) developed the innovation system approach to explain Japan’s economic miracle in the 1970- 80s. By analysing the R&D capabilities of large industrial groups in Japan and the institutional environment in which these groups operated, Freeman concluded the decisive role of the network of institutions in the public and private sectors. They initiate, import, modify and diffuse technological innovation in the national economy (Freeman 1987). Unlike Freeman, Lundvall was more concerned with how new economic, practical knowledge is produced through interaction within a nation's borders, such as social interactions between actors and their role in interactive learning (Lundvall 1992). Nelson (1993) identifies an innovation system as a set of institutions whose interaction determines the innovative performance, *institutions* meaning institutional actors such as government, businesses, universities, research laboratories, etc. Godin argues that the “system approach” is at the core of OECD work, which has been developed since the 1960s. It applies that modern economic activity is based on the idea of national innovation systems as fundamental constituents (Godin 2009).

The concept of national innovation systems attempts to change the analytical perspective away from allocation to innovation and from making choices to learning (Lundvall 1998). Then the critical question will be not "Was the choice of this sustainable technology optimal?" (which is difficult to measure due to the uniqueness of experience and absence of a comparable case), but rather "What did we learn through in the process of this innovation?" The positive side of this shift is that learning any outcome, be it positive or negative, is valuable. It encourages open evaluation and discussion without shying away from those parts of the process that turned out to be malfunctioning. The openness of evaluation significantly increases the knowledge base and the chance of improvement for future innovations (Öberg and Alexander 2019).

NIS theory inspired policy-oriented studies of NIS and the development of descriptive or analytical models to formally accomplish comparative studies of NIS. Some focus on specific aspects of NIS, like R&D partnership and its stimulation of innovation (Lee and Park 2006), universities and their contribution to knowledge-based economic development and change (Fagerberg and Godinho 2018), governmental policies for promoting entrepreneurial behaviour in rural areas (J. Wu, Zhuo, and Wu 2017), governance and economic development (Fagerberg and Srholec 2008). NIS has been used to analyse innovation systems of developed and developing economies. For example, research on the fragmentation and weakness of NIS in its connection to poor economic performance in Thailand (Intarakumnerd, Chairatana, and Tangchitpiboon 2002) and small countries' economies (Davenport and Bibby 1999).

Thus, the national system of innovation approach studies formal and informal institutions that interact with the economic system and shape the direction and dynamics of innovation. The weakness of the NIS approach is in its treatment of the power aspect of development (Balzat and Hanusch 2004). Besides, NIS has been used to describe, analyse and compare relatively substantial and diversified systems with well-developed institutional and infrastructure support for innovation activities. To the same extent, it has not been applied to system building.

This research aims to explore and apply the NIS framework to the case of GHP use in China with at least two distinct alterations from previous research. First, it is used to analyse sustainable innovation, which is different from technological innovation. The application of NIS presumes that the same causal agents and mechanisms that stimulate technological innovation in a country are the driving force of sustainable innovation, a vital part of which is technological innovation. On the other hand, technological innovation is always profit-oriented, while sustainable innovation is oriented towards social and environmental good. Agents of technological innovation are seeking benefits. What are agents of sustainable innovation driven by? Despite the challenges of sustainable innovation, causal agents and mechanisms are in place, driven by individual or collective goals or some other type of driver. This research aims to explore this topic.

Second, the understanding of *institutions* is extended compared to how it is traditionally defined within the NIS framework. Commonly NIS studies describe and consider national historically grown organisational and institutional structures (Balzat and Hanusch 2004). Meanwhile, in this research, the definition of social institutions will be extended to include external interaction between institutions and internal ones.

1.3.5. Definition of Institutions

Social institutions may be distinguished between more or less complex social forms, with less complex ones being conventions, rules, social norms, roles and rituals (Miller 2003). More complex social institutions are often organisations (Miller 2009). Some institutions are even *systems* of organisations embedded in economic and political spheres of activity (Hodgson 2007). Arguably those institutions associated with organisations play a central and vital role in a society, for example, the institution of religion that corresponds with the Catholic Church organisation or the institution of ideology that fits with a political party. These institutions are typically trans-generational, as their roles are usually fundamental and long-lasting (Miller 2003).

Institutions are attributed to four properties: structure, function, culture and sanctions (Miller 2003). The institution's structure is its constitutive roles and their relations. The function means realising ends reached by an interaction between institutional actors internally and externally with non-institutional actors. Institutional culture is an essential implicit and informal dimension of an institution. It includes the casual attitudes, values, norms, and ethos which pervade an institution. Institutions also involve informal sanctions, such as moral disapproval following non-conformity to institutional norms. Institutions are dynamic, evolving entities (von Tunzelmann 1996). They have a history, a narrative's diachronic structure, and a partially open-ended future.

The critical discussion in the context of institutions is whether institutions are reducible to the individual human persons who constitute them or whether institutions are themselves agents having their capacity (Epstein 2015). According to *atomistic* theories of institutions (Taylor 1985), a society consists of an aggregate of individual human persons who are not defined by institutional roles. Respective agents are the locus of moral value. Consequently, institutions have moral value only as they contribute to the needs or preferences of a particular agent (Bringselius 2018).

By contrast, *holistic* accounts stress the inter-relationships of institutions and their contribution to more extensive and complete social complexes, especially societies (Barnes 1995). Many institutional roles are possessed of, and therefore in part defined by, their internal relations to other institutional functions (Searle 2005).

On the *teleological* account, joint actions consist of the intentional individual actions of several agents directed to realising a collective end (Hindriks and Guala 2021). This approach grants individuals the power they might not be aware of, for example, in the case of bureaucrats, who often perform their functions within an institution according to norms and procedures and have little belief in their capacity to alter the processes (Macher 1988).

With these perspectives on institutions in mind, I intend to recreate the context in which Chinese bureaucrats operate, who appear to be critical agents in China's transition to sustainability. The hypothesis is that under pressure to perform various institutional functions simultaneously, they tend to favour one and act accordingly.

NIS theory fits the thesis research question for several reasons. First, it connects technology, institutions and actors. Second, it pays close attention to institutions and organisations that compose the context of sustainability transition. Despite the successful market reforms, the Chinese government had and still has significant control over the national economy. It means that economic theories based on the presumptions about the free market that ignore the specifics of the Chinese context, governance structure and style that explain the growth in GHP roll-out by its profitability compared to other heating options fail to show the complete picture. Besides, NIS provides a set of benchmarks for measuring innovation systems through its functions, making comparison and replication of research feasible.

1.4 Social Acceptance and Environmental Impact

Although sustainable technological innovation has a direct and indirect impact on people's everyday life, social acceptance has, so it seems, only a limited impact on the choice of technologies in China and appears instead to be based on expert opinion formulated by academics, practitioners and bureaucrats (A. L. Wang 2013). The end-users, i.e. the public, define the sustainability and future of technology in the post-installation phase and are excluded from the decision-making process. Below I shall discuss this counter-intuitive pattern of social impact and social acceptance of sustainable technological innovation in China.

1.4.1. Social Impact of Technological Innovation

Sustainable technological innovation inevitably affects society and individuals. Any socio-economic activity requires energy (Assefa and Frostell 2007). Sustainable technology changes the way energy is produced and used. Therefore, technological innovation brings about social change.

First, the way of life changes, that is, how people live, work, and recreate. For example, the development of hydropower energy tends to require the relocation of large numbers of people, meaning that broader society-level benefits must be weighed against harm inflicted on specific individuals and groups. For example, during the realisation of the Xiluodu Hydropower Station project by the Three Gorges Group, over ten thousand people were relocated due to the dam construction (Y. Li et al. 2015), with dramatic consequences for those forced to migrate from rural to urban areas and having to accommodate to new lifestyles. Urban living might improve the quality of life for the relocated and their offspring in the long run. However, the experience of relocation is a psychological and physical burden, especially for the elderly (Colsher and Wallace 1990).

Second, innovation transforms culture: shared beliefs, customs, and values. Technology can change users' perceptions and understanding of norms and, consequently, their behaviour. Technological change becomes a self-fulfilling prophecy when communities' norms develop in tandem with technological transformations (S. Zhou and Smulders 2021). The co-evolution of communication technology, specifically mobile phones, and large-scale labour migration in China is a vivid example (Wallis, 2020). Wallis coins this process as *technomobility*. The development of mobile communication facilitated migration and profound social change.

Third, community life is influenced by technological innovation, namely stability, cohesion, services, and facilities (Feenberg 2012). For example, hosting communities of wind farms play an essential role in decision-making and technology exploitation, changing their lives. Innovation offers stakeholding, local-level energy security and job creation. Benefits inclusive of all community members guarantee societal acceptance (N. Hall, Ashworth, and Devine-Wright 2013).

Fourth, innovation may lead to the redistribution of power and the gain of political weight in decision-making (Coy et al. 2021). The state is an energy monopolist in China, which controls all key energy sources. Implementing sustainable technologies may contribute to power redistribution at the local level. For example, PCV panels allow users not only autonomous production of energy for their needs but also the provision of energy to the grid. In other words, it empowers the owner. This process can be described as energy democracy (Stephens 2019). The state can incentivise technology adoption by allowing local ownership. Still, it may also impede it by failing to provide necessary infrastructure (e.g. better grid facilities), despite environmental benefits (D. Liu and Xu 2018).

Fifth, the development of sustainable technologies may negatively affect the environment, such as availability, quality, and access to other resources (Kemp 2010). The exploitation of open-loop geothermal heat pumps may lead to the exhaustion of water resources, which in turn leads to issues with the availability of drinking water. The negative visual impact of wind farms on the landscape demonstrates the same point (Wüstenhagen, Wolsink, and Bürer 2007).

Sixth, sustainable technologies may cause various technological risks to people's health and well-being. Innovation's disadvantages range from negative visual impact, routine and accidental release of chemicals, damage to land use, impact on water resources, effect on the ecosystem, and noise pollution, to growing burdens of waste management (Tsoutsos, Frantzeskaki, and Gekas 2005). So, nanotechnology, an up-and-coming technological innovation, threatens workers participating in its manufacturing (Subramanian et al. 2016). In China's state rhetoric, nuclear power is interpreted as a sustainable alternative to energy production based on fossil burning. Yet atomic power plants possess considerable disaster potential, including radiological pollution of humans and natural resources (Christodouleas et al. 2011), meaning that weighing pros and cons is not binary between harm and benefit but a balance between a scale of severity and a probability ranking.

Seventh, sustainable technologies may interfere with personal and property rights (Hanna and Munasinghe 1995). For example, wind farms have a visual impact. It is believed to be harmful to bird life and people's health, and consequently, irrespective of actual harm or risk, it negatively affects nearby property value (Gibbons 2015). The shift in role (from victim to owner of technology) changes beliefs and may make decision-makers blind to specific harms or risks, like impacts on birds.

Eighth, technological innovation tends to be associated with fears and aspirations, that is, perceptions of safety and future gains versus danger and future loss, caused by, on the one hand, often unpredictable outcomes, on the other hand by hopes to find a solution (W. D. Lv et al.

2018). The “not-in-my-backyard” (nimby) syndrome arising from this pits the individual, the neighbourhood and the community against large-scale social progress and, in some cases, lead to social activism. Thus, innovation has a profound social impact. For its success, social acceptance is critical.

1.4.2. Social Acceptance

Social acceptance of technological innovation reflects what the public knows, thinks and feels about innovation. According to Wolsink (Wolsink 2012), social acceptance could be of three types depending on the actors and factors involved: socio-political acceptance, community acceptance, and market acceptance. Socio-political acceptance is shaped by the responses of stakeholders, policymakers, and the public regarding innovative technologies, supporting policies and subsequent institutional change (Fast 2013). Community acceptance reflects the attitudes of residents and local authorities driven by place attachment, landscape identity, perceived fairness of process and trust (Hammami, Chtourou, and Triki 2016). Market acceptance suggests tolerance to novel parties, products, and functions expressed by consumers, investors and incumbents (Wüstenhagen, Wolsink, and Bürer 2007). Therefore, social acceptance is represented by the general public (civil society/state paradigm), residents whose interests are directly influenced by innovation (users/interest groups paradigm) and customers (demand/supply paradigm).

The decisive paradigm in decision-making and technology acceptance (failure) depends on the socio-political context and innovation proximity. An individual/group can simultaneously assume roles of public, activists and customers. Therefore, the mainstream socio-political climate that shapes public choices and behaviour is decisive in the industrial world market incentives public choices to a great extent. Businesses tend now to use AI profiling and social media for nudging and incentivising behaviour.

In the neo-classical economic theory, the public is conceptualised as consumer-citizens, global citizens, etc. The most common approach to involve individuals in pro-environmental practices is to treat them as consumer citizens. This automatically positions individual ecological responsibilities alongside the consumer choice logic of a neo-liberal socio-economic framework (Barr, Gilg, and Shaw 2011). This applies that GHP's value goes beyond its economic and environmental benefits. The city government chooses sustainable technologies to improve the city's image; property developers opt for them to increase property attractiveness for high-end consumers. Residents find technologically advanced heating prestigious and modern, demonstrating their social status.

Researchers also distinguish so-called high-cosmopolitan consumers, who demonstrate relatively deep environmental concern and engage in sustainable behaviour (Grinstein and Riefler 2015). They suggest that to stimulate this group of consumers, sustainable products should be promoted as having an impact on the global rather than the local environment. However, studies show that high-cosmopolitan consumers are also prone to support local environmental initiatives by activating their local identity (Grinstein and Riefler 2015).

The approach that dominates the analysis of social acceptance of sustainable technology innovation in China is the "not-in-my-back-yard" (NIMBY) perspective (T. Johnson 2010). The NIMBY approach seeks public approval. In the context of NIMBY, the public is understood as an entity that has to be educated (Dear 1992). NIMBY is often referred to as a syndrome, something abnormal and requiring a cure. In other words, public opinion is studied to adapt it to the interests of the government or technology developers. It is similar to China-specific discourses on improving people's *suzhi* and transforming civic behaviour through education and guidance (Jacka 2009). The NIMBY approach takes a nominative stance on sustainable technologies and innovation, claiming them as an unquestionable social good and explaining the public opposition to lack of knowledge and awareness.

In economic terms, social acceptance is expressed in a willingness to pay, that is, readiness to carry the environmental costs. Research on acceptance of renewable energy resources demonstrated that willingness-to-pay (WTP) was correlated to socioeconomic characteristics, including education, income, environmental consciousness and knowledge about renewable energy technology and cost benefits (Stigka, Paravantis, and Mihalakakou 2014).

However, public WTP for GHP implementation in Shenyang was irrelevant.[3] The Shenyang municipality agreed to internalise the costs under pressure from the central government. Binding targets motivated local officials to comply with new environmental policies.[4] Thus, Shenyang's government obliged developers in 2017 to equip with GHP all the buildings under construction at that moment. Most of the 360 GHP projects in Shenyang were a retrofit of public buildings or installations in newly constructed residential buildings. Therefore, the locus of decision-making lies within local government agencies.

Technological innovation requires a certain level of socio-political acceptance, a lack of which leads to difficulties (Wolsink 2012). Acceptance is achieved through institutional changes, which are driven by political decisions. Therefore, mechanisms behind bureaucratic decision-making

[3] Interviewees 3, 4, 6, 9, 10
[4] Interviewee 10

on sustainable technologies have to be analysed. In the Chinese context with top-down sustainability innovation, socio-political acceptance is represented by the local government's compliance or compromise with the national development plans.

The role of opinion leaders has been cited as an essential driver of social change in case studies of adaptive management of natural resources, sustainability studies, and research on social capital (Keys, Thomsen, and Smith 2010). In China, these are mainly government and its representatives. They also serve as the primary agents of change, unlike in the US, where owners play vital roles in supporting and investing in sustainable design and construction, followed by designers, government officials and engineers (Ahn et al. 2013).

Sustainable innovation benefits from China's planning policy tradition. Planning generates trust between actors (Wolsink 2012). Planning helps to identify and address concerns and effectively communicate the potential risks and benefits. However, it lacks market acceptance when non-competitive government contracts initiate technology applications not embedded in the regional or local economy. It ceases to grow once the government's supporting policy expires (Wolsink 2012). In China, local governments' low-carbon initiatives often fail to achieve market acceptance (X. Chen et al. 2013).

Relations of power and legitimising affect sustainability. Techno-scientific approach to sustainability, when decision-making is based on a set of quantitative indicators, overlooks socio-political concerns of power and local opportunities for development. Legitimisation through power relations and criteria for socially determining values affect the task of achieving sustainability and sustainable communities (Scerri and James 2009). Based on preliminary research and data collection, the Shenyang government facilitated the GHP rollout through policies, legislation, analysis and control. Still, it is not enough for the technology to be sustainable. The exploitation phase showed that residents chose not to use the system in summer for cooling to save costs, which led to an environmental disbalance of the underground temperature.

From the NIS perspective, that is, from the state analysis level, the role of social acceptance and public opinion in sustainability processes is defined by the political system. Ward (Ward 2008) found that liberal democracies typically promote weak sustainability. Stable core autocracies perform worse on strong sustainability measures than stable core democracies.

Solid democratic institutions fail to guarantee that individuals accept personal responsibility for climate change. In other words, perceive it as personally relevant. A survey in the US and Great Britain in 2006 showed that climate change was psychologically distant for most individuals in both states; that is, the impact, causes, and solutions to climate change appeared to the responders personally irrelevant (Lorenzoni et al. 2006). More recent studies show that a high level of environmental awareness does not directly translate into personal pro-environmental behaviour (M. P. Hall, Lewis, and Ellsworth 2018).

1.4.3. Impact of Environmental Outcomes on Decision-making

No technology is sustainable on its own (Fiksel 2003). While advantages of sustainable technologies include reduced energy use, minimising environmental impact, and improved living environments for disadvantaged populations, technology can potentially impose adverse effects during manufacture, exploitation or unitisation (Martínez et al. 2009). Any technology is meant to become a waste. It means some negative impact is inherited in its nature. Only long-term exploitation can prove technology to be or fail to be sustainable (Meadowcroft 2009). The environmental outcome largely depends on the initial intent of the actors. Decision makers' priorities are decisive in this case.

With multiple actors involved in a process, conflict of interest is inevitable. There are at least two dimensions of these conflicts: application of sustainable technology as a public interest versus sustainable technology as a private interest of developers, and sustainable technology in competition with various personal interests versus sustainable technology in conflict with the general interests of the community (Wolsink 2012).

In the case of sustainable technology, innovation actors include stakeholders in development (incumbents in the existing energy supply sector, existing power production companies, power distributing companies, grid managing organisations/companies), innovation developers, technology producers, actors with vested interests in domains relevant to establishing innovative technology, actors representing energy consumers' interests, authorities and public bodies, local governments, stakeholders in related fields (landscape protection organisations, environment and nature protection organisations, all actors with interests in competing spatial functions, actors with interests in economic sectors potentially affected by innovation), public (general public, individuals with any perceived interest in innovation, communities, civil society.

There are two well-established analytical tools for measuring environmental impact: life cycle analysis (LCA) and environmental impact assessment (EIA). LCA is more specific and mainly used for commercial purposes, while EIA is more general and considered an analytical tool for political decision-making.

These tools for evaluating environmental impact are rationally oriented to serve commercial or political interests, not environmental goals per se (Aung, Fischer, and Shengji 2020). Environmental outcomes are not paramount factors for decision-making. Each case of implementing sustainable disruptive innovation is unique and cannot be fully replicated. Therefore, data on the environmental impact of implemented projects or modelling of potential projects are considered. Still, modelling does not define the result of decision-making, which is dependent on actors' interests and preferences. Although positive environmental outcomes appear to be the core target of sustainable innovation, at the phase of decision-making on sustainable technological innovation, ecological outcomes are just another factor in the line of many other variables that decision-makers consider.

Environmental Impact Assessment

Environmental impact assessment is based on the rational comprehensive planning theory (Morgan 2012). EIA is a complex analytical tool that involves several stages. First, screening identifies projects requiring full assessment (Enserink 2000; Wood and Becker 2005). The second is scoping, which determines which potential impacts need evaluation (Mandelik, Dayan, and Feitelson 2005; Snell and Cowell 2006)—followed by impact prediction (Duinker and Greig 2007), significance (Cloquell-Ballester et al. 2007; Ijäs, Kuitunen, and Jalava 2010) and follow-up monitoring (R. S. Marshall, Cordano, and Silverman 2005; Morrison-saunders and Marshall 2007).

Bartlett and Kurian (1999) adopt a political science perspective and identify six models they consider to have been implicit in discussions of EIA in the literature. The information processing model is essentially the rationalist, decision-support model. The symbolic politics model shows how EIA suggests following specific values but not necessarily holding to those values. The political economy model indicates that the private sector uses EIA to reduce financial risk and, if possible, increase economic opportunities by internalising environmental externalities. The organisational politics model describes how changes occur in the internal politics of organisations required to use EIA. The pluralist politics model identifies how the EIA process is used to open opportunities for negotiation and compromise among different interest groups. Finally, the institutionalist politics model shows how political institutions are changed significantly by the effect of EIA on values, actions and perspectives in their policy-making processes.

There is a significant gap between the best practice thinking represented in the research and practice literature and the application of EIA on the ground. EIA retains its inherent rationalist purpose and character, but that is not incompatible with recognising how other actors in the process may value different aspects of the process and that these views should be actively encouraged and protected. Similarly, concepts such as environmental justice and inclusivity ought to inform and add value to the design of EIA practice.

EIA in China is a top-down administrative instrument that came as a response to severe environmental deterioration and external pressure from international funding organisations. Therefore, unlike in Western countries, there was no preconceived notion that the public should be involved in the EIA process. In addition, EIA has become a highly scientific and technical process in China, and most practitioners must have specialised engineering backgrounds (Y. Wang, Morgan, and Cashmore 2003).

Life Cycle Analysis

Life cycle analysis assesses the environmental impacts and resources used throughout a product's life cycle, from raw material acquisition via production and use phases to waste management (Finnveden et al. 2009). A fundamental tenet of LCA is that every material product must eventually become waste (Ayres 1995). LCA has been used to study the overall impact of new technology, its components before it enters the market, and its environmental superiority over competing options (Martínez et al. 2009). Currently, traditional environmental LCA is broadening to a more comprehensive Life Cycle Sustainability Analysis (LCSA) (Simonen 2014).

The indicators used in the LCA methodology are the price of generated electricity, greenhouse gas emissions during the complete life cycle of the technology, availability of renewable sources, the efficiency of energy conversion, land requirements, water consumption and social impacts (Evans, Strezov, and Evans 2009).

LCA was applied to analyse energy technologies' life cycle, showing that hydro, nuclear and wind energy technologies can produce electricity with the least life-cycle global warming impact (Weisser 2007). Another example of LCA application is the comparison of the environmental impacts made between the renewal options of maintenance, consolidation, transformation, and redevelopment for two typical cases of Dutch urban renewal (Itard and Klunder 2007). It turned out that changing the existing housing stock was a much more environmentally efficient way to achieve the same result.

Studies showed that wind power is the most sustainable, followed by hydropower, photovoltaic and geothermal (K. Li et al. 2015). Wind power was identified with the lowest relative greenhouse gas emissions, the minor water consumption demands, and the most favourable social impacts compared to other technologies. However, it requires more extensive land and has high relative capital costs. The cost of electricity, greenhouse gas emissions and the efficiency of electricity generation were found to have an extensive range for each technology, mainly due to variations in technological options and geographical dependence of each renewable energy source (Varun, Bhat, and Prakash 2009). The LCA methodology is often applied as a post-design evaluation and is not used to support or optimise design decisions during early design stages (Meex et al. 2018).

1.4.4. Learning Space for Sustainability

Sustainability is an ongoing learning process, rather than an agreed-upon outcome, that can be prescribed, transferred or taught (Wals and Lenglet 2016). Therefore, it requires creating a learning space. Sustainability calls for sustaining resources and maintaining a normative position of moral responsibility for caring for people and the planet. Yet discourse on sustainability is unwrapping in a fast-changing world in a context contradictory to the idea of longevity. It means that individuals require new forms of learning and qualities to function well in an ever-changing context yet with long-term perspectives in mind (Wals and Lenglet 2016). Sustainability citizenship suggests the capacity to question and disrupt existing dominant social, economic and technological frameworks, but at the same time, an ability to lead morally defensible, ethical and meaningful lives. It is a combination of adaptation capacity and resilience. Acquiring such qualities could be driven by creating the physical, social, cultural and phycological spaces and conditions for critique, dialogue and participation that make learning possible (Wals and Lenglet 2016).

Climate change discourse is a disruption that leads to rethinking knowledge, responsibility, scale and place. Discourse on climate change steers a conflict between new and embedded practices that challenge citizen-consumer's ability to act as agents for change (Barr, Gilg, and Shaw 2011). Climate change is a dynamic disrupting process that generates discursive conflict on its right around fundamental issues of *knowledge, responsibility, scale and place* (Barr, Gilg, and Shaw 2011). It includes a discussion of the objectivity of scientific knowledge, the moral responsibility of current generations for the future generation's well-being, environmental costs bearing, one-fit-all, and global and local solutions.

To sum up, social acceptance of sustainable technological innovation is essential to guarantee long-term sustainability. Nonetheless, it has limited influence on political decision-making regarding sustainable technologies in China. Life cycle and environmental impact analysis are well-established political and industrial decision-making tools. Despite their ecological orientation, final decisions are driven by actors' preferences rather than analytical reports. Sustainable development is a learning-by-doing process. Evaluation of sustainable projects is, therefore, necessary as a learning experience.

II. Methodology

2.1. Research Design and Methods

This research is built around a case study. A case study method proved to be legitimate in a situation when the research question is asked about a contemporary set of events over which an investigator has no control (Franklin and Blyton 2013). The case study method limits the scope of analysis to a spatially, temporally and structurally identifiable unit, defines its components and develops a scheme to understand how the unit operates (Ulriksen and Dadalauri 2016).

This thesis analyses the process and outcome of the GHP implementation in Shenyang between 2006-2016 in its connection to the city's sustainable development. The research scope is limited in space (Shenyang), time (2006-2016) and structure (party-state). It is focused on the decision-making, the actors and the project's outcomes to understand the internal logic.

A pilot project is a common developmental approach in China, especially regarding sustainable, low-carbon innovation (Song, Liu, and Qi 2021). Yet, a pilot project towards sustainability in Shenyang as a case study stands out due to Shenyang's specific administrative status in the party-state hierarchy (Cartier 2015). Shenyang is a sub-provincial city. A sub-provincial city is considered a provincial-level planning unit with economic and executive power and independence compared to provinces. Thus, the city's development plans result from direct negotiations between Beijing and Shenyang.

Sub-provincial cities are comparable to directly-administrated municipalities (Beijing, Shanghai, etc.), which have provincial status. Sub-provincial cities have negotiation power similar to directly-administrated municipalities but lack their wealth. Being economically advanced, directly-administrated municipalities have fewer challenges balancing economic and environmental targets (L. Zhang et al. 2020). Shenyang, however, a former heavy industry vanguard, struggles to recover its economy since the reform and opening-up, postponing internalising costs to nature as long as possible in favour of economic growth (Kostka and Nahm 2017). Yet, unlike an average sizeable Chinese city, it can negotiate its environmental targets directly with the central government agencies. Shenyang presumably is an example of a Chinese city with minimum necessary environmental efforts expected and approved by the central government. Thus, on the one hand, local-central relationships in the case of Shenyang are relatively straightforward, which makes causal connections simpler. On the other hand, compared to a province, a city is a structurally more accessible unit of analysis simply because the bureaucratic apparatus is smaller. Therefore, the GHP pilot project in Shenyang is suitable for studying the mechanism of local-central compromise on sustainable innovation.

A case study method reconstructs a real-life context. Due to the complexity of any socio-technological system, its modelling requires multiple sources of evidence, both qualitative and quantitative (Yin 1992). This includes official documents, local reports, statistical data, and stakeholder interviews.

One of the potential weaknesses of a case study method is subjectivity due to the probable difficulty in distinguishing between evidence and the investigator's interpretation. This weakness can be overcome if a case study report builds database readers can reinterpret (Yin 1992). Thus, data on individual GHP projects in Shenyang obtained from an internal report is objective and open for interpretation.

2.1.1. Policy Documents

Qualitative document analysis is a research method for systematically analysing the contents and themes of written documents (Wesley 2010). The approach is used in social sciences to facilitate consistent analysis of written policies. Policy documents provide an overview of policy issues, the history and context of political and legal developments, and the emergence of new concepts (Karppinen and Moe 2019). Policy documents are an efficient, cost-effective way to access contemporary and historical policy debates (Cardno 2018). Documents are stable, as they can be stored, retrieved and copied at any moment allowing for revisiting and reinterpretation (Bowen 2009). Most policy documents analysed in this theses are accessible online except Shenyang local reports obtained from interviewees.

Policy documents can be sources and texts (Karppinen and Moe 2019). In traditional policy analysis, documents are used as factual and contextual sources that help to identify policy actors, trace their activities and positions, and uncover facts about policy processes. Alternatively, some researchers focus on the quality of documents as text, treating them as meaningful social artefacts that have consequences independently of the authors' intentions (F. Fischer 2003). It implies that the document's words and language frame narratives and discourses worth analysis on their own (Moe and Karppinen 2011).

This research analyses policy documents as sources of background and contextual information. Sampling started with central and local five-year plans as China's core policy documents. Further, short and long-term development plans, laws and local policy papers were selected if they refer to sustainable development, environmental management, renewable energy, science and technology. All selected documents were in Chinese, in their original version. Chinese scholarship on policy documents was included in the analysis to avoid interpretation biases.

Although a policy document is understood as an objective source of factual information, it is a social phenomenon (Salminen, Kauppinen, and Lehtovaara 1997). It implies that policy documents are created for a specific purpose, by particular people, at a certain time and place. Draft versions of documents shared between government agencies remain unavailable to the public. This is particularly fair in the case of the Chinese policy processes that lack transparency (Ran and Jian 2021). Development plans in China are contractual documents between central government agencies or central and local governments. They are the outcomes of internal negotiations, the details of which are undisclosed. Therefore, while considering the issue framed by a policy document, the persistent question is how it sheds light on what has been left outside the suggested framework. Document analysis is often used with other qualitative research methods for triangulation, in this case - semi-structured interviews.

2.1.2. Semi-structured Interviews

A semi-structured interview is a dialogue between an interviewer and a respondent to get information or explore a particular field of action (Döringer 2021). Although the interviewer prepares a set of questions, the discussion unfolds in a conversational manner (Longhurst 2013). Unlike document analysis, semi-structured interviews are time-consuming, labour-intensive, and require interviewer sophistication (Adams 2015).

The theoretical basis of the national innovation system approach and skimming of the related policy documents allowed us to identify critical stakeholders: central and local governmental agencies and experts in academia and industry. Initially, users were considered to influence the decision-making process. However, research showed they hardly impacted the decision-making process regarding implementing GHP in Shenyang. Therefore, the sample of respondents was narrowed down to experts. An expert is a person who is responsible for policy development, implementation or control and/or a person who has privileged access to information about the process (Meuser and Nagel 2009).

Respondents were selected through snowball sampling. Snowball sampling is based on networking and referral (Naderifar, Goli, and Ghaljaie 2017). The researchers usually start with a small number of initial contacts who fit the research criteria and are invited to become participants and then asked for further references. Experience shows that the snowball method is effective in China once the entry point into the network is found.

Fourteen in-person expert interviews were conducted in Beijing and Shenyang between September 2015 and June 2016. My initial contacts in Beijing were professors at Renmin University, where I had affiliation at that moment. With their help, I was introduced to Beijing's representatives of governmental agencies. I was also invited to the 7th Geothermal Heat Pump Forum, which took place in Jinan in September 2015. There I was able to network with industry representatives. Direct contact with companies by e-mail, phone or visit was fruitless.

Networking in Shenyang started accidentally. I met a school principal on the train drive from Shenyang who got interested in my research and introduced me to a contact at the Shenyang government, leading to further references. All respondents were in the leadership of the respective departments.

The meetings were arranged on the phone or via WeChat. The interviews were held in Chinese. On average, a discussion took about an hour and a half. The experts generally were open to answering questions and sharing views. Assumed due to the GHP being a marginal topic related to the past. Besides, respondents appreciated and were eager to respond to the questions asked with a deep knowledge of the subject. The complete list of interviewees can be found in Appendix.

Methodologically semi-structured interviews are critiqued for lack of neutrality and high effects of interaction (Van Audenhove and Donders 2019). Information received during an interview is subjective and dependent on the interview setting. The interview procedures are not strictly standardised and cannot be repeated from respondent to respondent. An open non-structured dialogue makes the interviewer an active participant.

Nonetheless, experts provide valuable technical knowledge (specific data in the field), process knowledge (routine, interaction, processes) and explanatory knowledge (rules, beliefs, ideas, ideology). In the Chinese political economy, experts are a unique source of knowledge about the system's internal dynamics and logic.

2.2 Ethics

Ethical considerations are vital in constructing the research design that involves personal interviews. The design was based on the Social Research Association Ethics guidelines (Social Research Association 2021).

Interviewees were selected, and interviews were held with a clear ethical understanding of the research. Participants were informed about the purpose and nature of the research. If they consented to participate, they were told that the data received during an interview could be used in research.

Interviewees were invited to appoint the time and place of the interview, giving them control of the location where they would feel comfortable and secure. Most of the interviews took place at the interviewees' offices.

No interviews were recorded to guarantee a relaxed and friendly atmosphere, avoid any suspicion, tension or worry caused by the presence of a recorder, and prevent any potential harm that a recording could cause. Instead, after receiving the interviewees' consent, I took notes during and right after the interview. None of the participants is named or identifiable from the data presented in this thesis.

III. Introducing Geothermal Heat Pumps in Shenyang

3.1 Central Planning: Institutional Frameworks for Implementation

As discussed in Chapter I, policy processes in China are dominated and guided by planning. Most local policy decisions come as a reflection and expansion of national plans, with GHP implementation in Shenyang being no exception. This part will analyse national planning documents that prompted the Shenyang government to favour GHP to improve the environment. We will start with the 11^{th} five-year plan as China's primary development reference, then refer to sector-specific development plans.

3.1.1. 11^{th} Five-Year Plan

GHP projects were initiated in Shenyang in 2006. This coincides with the beginning of the 11^{th} five-year plan (State Council of China 2006), which makes their interconnection even more apparent. The hypothesis is that applying GHP technology hit several high-priority objectives stated in the 11^{th} FYP to the extent that risks associated with disruptive innovation such as GHP were worth taking. This part will explain why instead of choosing less radical heating options such as gas or air-to-air conditioning as it happened in Beijing or any other type of technological innovation for a social cause, the Shenyang government favoured GHP.

The 16th National Congress of the Communist Party of China and the 11^{th} FYP put forward the grand goal of building a well-off society in an all-around way. The 11^{th} FYP established a new growth model for the economy. The new model describes the transition from extensive growth to intensive growth. Economic growth is no longer mainly driven by investment but by science and technology and the development of related production-oriented service industries. It requires increasing independent innovation potential, industrial structure modernisation, promotion of the service industry, advancing urbanisation and improving living standards in rural areas. Accordingly, the system is more important than technology, and the key is the transformation of government functions to realise the 11^{th} FYP.

The 11^{th} FYP consists of 48 chapters divided into 14 thematic parts. All GHP-related information occurs in the first seven parts. Assuming that subjects introduced in five-year plans are organised based on priority, GHP appears as a convenient choice and solution.

Chapter 1 outlines the achievements of the 10^{th} five-year plan, key challenges and objectives. Among critical challenges are mentioned energy insufficiency, environmental vulnerability, and lacking technological innovation. Chapter 2 encourages further transformation of the economic growth mode, in which resource conservation is a basic national policy. It calls for the "development of recycling economy, protection of the ecological environment, acceleration of the construction of resource-saving and environmentally friendly society and promotion of the coordination between economic development and population, resource and environment". Besides, it highlights the necessity of "improving independent innovation ability" and "resolving the practical issues related to the people and masses' vital interest".

Chapter 2 explicitly recommends "to push forward development by saving resources and protecting the environment", "to increase resource utilisation efficiency", "to enhance independent innovation ability," and "to improve the people's living standard as the fundamental starting point and footprint". These objectives fit well GHP profile: energy saving, an ecologically friendly technological innovation that provides heating, which is an essential requirement to living standards in the severe cold climate.

Further, Chapter 3 states obligatory and anticipated quantifiable objectives. A total of 22 goals are combined into four classes: economic growth; economic structure; population, resource, environment; people life, and public service. Most obligatory indicators belong to the third class. Among eight mandatory indicators, two correspond with GHP benefits: a 20 % reduction in energy consumption per unit of gross domestic product and a 20 % reduction in the total emission of major pollutants.

While Part 2 (Chapters 4-9) is devoted to agriculture and the construction of new social villages, Part 3 (Chapters 10-15) highlights industrial structure optimisation and upgrading. The particular focus is on large-scale, high-efficiency clean power generation equipment: "optimally develop thermal power with emphasis given to large scaled high-efficiency environmental protection units" and "accelerate the elimination of backward small thermal power units", meaning coal heating units. While outside of China, GHP is mainly installed in private suburban houses, in China, GHP is typically applied in large apartments and office buildings.

Chapter 12 advises to "carry out preferential finance and taxation and investment policies and mandatory market share policies, encourage the production and consumption of renewable energy resources and increase its proportion in the primary energy consumption" and "actively develop and utilise solar energy, *geothermal energy* and ocean energy". Chapter 13 calls for the technical advancement of the building industry.

Chapter 24 highlights preventing air pollution and improving air quality and control. Local governments are appointed responsible for the environmental situation in their jurisdictions. They are also encouraged to yearly increase investments in environmental protection.

Provinces in China enjoy relative financial autonomy. Such financial independence means flexibility in economic activities, but it is naturally accompanied by the responsibility to increase revenues and attract investments, primary financial flows from the Central government. The 11th five-year plan identified key fields supported by the Central government investments. The critical areas included, among other things, cutting coal use in the public service sector, environmental protection and remediation, energy conservation projects, resource-saving technology research and development, and updating heating facilities. GHP profile overlaps with several required fields. Therefore, the choice of such technology increases the local government's chances of receiving funding from Beijing and is a substantial factor in decision-making.

3.1.2. The Renewable Energy Law of the People's Republic of China

The Renewable Energy Law of the People's Republic of China 中华人民共和国可再生能源法 (Standing Committee of the National People's Congress 2005) offers valuable insights as guidance for China's renewable energy developmental trajectory and local government's decision-making. Below I will analyse the sections of the Law which correspond with the GHP application.

The Standing Committee approved the Renewable Energy Law of the NPC in the 14th Session on February 28, 2005, one year before the 11th FYP and the intensive GHP application in Shenyang. It first defines what is understood by renewable energy, namely "non-fossil energy of wind energy, solar energy, water energy, biomass energy, geothermal energy, and ocean energy", with hydropower development being regulated separately.

The Law claims utilisation of renewable energy is the preferential area for energy development. It encourages various entities of ownership to participate in using renewable energy and guarantees the protection of the legal rights and interests of the developers and users of renewable energy. It appoints local governments responsible for managing renewable energy utilisation within their jurisdiction, including preparing renewable energy development and utilisation plans based on the targets set by the national government. The State Council must approve regional development plans. National standardisation authorities must provide technical standards for renewable technologies and products. The Law states the legal responsibilities of local governments and officials to comply with the Law.

The Law announces governmental funds for renewable energy R&D, pilot projects, renewable energy resource exploration, and equipment production. Specifically, the 2005 version of the Law mentions only such technologies as various types of grid-connected renewable power generation, biological liquid fuel, and solar energy utilisation systems. Geothermal technologies are not mentioned. However, the Law promises preferential loans to renewable energy development and utilisation projects listed in the national renewable energy industrial development guidance catalogue, including GHP.

Obliged by the Law, energy authorities compile development guidance catalogues for renewable energy industries to support actors' decision-making. The renewable *energy industry development guidance catalogue* 可再生能源产业发展指导目录 published in 2005 includes 88 technologies (National Energy Administration 2005). Apart from stating the technology type, the Catalog describes the functional purpose of each technology and its process status ranging from technology R&D and pilot projects to technology advancement, marketisation and promotion. The Catalogue explicitly mentions geothermal technology marked as "R&D and promotion of application". This recognises the emergent level of technology and simultaneously its high potential.

3.1.3. Medium and Long-Term Energy Conservation Plan of the People's Republic of China

China Medium and Long-Term Energy Conservation Plan 节能中长期专项规划 (National Development and Reform Commission of the PRC 2004), finalised by the NDRC in 2004, is the first energy conservation document issued by the central government since the reforms of opening. The Plan defines intense energy conservation as a strategic guideline in decision-making and a paramount factor for sustainable and rapid economic development. The Plan is an integral part of China's long-term energy development strategy.

According to the Plan, the main issues to be addressed are coal-based energy production and consumption, oil supply scarcity, high industrial energy consumption, and increasing residential energy consumption. It should be noted here that environmental considerations appear only later in the Plan's text in the context of conservation work tasks.

The Plan identifies as well key barriers to overcoming the above challenges. First, it is insufficient knowledge, first of all among policymakers about the importance of energy conservation. Second, it points to an inadequate legal base and a lack of laws and regulations. Thirdly, national policies fail to incentivise local governments in energy conservation work. Fourth, the existing energy conservation mechanism is administratively driven. It is primarily disconnected from the market and, therefore, unsustainable. Fifth, the underutilisation of energy conservation technologies prevents further development. Finally, regulatory and service institutions need to be further developed. All these challenges, except for the technological one, are institutional. This recognises the importance of institutions in hindering or fostering China's development and intends to reform them.

The Plan connects energy conservation to the transformation of the economic growth pattern. It is strategically important and shrewd because, for several decades, Chinese governments have oriented themselves towards economic growth at all costs. Transformation of the growth model requires a shift in the bureaucratic consciousness; the realisation of energy conservation demands an even greater effort. Associating energy conservation with economic growth sets it as a priority and instrument of transformation.

Secondly, the Plan connects energy conservation to technological advancement and institutional change. It explicitly encourages local governments to invest in technological innovations and adjust management structures to achieve set goals.

The Plan emphasises the necessity of market creation. The experience has shown that innovation led by administrative mechanisms is not sustainable. Therefore, innovation should be market-based with limited government regulation, mainly in legal management and policy incentives.

Finally, public participation is necessary for achieving energy conservation goals. Public participation is mentioned last, though, which proves the top-down strategy of the Chinese government in energy conservation and places the responsibility on the cadres' shoulders.

The Plan circles required fields of energy conservation, including crucial industries (electric power industry, nonferrous metals industry, oil and petrochemical industry, chemical industry, building material industry), transportation, construction, and commercial and residential building. The passage on energy conservation in construction, commercial and residential buildings explicitly mentions utilising geothermal energy for space heating. Moreover, building energy conservation projects are identified as critical projects. Residential and public buildings were expected to reach the strict 50% energy-saving standard through updated heating systems and energy-saving construction technologies and products. Besides, 20% of government agencies' buildings were expected to be retrofitted with energy-saving technologies for lightning, air-conditioning and space heating.

Local governments are asked to include energy conservation as a priority factor in formulating plans and policies per local conditions. They are also encouraged to adjust local policies for effective energy conservation, invest in innovation and promote advanced technologies.

The Central government commits to providing funding, subsidies and loans to significant energy conservation projects, technological innovation, and pilot projects. The local government had to accomplish a large-scale energy conservation project to receive financial support from Beijing. This, among others, explains why the local government opted for the large-scale rollout despite high risks and little previous experience with GHP in Shenyang.

3.1.4. Energy Conservation Law of the People's Republic of China

China's Energy Conservation Law 中华人民共和国节约能源法 (Standing Committee of the National People's Congress of China 2018) was adopted at the 28th Session of the Standing Committee of the 8th National People's Congress on November 1, 1997, and amended at the 30th Session of the Standing Committee of the 10th National People's Congress on October 28, 2007, and later in 2018.

The Law defines energy conservation as

> stepping up energy utilisation management, and taking measures that are technologically feasible, economically viable and environmentally and socially affordable for purposes of lowering consumption, reducing losses and pollutant discharge, and stopping wastefulness in all phases from energy production to its consumption, to realise an efficient and rational utilisation of energy resources (Standing Committee of the National People's Congress of China 2018).

As it follows from the definition, the leading role in energy conservation processes is given to management and technologies, which should not become a burden to the economy and be environmentally and socially acceptable.

Article 4 proclaims resource conservation as a fundamental state policy. This demonstrates a distinct contrast with the previous economic growth model, in which intense resource exploitation was the main development driver.

The Law demands local governments to incorporate energy conservation in economic and social development plans and formulate medium and long-term unique strategies for energy conservation with the obligation to report their progress annually to the people's congress or their standing committees at corresponding levels (Article 5). The target responsibility system obliges local governments and officials to commit to energy conservation goals (Article 6).

The Law mentions various actors responsible for energy conservation, such as any energy-consuming unit, individuals, news media, producers and importers of goods, producers and sellers of energy-consuming products, statistics departments, and industrial associations. They are obliged by the law to pursue energy conservation and have the right to report any act of wasting energy.

However, local governments of the provinces, autonomous regions, and municipalities directly under the central government are appointed as the driving force in the transformation process. They are expected to reform industrial structures, limit polluting industries, negotiate and pursue enterprises to decrease energy intensity, increase efficiency in energy utilisation, and support the development of renewable energy resources. These tasks become a burden for local governments, whose revenues rely on energy-consuming and polluting industries like Shenyang. Therefore, to meet the target in energy intensity set by the central government, they tend to divert their efforts from energy-intense yet profitable industries to other sectors, which are less essential for the local economy, such as the construction sector.

The Law encourages institutional innovation in the form of energy-conservation service agencies for consultancy, design, evaluation, inspection, auditing, and authentication work.

Article 57 advises local governments to prioritise energy-conserving technology in their R&D investments, support scientific research, formulate standards, and promote innovation. The Law identifies incentive measures such as special funds for R&D and pilot projects, supportive policies by the central and local governments, and preferential tax policy for producing and utilising energy-conserving technology and products.

Article 86 forbids corruption, favouritism, and power abuse in energy conservation management. Failure to prioritise energy conservation is also pronounced to be prosecuted with a warning, fine, public criticism, or legal procedures.

3.1.5. Medium and Long-Term Development Plan for Renewable Energy in China

The Medium and Long-Term Development Plan 可再生能源中长期发展规划 (National Development and Reform Commission of the PRC 2007) was drafted and issued by NDRC in 2007. It aimed to speed up the utilisation of renewable energy, improve energy conservation, reduce environmental pollution, mitigate climate change, and provide guidance and strategy for renewable energy development in China till 2020.

The Plan confirms that China's low and medium-temperature geothermal resources are abundant and suitable for industrial and agricultural use and space heating. In the section Priority Sectors, the Plan explicitly, among other technologies such as hydropower plants, biomass power generation, biogas technologies and biomass gasification, liquid biofuels, wind farms, solar PV, and solar thermal systems, mentions and encourages the promotion of geothermal heat pumps.

3.1.6. Critical Points of Renewable Energy Industry Development Plan 2000-2015

The Plan 2000-2015 年新能源和可再生能源产业发展规划 (State Planning Commission 2000) was formulated by the State Planning Commission, the State Science and Technology Commission and the State Economic and Trade Commission. It starts with a focus on the guiding ideology and basic ideas. Technology and market development potential come second. Recognising ideas and vision before the material base is a reoccurring narrative in Chinese planning documents.

The Plan includes five technology types: solar water heaters, solar cells and photovoltaic power generation systems, wind power technology, geothermal heating technology, biomass energy conversion technology, and promising technologies.

Geothermal technology gives the Plan an optimistic outlook due to the abundant geothermal resources across the country, successful pilot projects, and primary market conditions. The technology is described as mature and ready for widespread use.

The target was to reach 15 million square meters of the geothermal heating area by 2005, 22.5 million square meters by 2010 and 30 million square meters by 2015. This is to be achieved through a set of measures—first, the market's development and technology's localisation. Second, complete equipment supply, production, and utilisation guarantee are sustainable and environmentally friendly. Third, provide institutional support through a sound system of economic incentive policies in terms of tax, credit, investment, price, and subsidies. Lastly, promote scale development. In other words, the Plan shows evident support for GHP technology.

The National Medium- and Long-Term Program for Science and Technology Development (2006-2020) 国家中长期科学和技术发展规划 (The State Council The People's Republic of China 2006) drafted by the State Council of the People's Republic of China only mentions geothermal energy without specific reference to any technology.

Technical codes for GHP were developed relatively late in the early 2000s. The technical code for water-source heat pumps (GB/T19409-2003) was issued in 2003 (General Administration of Quality Supervision 2003) and replaced by GB/T19409-2013 in 2013 (General Administration of Quality Supervision 2013). The technical code for the ground source heat pump system (GB50366-2005) was approved by the Ministry of Construction in 2005 (Ministry of Construction 2005) and revised in 2009 (Ministry of Construction 2009). The abovementioned policy documents were crucial in creating an institutional framework for the GHP rollout in Shenyang.

3.2 Local Policy Priorities

3.2.1. Shenyang's Administrative Status

Shenyang has a special administrative and economic status in the Chinese system as a provincial capital and an agglomerate of the Northern East. Between 1983-1994, Shenyang was a city under direct central planning 计划单列市, meaning it shared much less of its revenue with the province, and its top leaders were directly appointed by the centre (Ling 2018). The policy delegated to such cities a wide range of economic decision-making power formerly reserved only for the provincial-level authorities. It allowed direct access to the central government over financial planning without going through the provincial government (Cheung 2005).

In 1994 with 15 other provincial capitals, Shenyang's status was changed to a sub-provincial city. In terms of national economic and social development planning, the State Council and other competent departments regard sub-provincial cities as provincial-level planning units, significantly increasing their importance.

Administratively speaking, the municipal party committee's secretary, the city People's Congress director, the mayor, and the chairman of the Municipal Committee of the CPPCC of the sub-provincial city are all cadres at the deputy ministerial level. They are not appointed by the provincial party committee but directly by the Organization Department of the Central Committee. The cadre level of other administrative organs is also different from that of ordinary prefecture-level cities. For example, the municipal districts and municipal institutions of sub-provincial cities are at the deputy department level; that is, the district head and the director of the municipal bureau are equivalent to the deputy mayor of prefecture-level cities, while the deputy district head and deputy director of the municipal bureau are at the deputy bureau level.

The distinction is helpful for city development and for demarcating power between the provincial capital government and the provincial government. There is evidence that the size and growth of the city are closely related to its administrative level. With the improvement of the executive level, the urban population and land use scale show an exponentially increasing trend (Wei 2014).

The direct appointment of Shenyang cadres by Beijing impacts the status of the city’s development plans. In Western democracies, an urban development plan introduced during elections is a negotiation between the city government and voters. The government gets access to political power to fulfil citizens' expectations; it’s contractual. In the case of China’s sub-provincial cities, development plans are contracts between the central and local governments.

The officially published plans are the final result of the negotiation process, agreed-on targets necessary and sufficient for the country's development and manageable for a local government.

3.2.2. Shenyang 11th Five-Year Plan (2006-2011)

Shenyang 11th FYP, like any local FYP in China, was drafted based on the national and provincial 11th FYPs (Shenyang Government 2005a). The revitalisation of Shenyang's old industrial base 全面振兴沈阳老工业基地 is the critical objective of Shenyang 11th FYP. This goal is described in the document in an emotional way creating a strong narrative that connects Shenyang’s past and future: *historical revitalisation… to create a new glory of Shenyang's old industrial base* 再创沈阳老工业基地的新辉煌. Revitalising the industrial base means reforming the local economic system, but it is not limited to it. On the one hand, it is about promoting enterprise system innovation, completing the separation of main and auxiliary enterprises of municipal state-owned enterprises, making progress in the overall joint venture of large enterprises, and restructuring small and medium-sized enterprises. On the other hand, revitalising the industrial base is also dependent on administrative reform and transformation of government functions, improving rural and urban infrastructure. Below I will analyse the content of Shenyang 11th FYP and show how sustainability-related goals are weaved into the development plan.

Shenyang 11th FYP has ten themes and consists of 37 chapters. Themes include discussion of the overall aim, guiding ideology, industrialisation strategy, coordinated development of rural and urban areas, urban planning and spatial development, innovation and opening up, education and talent management for the revitalisation of the old industrial base, resource use and sustainable development, social development, ethnic consolidation.

The Plan states that the city's GDP reached 224 billion CNY in 2005, double that of 2000, with an average annual growth of 13.8%, which the city planned to continue. Local fiscal revenue reached 18.13 billion CNY, almost four times that of 2000, with an average annual increase of 30.8%. The total investment in fixed assets of the whole society reached 361.9 billion CNY, 3.6 times that in the 9th FYP period, with an average annual increase of 39%. The total retail sales of consumer goods reached 91.4 billion CNY, with an average yearly increase of 11.7%. These local economic trends were higher than the national economy, with an average growth of 9.5%. The intensity of the economic growth, Shenyang's government orientation towards it and its intention to keep it up shows that among a variety of objectives set by the national 11th FYP, economic growth remains Shenyang's paramount priority.

According to the Plan, achieving these objectives means overcoming local challenges. China's accession to the WTO in 2001 intensified competition in the automobile industry, one of the cores of the Shenyang economy. It led to the 94internationalization of the domestic market, specifically in terms of resources, markets, technology, and talents. Besides, the consequences of low GDP, underdeveloped leading industries, institutional contradictions, the need for economic structure reform, lack of independent innovation, and unemployment added to the pressure of meeting the goals of the FYP.

Along with challenges, Shenyang's local context has its potential. International cooperation and investments in production and R&D, rich energy and human resources had the potential to create opportunities for further development, specifically in the heavy chemical industry and construction of Liaoning urban agglomeration.

Ideologically, FYP offers the vision of Shenyang as a harmonious “four in one” city 逐步把沈阳建设成为新型工业城市、法治诚信城市、先进文化城市、模范生态城市“四位一体”的和 谐沈阳, that is an innovative industrial city, law-based city, cultural city, and eco-city. This was to be achieved by expanding urban functions, strengthening leading industries, and promoting rapid economic development and social progress. Becoming a “four in one” city also meant first, entering the first tier of sub-provincial cities 全国副省级城市“第一集团, which is based on economic performance, and second, being a driving force for a national strategy of the revitalisation of Liaoning province and the northeast of China. It means becoming an advanced national equipment manufacturing centre, regional business logistics and financial centre.

The Plan offers guiding principles for the development. It calls for support of sustainable and rapid industrial transformation. It means the modernisation of the economic structure following sustainable development directions, speeding up resource-saving, construction of environmentally friendly cities, and coordination between economic development and population, resources, and the environment.

It requires coordinated development of urban and rural areas following the principles of *“industry feeding agriculture, cities supporting rural areas”,* agricultural modernisation and rural urbanisation, formation of a more dynamic and open institutional environment for international cooperation, and increasing cities’ livability through science and education, talent management and independent innovation, improvement of the legal system.

The Plan set ambitious economic goals. The average annual economic growth of the city was 13%, striving to reach 15%, and the per capita GDP was double that of 2005. The average annual growth rate of local fiscal revenue was 15%, striving to reach 20%. The total retail sales of social consumer goods increased by 12% annually. The average annual growth rate of foreign direct investment must get 15%. The average annual growth rate of total imports and exports is 20%. Investment in fixed assets was 15% annually, striving to reach 20%.

The Plan demands optimisation of the economic structure. The total output value of industries was expected to increase by more than 20% annually. It is to be reached through further development of the key sectors and enterprises with independent intellectual property rights and strengthening international competitiveness. The output value of the high-tech industry must account for 35% of the total industrial output value. The proportion of modern and emerging service industries in the service industry is to be increased to 53%. The transformation of the ownership structure of the state-owned enterprises is emphasised. The proportion of the non-public economy in the total economic output must reach more than 70%.

Industry development is treated as a fundamental policy. Integration of existing resources and strategic investment is the main strategical tools. The total output value of the city's industries was expected to reach 400 billion CNY in 2007 and 800 billion CNY in 2010. It suggested the realisation of 800 industrial projects with an investment of more than 5 million CNY annually.

The paragraph *Introduction and development of the industrial clusters with output value exceeding 10 billion CNY* 引进建设一批超百亿元产业集群 lists companies and industrial brunches that receive governmental attention. Among them are machinery and auto parts manufactory of Tiexi Cluster 铁西新区通用机械和汽车零部件产业集群, TBEA Group 特变电工集团 producing power transmission and transformation equipment, Yuanda Group 远大集团 specialising on the glass curtain wall, aluminium-plastic and steel structure. Shenggu Group 沈鼓集团 from this list deserves particular attention in the light of the research question.

Shenyang Blower Group 沈阳鼓风机集团股份有限公司 (or shortly Shengu Group 沈鼓集团) is a large-scale state-owned enterprise established in 2003 with about 6000 employees and total assets of 9.6 billion CNY. Its predecessor, Shenyang Blower Factory 沈阳鼓风机厂, was founded in 1932. It became China's first industrial fan manufacturer in 1952 with a state investment of 1.7 million CNY. In 2004 Shendu Group was transformed into Shenyang Water Pump Company and Shenyang Gas Compressor Company, respectively producers of water pumps and gas compressors. The reorganisation resulted from the national strategy of revitalising the Northeast's old industrial base and cooperation between provincial and city governments. From this perspective, favouring the GHP rollout in Shenyang since 2006 meant supporting the national project of revitalising the Northeast's old industrial base, guaranteeing production orders to the state-owned enterprise, and providing employment in the area.

Increase urbanisation level to 70%, simultaneously improving infrastructure and promoting the development of Liaoning urban agglomeration (Shenyang Economic Zone). Improving citizens' quality of life implies the development of education, spiritual-cultural life, health, sports activities, and support to ethnic minorities, for example, to reach an average life expectancy of 76 years and to keep the incidence rate of infectious diseases below 200 per 10 million.

Living standards measured by the per capita disposable income of urban residents were expected to reach 18,000 CNY, and the per capita net income of rural residents was expected to be 9000 CNY, the metropolitan residential floor area per capita to get 28 square meters.

Environmental targets include increasing forest coverage to 36%, reaching 85% of the urban sewage treatment rate, 20% less of the total energy consumption of GDP per 10,000 CNY compared to the 2005 level, laying the basis for the recycling economy, and constructing energy-efficient cities.

The 8th theme of the Plan *Focus on resource development and environmental protection, adhering to urban sustainable development* 坚持资源开发与环境保护并重，不断增强城市可持续发展能力 is devoted to sustainable development. It discussed the improvement of ecological construction and environmental protection by establishing the system of *"ecological security, environmental support, ecological industry and ecological culture*" 建立"生态安全、环境支撑、生态产业、生态文化"四大体系. This means working on the construction of an ecological city 生态市, taking measures against deforestation, environmental monitoring network, development of ecological tourism, river water quality control, construction of urban sewage treatment plants, domestic and industrial waste treatment, urban noise control, air quality improvement, control over coal and dust pollution.

Second, according to the Plan, sustainable development means constructing a resource-efficient city. Resource-efficient city seeks growth along with energy, water, land, and material efficiency by improving the resource management system.

Specifically, it requires energy conservation in high-intensity industries, including power generation, industrial production and building materials, energy efficiency in construction and transportation sectors, and promotion of technological innovation and renewable energy resources, which results in the energy consumption per 10,000 yuan worth of regional GDP lower down to 0.9 tons of standard coal equivalent.

Finally, sustainability is associated with developing a circular economy, that is, adherence to the principle of "*reduction, reuse and resource utilisation*" in equipment manufacturing, pharmaceutical and chemical industry, the automobile industry and significant energy-consuming households.

The paragraphs concerning restructuring the economic structure are precise and extended compared to the sections on social development, which are vague. This again demonstrates that the economy was the focus and concern of the local government in the 11th FYP.

GHP is implicitly mentioned in the Plan twice. First, the production of water pumps (part of a GHP system) is referred to in the 8th Chapter *Promotion of "sange yipi" projects* 集中推进"三个一批"项目建设 under the theme *New industrialisation path and rapid development of industrial economy* 走新型工业化道路，实现工业经济跨越式发展. Second, exploration of geothermal energy is discussed in the 18th Chapter, *Reinforcement of infrastructure construction and improvement of urban functions* 加强基础设施建设，不断完善城市功能 under the theme 拓展发展空间，加快建设东北地区中心城市.

3.2.3. Distribution of Tasks

Notice on Distributing the Responsibilities of the 11th Five-Year Plan for the Economic and Social Development of Shenyang City 关于印发沈阳市国民经济和社会发展第十一个五年规划纲要任务分解方案的通知 was issued in December 2006 (Shenyang Government 2006b).

The Notice highlights general goals, specific tasks, and governmental agencies responsible for realisation. The Notice defines three significant goals for the period of the 11th five-year plan. They are revitalising old industry 基地全面振兴, constructing a Northeast central city 加快建设东北地区中心城市 and entering the first tier of sub-provincial cities which is based on GDP growth 经济总量力争进入全国副省级城市“第一集团”. Besides, the focus is on key development areas such as industrial and high-tech parks, cultural centres, agricultural processing clusters, tourism and resort areas, the service industry in the metropolitan area, construction of landmark buildings.

The introduction identifies critical tasks, all of which are aimed at sustainability. The essential functions include a clear definition of arable land, a reduction of energy consumption, and decreasing industrial and domestic sewage discharge. Specifically, the total energy consumption of 10,000 CNY of regional GDP must have been reduced during the 11th FYP period by 20%, with an average annual decrease of 4%. The Municipal Economic Commission was appointed to achieve this goal, with the cooperation of the Municipal Development and Reform Commission, Agricultural Commission, Construction Commission, Transportation Bureau, and Bureau of Commerce.

The Municipal Economic Commission leads economic restructuring and bears responsibility for developing 800 industrial projects with an investment of more than 5 million yuan each year and supporting the development of enterprises exceeding 10 billion yuan.

The task of energy structure transformation is to be led by the Municipal Development and Reform Commission, coordinated by the Municipal Construction Commission, Economic Commission, Kangping County Government 康平县政府 and Municipal Gas Corporation 市煤气总公司. The energy reconstruction requires reasonable development and utilisation of coal and geothermal resources, introducing high-efficiency energy sources such as natural gas and coalbed methane and increasing the daily gas supply to 1.66 million cubic meters. The notice highlights the reconstruction and management of the heating system with the requirement for central heating to reach 90%.

Work on energy conservation in crucial energy-consuming industries and energy-consuming enterprises, as well as in buildings and transportation, is led by Municipal Economic Commission and distributed between the Municipal Construction Commission, Agricultural Commission, Transportation Bureau, Commercial Bureau, and district and county governments. The task is to decrease the energy consumption per 10,000 yuan of regional GDP to less than 0.696 tons of standard coal. The energy conservation rate must reach 65% in new residential buildings and 50% in public buildings.

The urban reclaimed water use rate must reach 30% under the supervision of the Municipal Construction Committee, coordinated by the Municipal Planning and Land Bureau, Water Conservancy Bureau, Urban Construction Bureau, and Environmental Protection Bureau.

Ecological protection work that aims at dealing with deforestation, land desertification, and soil erosion is lying within the responsibility of the Municipal Forestry Bureau, coordinated by the Municipal Construction Committee and Water Resources Bureau. Protection and restoration of wetlands, treatment of urban sewage, and improvement of the domestic waste treatment and industrial solid waste treatment systems are led by the Municipal Environmental Protection Bureau, coordinated by the Municipal Construction Committee and Water Resources Bureau.

3.2.4. Implementation Opinions on Comprehensively Promoting Construction and Application of GHP Systems

Implementation Opinions on Comprehensively Promoting Construction and Application of Ground Source Heat Pump Systems 关于全面推进地源热泵系统建设和应用工作的实施意见 is Shenyang government policy document issued in 2006, that describes plans for GHP promotion, distributes responsibilities and declares supporting policies (Shenyang Government 2006a).

According to the Opinions, Shenyang was listed by the Ministry of Construction as a pilot city for the GHP application. It states that the geological and hydrological conditions of the city fully meet the technical requirements for implementing GHP. For example, within the 455 square kilometre area of the city centre, 409 square kilometre area is fitted for GHP application. The work on GHP promotion is a part of the municipal Party Committee's and the municipal government's effort to build a resource-saving and environment-friendly society.

The document requires increasing GHP heated area from 3.12 million square meters to 18 million square meters by the end of 2007. By the end of 2010, the application area must reach 65 million square meters and account for 32.5% of the current heating area in the city.

GHP small leadership group was formed to coordinate the work of district and county governments. The Opinions oblige district and county governments to establish GHP Planning and Construction Office and implement GHP systems in all projects that are being declared but not approved and the projects that have been approved but not yet started. Existing public buildings such as government offices, hotels and office buildings should be retrofitted with GHP.

GHP users are exempted from paying water use fees to reduce operating costs. The electricity costs are charged according to the civil electricity price. Besides, districts that apply GHP are promised financial funds from the Ministry of Construction and policy preferences compared to the coal-fired heating areas. The city government establishes a technical consultation office to provide any necessary technical guidance and guarantee. It also promises to remove any admirative barriers and ease formal procedures for companies willing to promote or implement GHP.

Finally, the Opinions declare support for GHP market development and welcome local and international companies willing to invest and build factories producing GHP equipment and supporting materials in the city.

3.2.5. Measures of Shenyang Municipality for the Administration of Construction and Application of GHP Systems

Measures of Shenyang Municipality for the Administration of Construction and Application of GHP systems 沈阳市地源热泵系统建设应用管理办法 came into force in August 2007 (Shenyang Government 2007). In contrast to the Opinions, which focus on planning, the Measures create a detailed framework for the formal GHP application and post-installation monitoring procedure. Earlier GHP projects showed the need for standardisation of construction and application of GHP systems and post-installation monitoring. Any organisation that builds, applies, or uses GHP has to abide by the Measures.

Article 4 of the Measures state governmental agencies and their responsibilities. Thus, the Municipal Construction Commission 市城乡建设委员会 and the Municipal Real Estate Administrative Department 市房产行政主管部门 are respectively in charge of the construction and operation management. The Municipal GHP Planning and Construction Management Office 市地源热泵规划建设管理办公室 is responsible for the supervision and management of the building. The Municipal Heating Management Office 市供热管理办公室 is accountable for the monthly supervision and control. In contrast, the district and county (city) construction and real estate administrative departments are responsible for the daily management of the construction and application. Besides, the municipal planning, land and resources, water conservation, environmental protection, urban management and administrative law enforcement, quality control and technical supervision departments shall cooperate in promoting GHP.

The Measures demand to pay equal attention to development and environmental protection. It means that economic benefits should not be considered before ecological impact. It also asks district and county municipalities to prepare a detailed plan for GHP application in their jurisdiction.

The formal procedures of GHP construction involve several steps. First, a GHP project requires approval from municipal planning and the land and recourses department. Second, the GHP office should issue an opinion based on project design and environmental impact assessment. Third, the construction unit should issue a permit, and the Municipal Water Conservation Department should issue a license for water intake. Finally, the construction unit should organise relevant departments to get the final acceptance of the project.

The design of the GHP system shall comply with the current national technical codes. GHP equipment must obtain a production license. The GHP Office should be ready to address technical problems that occur during the construction and operation phases.

After a GHP system is implemented, the Municipal Construction Commission is responsible for monitoring ground and building settlement. The Municipal Water Conservation Department undertakes the monitoring of water volume dynamics. The Municipal Environmental Protection Department shall organise groundwater water quality control and inspect the reinjected water. While the unit using the GHP system must ensure that all extracted water is reinjected. GHP management unit must formulate an emergency plan to take relevant measures to eliminate dangerous situations. GHP operators shall receive technical training from relevant departments.

Illegal construction and use of GHP entail administrative penalties. Failure of water reinjection is fined no less than 10000 yuan, but no more than 30000 yuan. Users of intake wells unequipped with water meters are fined 5000-20000 yuan. Intentional damage to a GHP system constitutes a crime.

3.2.6. Other Plans and Regulations

The basic situation of adjustment and transformation of Shenyang's old industrial base 沈阳市老工业基地调整改造的基本情况 developed by the Shenyang Development and Reform Commission was published in August 2005 (Shenyang Government 2005c). Its topics coincide with the Shenyang 11th FYP. It does not mention renewable energy or GHP. Shenyang Land Use Plan for 2006-2020 沈阳市土地利用总体规划 (2006-2020 年) does not discuss renewable energy except for solar power (Shenyang Government 2005b).

Regulations on Shenyang Air Pollution Prevention and Control 沈阳市大气污染防治条例 published in 2003 require city and county governments to take measures to improve energy structure, promote central heating and cleaner energy sources (Liaoning Provincial People's

Congress 2003). It prohibits installing and using coal-fired boilers in areas where centralised heating is available.

Newly built and rebuilt residential quarters and other construction projects that require heating should be connected to the centralised heating system. The environmental protection bureau must approve the installation of individual coal-fired boilers when other options are unavailable. Using individual coal-fired boilers is forbidden when energy restructuring is encouraged, and GHP becomes a well-fitted alternative.

3.3 GHP Projects in Shenyang

Before 2006 GHP projects in Shenyang were individual initiatives. After 2006, GHP promotion became a government-led policy. The national and local context forced Shenyang to take measures to promote low-carbon heating technology. First, it responded to the pressure to optimise the energy supply and adjust its structure. Energy demand continues to increase along with population growth, further industrialisation and urbanisation, and expansion of the city's heavy chemical and construction industries. The contradiction of energy constraints faced by economic development and environmental pollution caused by energy consumption becomes more prominent. According to the deputy director of Shenyang Construction Commission, Sun Xiaoguang, it was essential to overcome the ideological constraints of considering an energy supply strategy limited to conventional resources. Thus, developing efficient and clean energy is the key to optimising the energy supply and adjusting the energy structure.

Second, the GHP technology rollout was necessary for environmental protection and for building an eco-city. According to the National 11^{th} FYP, by the end of the 11^{th} FYP, the energy consumption per 10000 yuan of GDP had to be reduced by about 20% compared with the end of the 10^{th} FYP, with an average annual energy saving rate of 4.4%. During the 11^{th} FYP period, 560 million tons of standard coal should have been saved to promote China's economic growth mode of high input, high consumption, high pollution and low efficiency to low information, low consumption, and low pollution. The 11th FYP for environmental protection of Shenyang required that during the 11th FYP period, the number of days with good urban ambient air quality or equivalent level 2 standard had to reach 330 days; the concentration of PM10, the primary pollutant in the ambient air, to decrease to 0.110mg/ m^3; the concentration of SO2 remains lower than 0.06mg/ m^3; the concentration of NO2 be lower than the national level 2 standard; the energy consumption of 10000 yuan GDP reach 0.9 tons of standard coal; and the SO2 emission decrease to 2.7kg. Developing a GHP heating system and reducing coal consumption met the requirements of the state and Shenyang for energy conservation and environmental protection.

Third, the GHP promotion is a necessary condition for the development of building energy conservation. In the 11^{th} FYP, China's heating energy consumption per unit building area was 2-3 times higher than developed countries with similar sub-climatic conditions. According to experts, it was feasible to fully implement the 50% energy-saving standard in public and residential buildings in China. Compared with developed countries, even after reaching the goal of 50 % energy saving. Shenyang's 11th FYP for building energy conservation stipulates that all new residential buildings must get 65% of the energy-saving rate. In comparison, all public buildings must reach a 50% energy-saving rate. Using renewable energy for buildings' energy supply is integral to building energy conservation.

Thus, the local government was pressured to address air pollution and was pushed by the central government to cut emissions.[5] Apart from relocating factories to the outskirts, which was done successfully and contributed to improved air quality and lower emissions levels,[6] the municipality considered various renewable sources.[7] The leading principle for technological innovation was either economic benefit or reduction of emissions.[8]

There are limited conditions for exploring wind and solar energy in Shenyang. However, the local underground water resources are abundant. Especially after heavy industry's relocation outside the city, Liaohe and Huhe River crossing Shenyang became affluent again.[9] The gas heating alternative was considered but rejected as unsustainable because it would increase the city's dependence on gas supply from outside of the province.[10]

Thus, Shenyang Municipal Development and Reform Commission suggested to the city leaders to promote GHP technology as a low-carbon heating alternative.[11] In the following two months, meetings with experts took place, and city leaders visited GHP-operated sites in China and abroad.[12] Afterwards, a decision to promote GHP in Shenyang was made.

In 2006, the municipality established two agencies to promote GHP implementation Shenyang Ground Source Heat Pump Association 沈阳市地源热泵协会 responsible for research and training и Ground Source Heat Pump Office 地源热泵办公室 responsible for actual policy implementation. Functionally Ground Source Heat Pump Office, the leader of related

[5] Interviewee 6
[6] Ibid.
[7] Interviewees 5, 10
[8] Interviewee 1
[9] Interviewee 3
[10] Interviewee 6
[11] Ibid.
[12] Interviewees 5, 6, 10

departments, was an efficient and critical driver for policy realisation.[13] District leaders signed obligations to implement GHP measured in a heated area.[14] GHP construction contracts were allocated through the bidding system. GHP policies allowed companies, most not local[15], to pay lower taxes and utilise underground water free of charge.[16] Besides, the government set electricity prices for operating GHP at a residential rate rather than commercial. The provincial government was not financially involved in the pilot project.[17] In June 2016, the respondent stated that GHP technology is no longer promoted in Shenyang.[18]

Although GHP promotion in Shenyang was a government-led initiative, its implementation involved many actors. Below I provide detailed information about 30 GHP projects in Shenyang from an internal governmental report. These projects include newly constructed residential, public, and industrial buildings and retrofits. The focus is on companies involved in the design, construction, and supervision of GHP projects and GHP producers. Most of the projects were completed in 2007-2008. However, some projects were completed earlier. That data is provided for comparison between projects built before and after 2006. These 30 projects are part of 483 projects completed in Shenyang by the end of 2008.

Chengjian Dongyi Garden

Chengjin Dongyi Garden condominium 城建东逸花园 is located along the Xiaohe road in Shenyang Dadong District, covering a total area of 20 hectares and 510,000 square meters. GHP is used to heat in winter, cool in summer, and provide a swimming pool and bathing centre with hot water.

---

[13] Interviewee 3
[14] Ibid.
[15] Interviewee 6
[16] Interviewees 6, 11
[17] Interviewee 9
[18] Ibid.

Chengjian Dongyi Garden GHP project, with a construction area of 370,000 square meters, was completed and put into operation in November 2005. The project was jointly designed by Shenyang Urban Construction and Real Estate Development Co., Ltd. 沈阳市城建房地产开发有限公司[19]and Singapore Yakuben Design Management Service Co., Ltd. 新加坡雅科本设计管理服务有限公司. Shenyang Urban Construction and Real Estate Development Company developed and constructed the project. Shenyang Ruizhi Urban Construction Consulting Co., Ltd. 沈阳瑞志城建项自管理咨询有限公司[20] supervised the project. The heat pump units were produced by Yantai Lande Air Conditioning Production Co., Ltd. 烟台蓝德空调工业有限责任公司[21].

The project is one of the largest in China. It uses terminal units of several types, including 156,000 square meters heated by a radiator heating system, 87,000 square meters heated by underfloor heating, 120,000 square meters heated by a fan coil unit, 10,000 square meters of swimming pool and bathing centre heated by a hot water distribution system. Use purposes were matched with eleven GHP units of a different type, including four high-temperature units. The total heating load is 17000kW, and the entire cooling load is 24000 kW. There are 15 intake wells and 43 reinjection wells.

[19] State-owned enterprise founded in 1999 specialising in real estate development, commercial housing sales, housing rental, venue leasing, and municipal engineering construction.
[20] State-owned small enterprise was established in Shenyang in December 2004, with no official web page.
[21] Founded in 2001, Yantai Lande Air Conditioning Industry Co., Ltd. is a high-tech enterprise integrating scientific research, production, and sales located in Yantai (Shandong province). It designs and manufactures environmentally friendly, energy-saving and emission-reduction heat pumps. The company is listed as China's water (ground source) heat pump industrialisation base by the Ministry of Construction. It has been China's leading production enterprise of water heat pump units since 2008, a member of the National Ground Source Heat Pump Committee, the China Refrigeration Society, and China Refrigeration and Air Conditioning Industry Association (Lande Official Website n.d.).

The indoor temperature meets the requirements of national design specifications. According to the survey, the users felt the changes brought by GHP technology, namely warm and clean environment and lower operating costs.

This project is a successful GHP application in a large multi-functional building in a severe cold climate zone with a relatively low temperature of underground water. Apart from saving energy and providing comfortable living conditions, GHP equipment takes less space in the machine room than traditional technologies.

Shenyang Qipanshan Ocean World

Shenyang Ocean World 沈阳市棋盘山海洋世界 is located in the middle of Qipanshan International Tourism Development Zone 棋盘山国际风景旅游开发区, 15 km away from the centre of Shenyang City, with an overall area of 1.53 million square meters. It is one of the highlights of the 2006 Shenyang Expo. It includes a large aquarium, a dolphin hall, and a museum.

Shenyang Qipanshan Ocean World GHP project, with a construction area of 28,500 square meters, was completed in August 2006. The project was undertaken by Liaoning Rixin Industrial Group Co., Ltd. 辽宁日新实业集团有限公司[22]. Liaoning Jindi Second Construction Co., Ltd. 辽宁金帝第二建筑工程有限公司[23] and Shenyang Hexing Construction and Installation Co., Ltd. 沈阳合兴建筑安装工程有限公司[24] took over construction work. Shenyang Changhua Supervision Company 沈阳长华监理公司[25]was responsible for supervision. The GHP units were produced by Yantai Lande Air Conditioning Production Co., Ltd.

[22] Established in July 2006
[23] State-owned construction enterprise was established in Shenyang in 2001
[24] Established in 2001
[25] Established in Shenyang in 1995

The seawater aquarium consumes 2500 kW with a temperature requirement of 23-25 °C, and the freshwater aquarium and tropical rain forest zone take 300 kW. The dolphin hall's thermal load and air conditioning require 675 kW, the heating load of swimming pool water is 1000 kW, while the thermal load of the bathing centre and diving area is 350 kW and 230 kW, respectively. The air conditioning of the tropical rainforest zone requires 680 kW. The aquarium and ticket hall utilise 130 kW and 110 kW, respectively, plus 2110 kW used by other areas. The total heat load of the project is 8055 kW. It includes heating pool water (4000 kW) and, bathing centre water (350 kW), air conditioning (3705kW).

The GHP system consists of three independent and interrelated parts: air conditioning, pool water heating, and hot water supply. Two GHP sets of type GSHP-C1878D are used for air conditioning, two sets of GSHP-C2078D pumps are installed for pool water heating, and one GSHP-C0348D pump is utilised for the hot water supply system.

Due to the improved design, the underground water used for air conditioning in summer with an outlet temperature of around 25°C is partially recycled. Apart from decreasing underground water consumption (inlet temperature 12°C), it also improves the energy efficiency of two central heaters and reduces operation costs.

According to the business owners, since the GHP system was used, it has been operating steadily. It meets the requirements of pool water heating, air conditioning and heating and has a low operation cost.

Shenyang Party Committee Office Building

Shenyang Party Committee Office Building 沈阳市委办公楼, with a construction area of 40,000 square meters, was retrofitted with GHP in October 2007. The project was designed by China Northeast Architectural Design and Research Institute Co., Ltd. 中国建筑东北设计研究院有限公司[26] and constructed by Shenyang Langchen Environment Co., Ltd. 沈阳朗晨环境有限公[27]. The construction work was supervised by Liaoning Architectural Design, Research and Project Management Consulting Company 辽宁省建筑设计研究院工程项目管理咨询公司[28]. The heat pump units were produced by Tsinghua Tongfang Artificial Environment Co., Ltd 清华同方人工环境有限公司[29]. The system consists of two SGHP1200 units. The GHPs use thirteen wells, including two intake wells, nine reinjection wells and two standby wells.

Liaoning Provincial People's Hospital

Liaoning Provincial People's Hospital 辽宁省人民医院, with a construction area of 70000 square meters, was equipped with GHP in May 2004. The project was designed by Shenyang Architectural Engineering Design Institute 沈阳建筑工程设计院[30], constructed by Shenyang Langchen Environment Co., Ltd. 沈阳朗晨环境有限公 and supervised by Zhongliao Supervision Company 中辽监理公司[31]. A preliminary geological survey was done by Liaoning

[26] A daughter company of China State Construction Engineering Corporation 中国建筑工程总公司 (World's Top 500 Enterprises 2018) was founded in Shenyang 1993.

[27] Founded in July 2004

[28] Established in Shenayng 1993

[29] The company was established in Beijing in 2000. It is specialized in R&D, manufacture of air conditioning equipment.

[30] Established in 1987

[31] The company information is not to be found online.

Architectural Design Institute 辽宁省建筑设巧研究院岩土公司[32]. The heat pump unit was produced by Tsinghua Tongfang Artificial Environment Co., Ltd 清华同方人工环境有限公司.

The five sets of SGHP1000 were installed. The cooling load of the project is 4872 kW, and the heating load is 5170 kW. The GHP system allows for saving 7600 tons of standard coal equivalent every year. The initial investment payback is seven years. The project was rated as a national GHP pilot project and received an 8-million-yuan subsidy from the Ministry of Finance in a direct loan.

Northeast University Swimming Pool

The GHP project at the Northeastern University swimming pool 东北大学游泳馆, with a construction area of 6775 square meters, was completed in November 2005. Northeast University initiated the project. Beijing Zhongke Huayu Energy Technology Co., Ltd. 北京中科华誉能源技术有限责任公司[33] acted as a construction unit, the assessment was done by survey engineering company of Shenyang Cuohuan Design Institute and Engineering Assessment Company 沈阳市错缓设计院勘察工程公司[34], and the supervision was undertaken by Shenyang Yuchen Supervision Company 沈阳市宇晨监理公司[35]. Beijing Zhongke Huayu Energy Technology Co., Ltd produced the heat pump units.

Although the construction area was 6775 square meters, due to the floor height of 21 meters, it is equivalent to 47425 square meters of heating area. The GHP system serves to supply heating, cooling, and water heating. It consists of seven HE450 units, three of which are used for heating

[32] Established in Shenyang in 1993
[33] Established in Beijing in 2002
[34] It is the largest state-owned city survey enterprise in Northeast China founded in 1952.
[35] Established in 1998

water in the pool and shower area, and four units provide heating in winter and cooling in summer. The terminal units include two types of technology: fan coil and underfloor heating.

The system relies on six wells, which can be used interchangeably. During the system's operation, two wells are used for pumping, and four wells are used for reinjection. The ratio of pumping wells to reinjection wells is maintained at 1:2. The wells depth is 46 m, the designed pumping capacity of a single well is 100 t/h, and the reinjection capacity of a single well is 50 t/h. Since the project was completed and put into operation in November 2005, the average indoor temperature in winter is 30 ° C, the average indoor temperature in summer is 28 ° C, and the pool water temperature is 27-28 ° C. The system operates well and meets the design requirements.

The total investment was 3.5 million yuan, excluding the cost of the terminal units, which were equivalent to 73.80 yuan/ m^2. The average price of each heating period is 22.50 yuan / m^2, including electricity, equipment depreciation, labour cost, etc. In 2007 the project was rated by the Ministry of Construction as "China’s Building Energy Conservation Exemplary Project” “2007 年中国建筑节能年度代表工程".

Shenshuiwan Sewage Treatment Plant

The first phase of equipping Shenshuiwan Sewage Treatment Plant 沈水湾污水源热泵集中供暖系统工程 with a GHP system for heating was complete in March 2008. The heating area reached 2.6 million square meters. The project was designed by Shenyang Thermal Power

Research Institute 沈阳热力研究院[36], constructed by China Railway 18th Bureau 中铁十八局[37] and supervised by Huasheng Supervision Company 华盛监理公司[38].

The heat pump unit was produced by Shenyang First Refrigerator Co., Ltd 沈阳第一冷冻机有限公司[39]. It was then the largest in capacity and highest efficiency GHP made in China. The innovation was based on technology transferred from the British Hall Group. The screw compressor was three times more effective than any existing option on the domestic market. The direct link between the control system and the steam engine produced an energy-saving effect. The sewage source heat pump extracts heat from the sewage water with an output temperature of 70 ° C. The total heating capacity is 120 MW. The project was listed as a critical demonstration of sewage water utilisation in Shenyang.

The Second Hospital of China Medical University

The project of GHP installation at the Second Hospital of China Medical University 中国医科大学第二临床医院 was completed in November 2002. The project was designed by China Construction Northeast Design and Research Institute Co., Ltd. 中国建筑东北设计研究院有限公司, constructed by Guangdong Jirong Construction and Installation Co., Ltd. 广东吉荣建筑安装有限责任公司[40], and supervised by Shenyang Institute of Construction and Engineering 沈阳建工学院. The heat pump units were produced by Shandong Fulda Air Conditioning Equipment Co., Ltd 山东富尔达空调设备有限公司[41].

[36] Established in 1985
[37] A state-owned construction enterprised founded in 1958 with headquarters based in Tianjin
[38] Esbalished in Beijing in 2000
[39] Formerly a large state-owned Liaoning Test Equipment Factory. Founded in 1949, it is one of the earliest manufacturers or refrigeration equipment, central air conditioning equipment in China.
[40] The company information is not to be found online.
[41] Established in Yantai in 1995, the company develops and manufatures various types of geothermal heat pumps.

The location of the hospital is rich in groundwater, which is suitable for applying a water source heat pump. The total construction area of the central hospital building and office building is 61,000 square meters, the total heat load is 5640 kW, and the entire cooling load is 5150 kW. The GHP system consists of five LSBLGR(I)-1100 pump sets for heating and cooling with a fan coil system as terminal units. Eighteen wells were drilled, five were intake wells, and thirteen were reinjection wells.

It is one of the earliest water source heat pump projects in Shenyang. It has been operated safely ever since. The indoor temperature reaches 22 degrees in winter and 26 degrees in summer. The GHP installation has improved the hospitalisation environment for patients and brought economic benefits to the hospital.

Tiexi Department Store

The GHP installation at the Tiexi department store 铁西百货, with a construction area of 20,000 square meters, was completed in December 2004. The project was designed by Shenyang Huawei Electromechanical Design Institute 沈阳华维机电设计所[42], constructed by Shenyang Huawei Engineering Co., Ltd. 沈阳华维工程有限公司 and supervised by Shenyang Jianxin Supervision Company 沈阳建新监理公司[43]. The two sets of 30HXC-400 HP2 GHP units were provided by the US Carrier Global Corporation and Shanghai Yileng Carrier Air Conditioning Equipment Co., Ltd. 上海一冷开利空调设备有限公司[44].

[42] Established in 1992
[43] Established in 1998
[44] Established in 1995 and specialised in HVAC equipment

The GHP system is used for heating and cooling. The project has been functioning safely and reliably.

Shenyang Hotel

The retrofitting of Shenyang Hotel 沈阳宾馆 with a GHP heating system, with a building area of 36,000 square meters, was completed in January 2007. The project was designed by Shenyang Huawei Electromechanical Design Institute 沈阳华维机电设计所, constructed by Shenyang Huawei Engineering Co., Ltd. 沈阳华维工程有限公司 and supervised by Shenyang Supervision Company 沈阳监理公司. The heat pump units were produced by the US Carrier Global Corporation and Shanghai Yileng Carrier Air Conditioning Equipment Co., Ltd. 上海一冷开利空调设备有限公司. The heating system includes two sets of 30HXC-250HP2 heat pumps with a heating capacity of 560 kW and a water outlet temperature of 60 ° C. There are three dual-purpose wells and six reinjection wells.

The system is used for heating in winter, cooling in summer, and hot water supply for hotel rooms, a swimming pool, a sauna, a laundry, etc. Compared with the original heating system, the one-year operation costs were reduced by 30%.

Taiyuan Lakeside Garden

Located in Heping District, Taiyuan lakeside garden 泰袁湖畔佳园 has a construction area of 247,000 square meters, which includes residential buildings, office buildings, hotels, clubs, and other buildings. The Municipal Construction Commission, the GHP Office and the Water Resources Office supported the project.

The GHP project of Taiyuan lakeside garden was completed in October 2007. The project was constructed by Liaoning Tianyi Construction Co., Ltd. 辽宁天一建设有限责任公司[45], supervised by Shenyang Zhendong Construction Project Supervision Co., Ltd. 沈阳市振东建设工程监理有限公司[46]. The geological survey was done by Liaoning Geological Engineering Survey and Construction Group 辽宁地质工程勘察施工集团公司[47]. The heat pump units were produced by McQuay Air Conditioning and Refrigeration (Wuhan) Co., Ltd. 麦克维尔空调制冷(武汉)有限公司[48].

The system comprises eight sets of water source heat pumps, three circulating pumps for high and low areas, and water reinjection and water treatment equipment. The total heating capacity is 2901 kW, and the entire cooling capacity is 11867 kW. The ratio of intake and reinjection wells is 1:2. The depth of the wells is 52 m, the spacing between reinjection wells is 35-38m, the spacing between intake wells and reinjection wells is 50 m, and the spacing between intake wells and reinjection wells is 70 m. A remote monitoring system is installed in the intake wells and reinjection wells to display the water level, water temperature and flow in the well in real-time and transmits data to the municipal water resources management office.

The total water consumption is 700 - 900 m^3/h, and the total circulation volume of the pump power frequency conversion system is 1100 m^3/h. The pumping water temperature is 13 -13.6°C, and the return water temperature is about 7°C. The supply water temperature of the GHP unit is 45°C, and the return water temperature is 40°C. The average indoor temperature of the residence and office is 20-22°C. The system operates well and meets the design requirements.

[45] Founded in Shenyang in 2003, the company designs and installs HVAC systems
[46] It is a large enterprise established in Shenyang in 1996.
[47] Established in Shenyang in 1992
[48] Established in Wuhan in 1992. The company drafted the national GHP technical codes.

Shenyang Civil Air Defense Office

The GHP reconstruction of Shenyang Civil Air Defense Office 沈防市人民防空办公室, with a construction area of 40,000 square meters, was completed in November 2007. The project was designed by Liaoning Architectural Design and Research Institute 辽宁省建筑设计研究院. Northeast Jincheng Hanxiang Project Department 东北金城汉翔项目部[49] undertook the construction. The geological survey was run by the Liaoning Institute of Geology and Mineral Resources Assessment 辽宁省地质矿产局综合勘察院[50]. The construction work was supervised by Liaoning Zifa Construction Consulting Co., Ltd 辽宁咨发建设预算咨询有限公司[51]. The heat pump units were produced by McQuay Air Conditioning and Refrigeration (Wuhan) Co., Ltd. 麦克维尔空调制冷(武汉)有限公司.

The total heating load is 2863 kW, and the entire cooling load is 2594 kW. The system consists of three GHP sets with a fan coil as a terminal unit. There are three intake wells and five reinjection wells.

Institute of Metal Research, Chinese Academy of Sciences

The GHP project as the Institute of Metal Research, Chinese Academy of Sciences 中国科学院金属研究所, with a construction area of 30,000 square meters, was completed in 2004. The project was constructed by Shenyang Sanse Air Conditioning Engineering Co., Ltd. 沈阳三色

[49] A large state-owned construction company established in 1952
[50] Established in 1988
[51] A state-owned enterprise founded in Shenyang in 2002

空调净化工程有限公司[52]. The heat pump units were produced by Yantai Ebara Air Conditioning Equipment Co., Ltd. 烟台荏原空调设备有限公司[53].

The total heat load of the project is 2008 kW, and the entire cooling load is 1892 kW. The system consists of two RHSBW930HS8 GHP units, two intake wells and three reinjection wells with a fan coil as a terminal unit. Since its operation in 2004, the system has had stable performance and function. The indoor temperature can reach over 20°C and be freely adjusted in the office.

Shenyang Haiyun Plaza

Haiyun Plaza 沈阳海韵广场 was developed and built by Haiyun Real Estate Development Co., Ltd. 海韵房地产开发有限公司 of Dalian Economic and Technological Development Zone. It is located in Tiexi District. The complex includes a five-star hotel, high-end apartments, and an office building. There are 387 apartments and 400 hotel rooms.

The GHP air conditioning project at Shenyang Haiyun Plaza has a construction area of 100,000 square meters. The construction was undertaken by Dalian Zhongxing Refrigeration Co., Ltd. 大连中星制冷有跟公司. The heat pump unit was produced by Qingdao Haier Air Conditioning Electronics Co., Ltd. 青岛海尔空调电子有限公司.

The GHP system consists of two LSBLGR1800D units, two LSBLGR1620 D units for heating and cooling, and one LSBLGR850D/R4 unit for hot water supply. The GHP system uses underground water. There are four intake wells and nine reinjection wells, which are 50m deep

52 Established in Shenyang in 1992

53 It is a joined enterprise of Japan's Ebara and Yantai Binglun Company 烟台冰轮股份有限公司 established in 1996. It specilises in production of air conditioning equipment.

with well spacing of 30m. The pumping capacity of a single well is 125t /h, and the reinjection capacity of a single well is 40 t/h. The pumping and reinjection wells could be used interchangeably in winter and summer. The control system monitors the temperature of the inlet and outlet water to regulate water intake. This reduces the GHP energy consumption and guarantees the optimal operation of the system. The system is equipped with a fan coil as a terminal unit.

The system's operation is efficient and stable. In winter, the temperature of hot water is 50°C / 45°C, the temperature of the well water is 11°C / 4°C, and the indoor temperature is 20-23°C. The heating period lasts 152 days (from November 1 to March 31 of the following year). The daily average power consumption in 152 days is 15579 kW h/d, and the cost is 17.05 yuan /m2. The hot water is supplied 24 hours, automatically controlled by PLC to achieve the best operation.

Shenyang Northern Passenger and Freight Transport Terminal

The GHP project of Shenyang Northern Passenger and Freight Transport Terminal 沈阳市沈北新区客货联运总站, with a construction area of 11,191 square meters, was completed in 2007. The project was designed by Shenyang Architectural Design Institute 该工程由沈阳市建筑设计院, constructed by Liaoning Hengyuan Heat Pump Technology Development and Application Engineering Co., Ltd. 辽宁恒源热泵技术开发应用工程有限公司. The geological survey was undertaken by the Antai branch of Liaoning Geological Engineering Assessment and Construction Group 辽宁地质工程勘察施工集团公司安泰分公司. The construction work was supervised by Shenyang Shenfei Construction Management Co., Ltd. 沈阳市沈飞建设管理有

限公司[54]. The heat pump units were produced by Tianjia Air Conditioning Equipment Co., Ltd. 天加空调设备有限公司[55].

The system consists of two GHP sets. The total heating capacity is 1682 kW, and the entire cooling capacity is 1558 kW. The underfloor heating is used in winter, and the fan coil is used in summer for cooling.

The underground heat exchange wells of the system adopt the self-developed geotechnical tester to collect and extract the thermophysical property data of the subsurface soil in this area. After professional software model calculation, the length of the underground heat exchange pipe is 6400 m, the size of the heat exchange well is 1600 m, and the depth of a single well is 83 m. One hundred ninety-two heat exchange wells are drilled, with a well diameter of more than 150 mm and a well spacing of 5m. The heat exchange wells cover an area of 4800 square meters and are arranged in a rectangular shape. The inner heat exchange pipe adopts a high-density polyethene pipe and a double U-shaped pipe with a diameter of 32mm.

Shenyang Ceramic World Building Materials Market

Shenyang Ceramic World Building Materials Market 沈阳陶瓷大世界建材市场 is located in the northeast of Shenyang. It is a 5-storey steel structure building.

The GHP project of Shenyang Ceramic World Building Materials Market**,** with a construction area of 78,000 square meters, was completed in May 2007. The project was constructed by Shenyang Sanse Air Conditioning Purification Engineering Co., Ltd. 该工程由沈阳三色空调

[54] Established in 2004
[55] A Sino-British joint venture established in Nanjing in 2004 specialises in production of HVAC equipment.

净化工程有限公司 and supervised by Shenyang Construction Supervision and Consulting Co., Ltd. 沈阳市工程建设监理咨询有限公司. The heat pump units were produced by Tsinghua Tongfang Artificial Environment Co., Ltd. 清华同方人工环境有限公司.

The total cooling capacity is 6059 kW, and the total heating capacity is 3495 kW. The GHP system consists of four SGHP1600M units. The entire cooling capacity is 6059 kW, and the total heating capacity is 3495 kW.

Shenyang Kebao Industrial Park

The GHP project of Shenyang Kebao Industrial Park 沈阳科囊工业园, with a construction area of 6500 square meters, was completed in November 2006. The project was designed by the Northeast Qiajin Design Institute 东北洽金设计院[56] and constructed by Shenyang Zhengda Air Conditioning Installation Co., Ltd. 沈阳正大空调安装有限公司[57]. The Northeast Assessment and Design Institute 东北勘察设计院 was in charge of the geological survey, and Liaoning Zifa Construction Supervision and Consulting Co., Ltd. 辽宁省咨发建设监理咨询有限公司 supervised the project. The heat pump unit was manufactured by Shandong Fulda Air Conditioning Equipment Co., Ltd. 山东富尔达空调设备有限公司.

The GHP system is used for heating and cooling. The total heating load is 594 kW, and the entire cooling load is 530 kW. The system consists of one GHP unit equipped with a fan coil as a terminal unit. There is one intake well, and there are two reinjection wells.

[56] Established in 1992
[57] A daughter company of Gree Electric established in Zhuhai (Guangdong province) in 1992

Mingdu Huihe Plaza

Mingdu Huihe Plaza 名都惠和大厦 is located in Tiexi District. The complex hosts a shopping mall, a hotel and a residential building. The GHP project of Mingdu Huihe Plaza, with a construction area of 55,000 square meters, was completed in August 2007. The project was constructed by Shandong Greider Group Co., Ltd. 山东格瑞德集团有限公司[58]. The same company produced the heat pump units.

The GHP system includes two LSWD460H GHP units with a total heating load of 3580 kW and a total cooling load of 3184 kW. The system also supports a hot water supply. The terminal units are of two types: fan coil and underfloor heating. The system has eight wells, which can be used interchangeably. When the system is in operation, three wells are used for intake, and five wells are used for reinjection. The wells are 63m deep, the intake capacity of a single well is 110 t/h, and the reinjection capacity of a single well is 66 t/h. The average indoor temperature is 22°C in winter and 26°C in summer. The system runs stably and meets the design requirements.

Hunnan Branch of Shenyang Military Region Hospital

The hospital includes a clinic building and a residential building. The GHP project of the Hunnan Branch of Shenyang Military Region Hospital 沈阳军区总医院浑南分院, with a construction area of 81,000 square meters, was completed in October 2007. The construction was undertaken by Shenyang Shuangdeng Environmental Engineering Co., Ltd. 沈阳双登环境工程有限公司[59]. The geological survey was done by Dongmei Shenyang Geotechnical Engineering Co., Ltd. 东煤沈阳岩土工程公司. Shenyang Civil Construction Supervision Company 沈阳民用建设监理

[58] Established in Dezhou (Shandong province) in 2000
[59] Established in May 2007

公司[60] was responsible for the supervision. The heat pump units were produced by Clement Jielian Refrigeration Equipment (Shanghai) Co., Ltd.克莱门特捷联制冷设备(上海)有限公司[61].

The total heating capacity of the project is 4630 kW, the full cooling capacity is 4580 kW, and the heat recovery of the hot water supply is 230 kW. The project adopts two GHP FOCSWH4802 units and one FOCSWH5203-D unit. The clinic building is equipped with a fan coil. The residential building is equipped with underfloor heating. Three GHP units operate in winter for heating and hot water supply. The FOCSWH5203-D unit is used in the transition season for hot water supply. In summer, the FOCSWH5203-D unit provides cooling in the clinic building. At the same time, the Clement heat recovery function is used for the hot water supply. There are nine wells, including three intake wells and six reinjection wells. The project's functioning is stable and efficient.

Shenyang Commercial City

Shenyang Commercial City 沈阳商业城 is located in Shenhe District. It hosts a shopping mall, office building, four-star hotel, and other units. In August 2007, Shenyang Commercial City Co., Ltd. decided to transform the project from the original traditional coal-fired heating, electric refrigeration, and air conditioning system to a water source heat pump system for heating and cooling.

The GHP project of Shenyang Commercial City, with a construction area of 140,000 square meters, was completed in March 2008. The project was designed by Liaoning Architectural

[60] Established in 1994
[61] Established in Shanghai in 2003

Design and Research Institute 辽宁省建筑设计研究院, constructed by Beijing Huadian Huayuan Environmental Engineering Co., Ltd. 北京华电华源环境工程有限公司 and geologically assessed by Liaoning Geological Engineering Survey and Construction Group 辽宁省地质工程勘测施工集团公司. The heat pump units were produced by Kunshan Taijia Electromechanical Co., Ltd. 昆山台佳机电有限公司[62].

The GHP system consists of three SRSW-840-4 units. The total heating capacity of the project is 9600 kW, and the full cooling capacity is 8820 kW. The system has the functions of cooling, heating, and ice storage and adopts the double evaporator design of Taijia patented technology.

There are six intake and reinjection wells distributed to the north of the Commercial City and 13 reinjection wells distributed in Zhongjie and Chaoyang Street. The proportion of intake and return wells is 1:2. The total water consumption is 800 m^3/h. The intake water temperature is 12°C, and the reinjection water temperature is about 4°C. The GHP water supply temperature is 50°C, and the return water temperature is 45°C. The average indoor temperature of the mall is 18-20°C in winter and 22-26°C in summer. The system operates well and meets the design requirements.

Total investment in GHP retrofitting was 18 million yuan. The GHP system of Shenyang Commercial City was rated as the national energy-saving demonstration project in 2007 国家节能示范工程 by the Ministry of Finance and received financial subsidies.

[62] Established in Jiangsu province in 1998

Shenghai Sunshine Residential Complex

Shenghai Sunshine Residential Complex 晟海阳光小区 GHP project is located in Sujiatun District, with a construction area of 150,000 square meters. The project was completed in November 2007. The project was designed by the Comprehensive Design and Research Institute of Zhengzhou University 郑州大学综合设计研究院. The water source heat pump units were produced by Zhengzhou Kelai Cooling and Heating Equipment Manufacturing Co., Ltd. 郑州科莱冷暖设备制造有限公司[63]. The GHP system was installed for heating with underfloor heating as a terminal unit.

Two KFWH9601 GHP units were used to heat 40,000 square meters of the residential complex. The cooling capacity is 911.8 kW/166.9 kW. The heating capacity is 1008.2 kW/210.3 kW. There are six wells, of which two are intake wells, and four are reinjection wells. The water consumption is 170-190 m^3/h, the groundwater temperature is 11°C, and the reinjection water temperature is 4°C. The indoor temperature meets the design requirements of 20°C.

Times Shopping Center

Times shopping centre 时代购物中心 GHP project in Heping District, with a construction area of 11,800 square meters, was completed in November 2007. The project was jointly designed by Guangxia Design Bureau 广厦设计事务所 and China's Architecture Northeast Design and Research Institute Co., Ltd. 中国建筑东北设计研究院有限公司. The construction was led by Hengactive Technology Development Co., Ltd., 恒有源科技发展有限公司[64]. The geological survey was undertaken by Shenyang Water Supply Engineering Survey, Design and Research

[63] Established in 2004 in Hangzhou
[64] Established in Beijing in 2002

Institute 沈阳市给水工程勘察设计研究院. Zhongliao International Engineering Construction Project Management Co., Ltd 中辽国际工程建设项目管理有限公司 acted as a supervision body. The GHP units HT380A and HT760A were produced by Hengactive Technology Yongyuan Heat Pump Co., Ltd. 恒有源科技下属永源热泵有限责任公司.

The total heating capacity of the system is 1094 kW, and the full cooling capacity is 975 kW. The maximum heating power is 279 kW. The wells are located north of the Times Shopping Center, with 13 meters between the wells. The well depth is 42 m, and a single well's pumping and returning water volume is 50 m^3/h. The GHP system adopts the single well pumping and irrigation technology invented by Hengyang Technology. After extracting the water and heat from the well water, the well water returns to the original water intake well.

Zhenggui Garden of China Shenyang World Horticultural Expo

The GHP project in Zhenggui Garden of China Shenyang World Horticultural Expo 中国沈阳世界园艺博览会玫瑰园, with a construction area of 7,531 square meters, was completed in December 2005. The construction and geological survey were carried out by Jigao Construction Co., Ltd. 际高建业有限公司[65]and supervised by Shenyang Fanhua Construction Supervision Co., Ltd. 沈阳泛华建设监理有限公[66]. SIAT (France) produced the heat pump unit.

Shenyang Zhenggui Garden is a greenhouse of China Shenyang World Horticultural Expo, mainly displaying roses. The average height of the building is 15 m, and the envelope structure adopts a vacuum glass curtain wall. The combined ground heat pump system is adopted for cooling and heating. The cooling load is 1653 kW, and the heating load is 1764 kW. A total of

[65] Established in Beijing in 1992
[66] The company information is not to be found online.

286 wells of 80 m depth have been drilled in Zhenggui garden, which fully meets the use requirements of the exhibition hall of above 15°C in winter and 25°C in summer.

Liaoning Armed Police Headquarters

Liaoning Armed Police Headquarters 武警辽宁省总队指挥中心 is a complex of public and residential buildings. The cooling and heating of all facilities are provided by the ground heat pump system located in the machine room on the first floor of the office building.

The GHP project of Liaoning Armed Police Headquarters, with a construction area of 59,920 square meters, was completed in December 2007. The project was constructed and geologically surveyed by Jigao Construction Co., Ltd. 际高建业有限公司 and supervised by Shenyang University Architecture Construction Supervision Co., Ltd. 沈阳建筑大学建设监理有限公司. The heat pump unit was produced by Clement Jielian Refrigeration Equipment (Shanghai) Co., Ltd. 克莱门特捷联制冷设备(上海)有限公司.

The total cooling load is 4957 kW, and the complete heating load is 4910 kW. The GHP system includes 753 underground heat exchangers in the shape of double vertically buried pipes. The adequate depth of the underground heat exchanger is 100 m.

Shenyang Military Region Jinhui Hotel

Jinhui Hotel 沈阳军区金辉宾馆 includes guest rooms, meeting halls, a bathing complex and catering. Jinhui Hotel used to be equipped with coal-fired boilers for winter heating and chillers for summer cooling.

The GHP project of Shenyang Military Region Jinhui Hotel, with a construction area of 20,000 square meters, was completed in October 2006. The project was designed by the Beijing Guangxia Architectural Bureau 北京市广厦建筑事务所, constructed by Liaoning Construction and Installation Group Co., Ltd. 辽宁建设安装集团有限公司. The geological survey was undertaken by CSCEC East Geotechnical Engineering Company 中建东设岩土工程公司. The project was supervised by Shenyang Tiecheng Engineering Supervision Company 沈阳铁城工程监理公司. The heat pump units were produced by Beijing Yongyuan Heat Pump Co., Ltd. 北京永源热泵有限责任公司[67].

The GHP uses underground water for its operation. It provides heating, cooling and hot water. The total heat load is 1700 kW, and the cooling load is 1250 kW. The system consists of three heat pump units with underfloor heating and a fan coil as a terminal unit. The system relies on five water wells.

The GHP system consists of three units. Two GHP sets of HT760A type are used for heating and cooling, and one HT380A unit for hot water supply. The unit has patented heat recovery technology, uses the latest compressor and heat exchange pipe, has a high-performance coefficient, and can be used for more than one machine. Each well has an intake and reinjection function, which can not only prolong the lifting and cleaning cycle of the well but also better balance the cold and heat load of the soil layer in different seasons.

[67] Established in Beijing in 2002

Shenyang Modern Electric Power Company

The GHP project of Shenyang Modern Electric Power Company 沈阳时尚电力有限公司, with a construction area of 20,000 square meters, was completed in 2005. The heat pump units were produced by Yantai Ebara Air Conditioning Equipment Co., Ltd. 烟台荏原空调设备有限公司.

The project adopted groundwater source heat pump technology, with a total heat load of 1128 kW and a total cooling load of 1046 kW. There are two heat pump units, two intake wells and tree reinjection wells. The fan coil is used as a terminal unit.

Shenyang Institute of Automation of the Chinese Academy of Sciences

Shenyang Institute of Automation 科学院沈阳自动化研究所 is located in Shenhe District. The institute complex includes an office building, a scientific research building, a student dormitory and a family dormitory building.

The GHP project of Shenyang Institute of Automation, with a construction area of 70,000 square meters, was completed in November 2000. The project is jointly designed by Shenyang New World Design Company 沈阳新大陆设计公司 and Shenyang Huawei Engineering Co., Ltd. 沈阳华维工程有限公司. The construction was undertaken by Shenyang Huawei Engineering Co., Ltd. 沈阳华维工程有限公司. The project was supervised by Shenyang Huake Engineering Construction and Engineering Supervision Co., Ltd. 沈阳华科工程建设工程监理有限公司. The heat pump units were produced by Shanghai YILENG (US Carrier) Air Conditioning Equipment Factory 美国开 利、上海一冷(开利)空调设备厂.

The GHP system consists of four GHP units. The total heating capacity is 5200 kW, and the outlet water temperature is 60°C. The system has sixteen wells, including six intake wells and ten reinjection wells. The groundwater temperature is 13°C, and the maximum water consumption of the system is 450 m^3/h. The system has been running safely and reliably. This project was rated as a successful case of energy conservation in 2001 and has been promoted by the Chinese Academy of Sciences.

Yinji Diwang Garden

Yinji Diwang Garden 银基地王花园 is located in Shenhe District, Shenyang. The complex includes an office building and residential buildings. It is a comprehensive community that integrates residence, office, apartment, and commercial residences.

The GHP project of Yinji Diwang Garden, with a construction area of 86,000 square meters, was completed in October 2004. The project was designed by Shenyang Architectural Design Institute 沈阳建筑设计院, supervised by Zhongliao Supervision Company 中辽监理公司 and constructed by Shenyang Langchen Environment Co., Ltd. 沈阳朗晨环境有限公司. The heat pump units were produced by Tsinghua Tongfang Artificial Environment Co., Ltd. 清华同方人工环境有限公司.

The GHP system provides heating, cooling and hot water supply with a fan coil as a terminal unit. The office building adopts two GHP sets of SGHP1000 type, and the apartment buildings are equipped with three GHP sets of SGH1000 type and three sets of SGHP600 type. The indoor temperature is maintained at 18-22°C. The system operates efficiently and meets the design requirements.

Wanhe Shunjing

Wanhe Shunjing 万和顺景 is located in Dadong District. The project is financed, developed and constructed by Shenyang Wanhe Shunjing Real Estate Development Co., Ltd. 沈阳万和顺景房地产开发有限公司, covering an area of 48,000 square meters.

Wanhe Shunjing GHP project, with a construction area of 110,000 square meters, was completed in August 2007. The project was designed by Shenyang Architectural Design Institute 沈阳建筑设计院, constructed by Shenyang Langchen Environment Co., Ltd. 沈阳朗晨环境有限公司, surveyed by the Rock and Soil Company of Liaoning Architectural Design and Research Institute 辽宁省建筑设计研究院岩置土公司, and supervised by Zhongliao Supervision company 中辽监理公司. The heat pump units were produced by Tsinghua Tongfang Artificial Environment Co., Ltd. 清华同房人工环境有限公司.

The project adopts two GHP units of SGHP2000H type and two units of SGHP600H type. The system relies on sixteen wells, including four intake wells and twelve reinjection wells. The heat load of the project is 5142 kW. The annual coal consumption saved reaches 13,040 tons of standard coal. The building energy saving standard comes at 50%. The investment payback period was eight years.

Assembly Hall of Shenyang Municipal People's Government

The GHP project of the Assembly Hall of Shenyang Municipal People's Government 沈阳市人民政府礼堂, with a construction area of 8,000 square meters, was completed in December 2007. The project was designed by CSCEC Northeast Design and Research Institute Co., Ltd. 中国建筑东北设计研究院有限公司, geologically surveyed by Liaozhong Geological Survey Bureau

辽中地质勘查局, supervised by Urban Construction Supervision Company 城市建设监理公司, and constructed by Shandong Gered Group Co., Ltd. 山东格瑞德集团有限公. The heat pump unit is produced by Yantai Lande Air Conditioning Industry Co., Ltd.烟台蓝德空调工业有限责任公司.

The project's total heating load is 1126 kW, and the complete cooling load is 1214 kW. The GHP system consists of two GHP units of GHSP-C0558G, one intake well and two reinjection wells, with a fan coil as a terminal unit.

The unit is equipped with GSM wireless monitoring system, a high-efficiency oil separator, multiple security systems and an climate compensation system. According to the change in outdoor temperature, the unit can automatically adjust the outlet water temperature of the unit. Thus, the operation cost of the air conditioning system decreases while ensuring indoor temperature comfort.

Yinfan Residential Complex

The GHP project of Yinfan Residential Complex 银范小区, with a construction area of 100,000 square meters, was completed in 2001. The complex consists of nine residential buildings. The project was designed by the CSCEC Northeast Design and Research Institute Co., Ltd. 中国建筑东北设计研究院有限公司, constructed by Shenyang Keda Smart Building Engineering Co., Ltd. 沈阳科大智能建筑安装工程有限公司, and supervised by Shenyang Huake Engineering Construction Co., Ltd. 沈阳华科工程建设造理有限公司. The heat pump unit was produced by Yantai Lande Air Conditioning Industry Co., Ltd. 烟台蓝德空调工业有限责任公司. The Shenyang Branch of the People's Bank of China financed the construction.

The project adopts five GHP sets of RHSBW300YM type and fan soil as a terminal unit. The intake capacity is 415t/h. The GHP system serves 22 wells, including nine intake wells and thirteen reinjection wells.

Since the system was put into operation in the winter of 2001, the operation has been stable and effective. The room temperature in winter reaches 23-26 degrees. According to statistics, in 2002, with the community's occupancy rate of over 90%, the unit cost of heating power consumption was 10.46 yuan / m^2. In 2004 it increased to 12.8 yuan / m^2.

According to the residents, with no smoke or dust produced by the heating system, the machine room and the environment of the residential complex was significantly improved. The residential complex was rated a demonstration community of energy projects in Shenyang.

Discussion

The above details on GHP projects in Shenyang are essential and valuable for understanding the process and logic. Every project involved four parties: the design company, the construction company, the supervision body and the GHP unit producer. There is no obvious pattern in the distribution of companies, no dominant player. Most companies were established in the 90s. Construction and supervision agents were primarily local, whereas most GHP manufacturers were from other provinces (Shandong, Shanghai, Beijing, Guangdong). The pilot project in Shenyang did not create local industry and did not mean to. The decline in GHP applications started in 2011.

The majority of projects are public buildings. This tendency increased in the second phase between 2011-2016.[68] It turned out the GHP is less suitable for residential buildings because users refused to use the cooling function in summer to save on electricity costs. This led to an underground temperature imbalance (Bisengimana et al. 2022; You and Yang 2020). It was decided after that to implement GHP primarily in public buildings.[69]

Interviewees did not show disappointment or regret that GHP implementation eventually ceased. It was not considered a failure.[70] Shift to alternative energy was expressed as inevitable, and the GHP pilot project was a step towards it.[71] Deciding on promoting GHP in 2006, the Shenyang government had no intention to radically replace all existing coal boilers but rather contribute to the low-carbon future within available resources and at minimal costs.

3.4 Outcomes

3.4.1. Benefits for Residents: Liveability

The outcomes of sustainable innovation are hard to measure (Gunarathne 2019). First, the benefits of sustainable innovation are postponed due to its accumulative impact (Nidumolu, Prahalad, and Rangaswami 2009). Thus, evaluation at the end of a construction project cannot demonstrate or guarantee the project's sustainability. Second, sustainable innovation follows an unbeaten path. Therefore, there is often no reference to what it should be like. It is a try-and-fail experiment, with some fails or benefits appearing only during further exploitation. Moreover, the diversity of sustainability projects makes a unified evaluation system unfeasible (Campos-Guzmán et al. 2019).

[68] Interviewee 10
[69] Interviewee 11
[70] Interviewee 9
[71] Interviewee 6

Nonetheless, the evaluation of sustainable innovation is necessary. Evaluation is an essential stage of the innovation process, which decreases uncertainty inherent to innovation and directs its further development. Technological lessons are valuable for technical adjustment and advancement (Kemp 1994). Besides, while sustainable innovation orients primarily towards the future and well-being of future generations, it cannot ignore current users' experiences with innovation. Thus, evaluation can provide an overview of sustainable projects' impact on people's lives.

The following sections evaluate GHP projects in Shenyang in terms of their liveability, impact on city image, contribution to the technological advance of GHP, and demonstration of Shenyang's ideological conformity.

Liveability is a valuable tool for measuring sustainability. While the concepts of liveability and sustainability are closely associated, they are pragmatically not equal (Howley, Scott, and Redmond 2009). There is a temporal distinction between the two. Sustainability has long-term, intergenerational advantages, whereas liveability implies direct benefits. Moreover, some urbanists see liveability and environmental sustainability as conflicting (Valcárcel-Aguiar, Murias, and Rodríguez-González 2018).

The concept of sustainability, as it evolved through time, has become less human-centred (de Haan et al., 2014). Established as a solution to climate change and anthropogenic effects, sustainability serves societal and non-human systems (such as the economy or ecology) rather than meeting the immediate needs of the current human population. Liveability, in contrast, has a more direct connection to human needs and systems.

Liveability focuses on the benefits of innovation for current residents. It can be defined as residential satisfaction or neighbourhood satisfaction (Howley, Scott, and Redmond 2009), a subjective evaluation of the residents toward their living environment (Lau Leby and Hariza Hashim 2010). However, satisfaction is not only a subjective but also a relatively flat concept (de Haan et al., 2014). The results of this approach have limited use for further innovative projects. Meanwhile, if we look at liveability as a result of interaction between the community (individual) and its environment (Shafer, Lee, and Turner 2000), it provides descriptive data which could be applied in planning other projects with similar variables.

Ideally, livable innovation should be functional, affordable, healthy, safe and resilient to economic and environmental risks (Badland et al. 2014). The balance between economic, physical, ecological and social conditions of liveability embraces the features of urban environments that make them attractive places to live (Lau Leby & Hariza Hashim, 2010). Livable innovation contributes to the creation of livable neighbourhoods. The liveability of communities is critical to the prosperity and development of cities, which give their citizens a choice and opportunity to live their lives to their fullest potential (Major Cities Unit, 2010).

Liveable housing is unthinkable without proper temperature control. Tapsuwan et al. found that homeowners identify home affordability and a good temperature regime in summer and winter as most important (Tapsuwan et al. 2018). Whether comfortable housing requires heating, cooling, or both, regardless of the climate zone. In cold and severe cold zones, home heating is an essential prerequisite.

Researchers rely on residents' experiences to measure liveability (Lau Leby & Hariza Hashim, 2010). Those experiences are influenced by innovation's economic, social, functional and safety impact. The economic factor is the most straightforward. It reflects the actual maintenance costs compared to other alternatives, in the case of GHP - other available heating options. Analysis of functionality shows if technology fulfils residents' expectations of its intended functions – if the temperature regime provided by the system is comfortable throughout the year. Safety considerations include the immediate environmental impact that can be experienced by residents, such as harm risk during exploitation and cleanness of a boiler room. Finally, the social factor, the most subjective of all, refers to satisfaction with the aesthetics of the living environment and, if present, resident pride. Thus, liveability has physical-environmental and cultural dimensions experienced and constructed by the inhabitants (Paul & Sen, 2020).

Costs

GHP is significantly more energy and emission efficient than other heating options (such as district heating, coal boilers, gas boilers, and air-source heat pump); however, it is not cost-effective unless subsidised (M. Zhou et al. 2022). Thus, users of the district heating have to pay 24 CNY/m2, whereas GHP users pay 31 CNY/m2 (Yang et al. 2021). From a liveability perspective, with residents expecting lower heating prices, GHP is less attractive. Nonetheless, some factors make the implementation of GHP reasonable.

Heating system costs are a sum of capital costs and operational costs. Capital costs include equipment (heat exchanger, outdoor pipes, heating radiators) and installation (well drilling) costs. Depending on the equipment quality and heating/cooling area, the initial investments may vary between 300-700 CNY/m2.

Unlike most common GHP implementation scenarios worldwide, when individual homeowners choose to equip their single-family houses with a particular heating option, most GHP were installed in public or newly constructed apartment buildings in Shenyang.[72] It means that local government, enterprises and real estate developers bore the capital costs. Pushed by the related policies and regulations and driven by subsidies, they undertook GHP projects. By 2017 the subsidies were discontinued when GHP implementation in Shenyang slowed down.

Similar observations with subsidies driving technology implementation are found in the solar heating sector (Xiong and Hassan 2022). The solar heating market expanded rapidly since solar heating was integrated into the energy-saving livelihood program. Energy-saving livelihood program started in 2012 by providing subsidies for energy-saving products, including solar water products. However, the growth rate began to decline in 2014 due to the program's expiration.

Thus, in Shenyang, only operational costs are relevant to residential satisfaction. GHP system is run by electricity; electricity prices and their fluctuations define the maintenance costs. Although the operational costs of an individual coal boiler are lower compared to GHP, they are less predictable. Due to resource scarcity, fossil fuel prices are sensitive to geopolitical situations and national policies. Meanwhile, electricity prices are essential indicators of government efficiency and party legitimacy in China. It applies that being of core importance, electricity prices are more stable and predictable.

Environment

A resident-friendly heating system means a comfortable temperature regime, a clean environment and safety. According to the heating standards in the Heating Management

[72] Interviewee 4

Regulations of various heating areas and cities, the indoor heating temperature standard determined in most areas of China is 16-20 °C. A properly functioning GHP system provides even higher temperatures.

It is observed that social norms play a role in satisfaction levels with indoor microclimates (Freyre et al. 2021). Average temperatures in public and residential spaces in winter in the Northeast are around 16-18°C (Guo et al. 2015). Therefore, if the temperature regime is around or above average, it is already satisfactory for users. Reports from property managers (hotels, public institutions, hospitals) mention that the heated spaces became warmer and more comfortable after the GHP installation.

There is, however, also negative feedback. A forum user on one of Shenyang's local networks complains about the low temperature in his newly bought apartment (in 2006), asking other users about their experiences. It turned out that the wells for water extraction were drilled too close to each other to provide enough heat for the building. No more user complaints about GHP heating in Shenyang found on the Internet in open access. It might be that GHP projects built later were planned and constructed more thoroughly, and the temperature levels provided by GHP were at least kept above average.

The lack of users' discussion of GHP experiences on the Internet has an alternative explanation. Research on residents' housing satisfaction in China showed that only homeownership and house size significantly affect overall happiness (Zhang et al., 2018). Thus, a heating system is less critical for residents as long as it provides minimal comfort.

Although GHP has a dual function of heating in winter and cooling in summer, the data showed that Shenyang residents were unwilling to use the cooling option to save on electricity expenses. In some cases, this led to a disbalance in the system's functioning, with the heat extracted from the underground water not being reinjected. Growing living standards against increasing summer temperatures might resolve this issue when residents would be willing to pay extra for a comfortable indoor microclimate in summer.

Aesthetics of living environment

Apart from economic, environmental and technical factors, the experiences with a heating system are influenced by its comfort and aesthetics (Freyre et al., 2021). Until recently, coal boilers were China's most common heating devices; they are not significant in size but are associated with a dusty unpleasant environment. A coal boiler needs storage, and burning coal produces fume and dust. In contrast, the GHP boiler room is typically clean and quiet. Users often mentioned this fact as a positive experience with GHP.

3.4.2. Shenyang as Sustainable City: The Image

A city image is a mental representation of a city. It is a product of immediate perception and past memorised experiences (Neacsu 2009). The mental image helps to interpret and organise information. It works as a guide for decision-making at an individual and organisational level. An attractive image is an important economic factor, as it will always attract investors, tourists and new residents compared to a city with a less favourable impression (Kampschulte 1999).

An ideal modern city image is associated with an attractive and safe environment for life, work and development, good governance, a competitive economy, high quality of life and environmental sustainability (Sasanpour 2017). Approaches to image development include changing the physical city by creating new landmarks or views, restructuring the street system, strengthening weak edges, and intensifying district character by changes in land use and form (Southworth, 1985). In other words, such elements as aesthetics, landmark architectural design, place-making, and eco-efficiency become essential (T. C. Wong & Liu, 2017).

In the past, city image was shaped spontaneously with an accuracy of events, incidents or accidents that would draw nationwide attention and put a label on a city. A city image is a caricature that exaggerates one-two feature of a city that sticks in the memory. Paris is romantic. New York is a global pot. Slams surround New Delhi. Produced once, these images get reproduced through media and popular culture.

Currently, cities intentionally build their image, significantly if a negative stereotype hinders their development due to economic, social or historical reasons. Self-profiling practices enhance the city's positive visibility and loyalty among stakeholders relevant to their financial success. This goes beyond changing physical appearance or environment. Language and marketing play an essential role in constructing a city's image. Whatever transformations take place must be given a catchy name, slogan or label (such as eco-cities, low-carbon cities, smart cities, knowledge cities, resilient cities, etc.) and be actively publicised (Han et al. 2018). Orientation towards high-tech or/and sustainability is most appealing in modern times.

Although there is a generalised image of an ideal modern city, it does not necessarily mean that cities strive to be identical, to become faceless. On the contrary, an efficient city image emphasises the city's peculiarity and uniqueness (Kampschulte, 2000). Image-making is based on the history of a place (its cultural, social and economic legacy), its current socio-economic profile (its specific composition of the population and dominant industries) and future aspirations (Southworth, 1985).

Thus, an image is a link between the present and the past, a negotiation between local, national and global values (W. Ma et al. 2020). The image appears attractive and credible if there is a continuity between future ambitions and the current situation aligned with the city's historical and cultural background. On the contrary, if the present situation and future goals deviate strongly from each other without stakeholders grasping how this gap can be closed, then the city's image will not work (Han et al. 2018). Once citizens internalise social norms and values set by the city image, they keep being reproduced, bringing further changes to the normative and physical landscape. Thus, city imaging is an ongoing communication process beyond economic growth.

City imaging, or branding, is a common practice in China. It has stimulated and enabled cities to experience urban and industrial transformation, economic restructuring and policy change (W. Ma et al. 2020). Due to China's financial specifics, a municipality must be visible, with the central government's investments playing a pivotal role in city development. A distinctive city image allows for reaching a particular status in the regional and national hierarchy. While more prosperous and globalised cities such as Beijing, Tianjin, Shanghai, Shenzhen and Guangzhou have set successful examples in city branding, others, like Shenyang, are struggling with their transformation.

Along with its glorious industrial past, Shenyang has inherited the reputation of a city with an outdated resource-based heavy industry and severe air pollution. The city government used planning to alter the city's image. The analysis of Shenyang's Five-year Plans and Urban Master Plans reveals that the most frequently used city labels are *advanced manufacturing city*, *service city*, *low carbon city*, and *innovation city.* This draws a clear image of an industrial, technologically advanced city comfortable for working and living. Taking up the GHP initiative appears as a logical step toward achieving the goal.

As the nation's first pilot city in GHP application, Shenyang and the local and national media actively reported on progress on GHP projects throughout the 11^{th} and 12^{th} Five-year Plans. The Shenyang government organised regular conferences and exhibitions, attracting local and external experts and businesses. All this implies that GHP's implementation in Shenyang has contributed to rebranding and upgrading its image.

The impact of a city's image on its development can be measured by economic indicators and also by the size of the population. If image-related policies positively affect city development, then there should be an upward tendency in the economy and population size after implementing the procedures. It is impossible to isolate the impact of the GHP policy from other steps taken by the Shenyang city government toward a better city image. Nonetheless, if there is an optimistic tendency in economic and social indicators, it indirectly proves that the GHP policy impacted the city's image.

Shenyang GHP per capita has been steadily increasing from 28.115 CNY in 2006 to 72.936 CNY in 2020, with a slowdown starting in 2015 (Shenyang Yearbook 2021). The population size has grown from 8.5 million in 2015 to 9.073 million in 2020. Research on air quality in Shenyang registers improvement, yet experts still urge strengthening air pollution policies (Liang et al., 2016; Y. Ma et al., 2021). Based on this, it can be argued that Shenyang city image has a positive tendency, but its transformation is still in progress.

The GHP pilot project was not central to Shenyang's efforts to cut emissions during the 11^{th} FYP. It was instead the relocation of factories to the city's outskirts.[73] Nonetheless, the GHP pilot

[73] Interviewee 6

project was publicly promoted due to its social and political attractiveness. GHP aims at mitigating air pollution and serves a vital societal function by providing heating to citizens. GHP is a technological innovation associated with progress. Therefore, publicising the GHP pilot project benefited the city's image and promoted city leaders' careers. Both Shenyang majors who directly planned and implemented the GHP policy got announced to higher posts after their time in office was over, indicating that they fulfilled their obligations imposed by the central government.

Cadre rotation is a standard administrative practice in China to prevent corruption and the rise of localism (Jie Chen et al. 2017). Promotion to a higher position in the cadre hierarchy signifies successful performance in the previous post (Landry 2003). Chen Zhenggao 陈政高, Shenyang major (2001-2005) and Secretary of Shenyang Municipal Party Committee (2005-2008) insisted on GHP promotion in Shenyang.[74] Later, Chen Zhenggao received the post of Deputy Secretary of the Liaoning Provincial Party Committee and Acting Governor of Liaoning Province. Chen then served as the Governor of Liaoning Province and eventually became Minister of Housing and Urban-Rural Development.

Li Yingjie 李英杰 served as Deputy Secretary of the Shenyang Municipal Party Committee and Shenyang major between 2006-2010. He approved and led GHP policy implementation.[75] In 2010, Li Yingjie was promoted to the Deputy Director of the Standing Committee of the 11th People's Congress of Liaoning Province. This indicates that Shenyang's 11th FYP was carried out successfully, and environmental targets were met.

[74] Interviewees 5, 9
[75] Interviewees 3, 5

Multiple interviewees mentioned that pilot projects were a career growth engine. Officials use highly publicised pilot projects to seek political power and promotion, and the leader's position plays a crucial role in the decision-making process.[76] Thus, local policy decision-making lies at the intersection of the central government's guidelines and local leaders' ambitions.[77] Environmental planning targets are a crucial tool for the centre to enforce sustainable agendas within local authorities, mainly focusing on economic growth.

3.4.3. Technological Advance: Lessons Learnt

Scientific research

To ensure the safe operation of the heat pump systems, Shenyang City has invested 10 million CNY in scientific research. Ten research projects were completed by the end of 2018, including

- "Research on the technology of groundwater source heat pump recharge in Shenyang area"
- "Report on the Influence of GSHP Groundwater Pumping and Recharging on Building Settlement in Shenyang Urban Area"
- "Comparative Analysis of Energy Saving and Economy of GSHP Operation"
- "Report on Shenyang GSHP System's Impact on Groundwater Quality"
- "Shenyang GSHP System Engineering and Technical Regulations"
- "GSHP Engineering Technology and Management" (textbook published by China Construction Industry Press)
- "Shenyang GSHP Geographic Information Management System"
- "Compound type high-temperature water source heat pump unit"
- "Research on Multifunctional Household Water Source Heat Pump Units"

[76] Interviewees 3, 5, 12, 13
[77] Interviewee 6

- "Research on GSHP and Central Heating Combined Supply System with Thermal Compensation"

The above research draws several important conclusions. First, the shallow strata in Shenyang urban area mainly comprise medium sand and gravel. The amount of groundwater is abundant, the thickness of the aquifer is large, the water-seeking ability is strong, and the permeability coefficient is significant. Second, the ratio of pumping and returning wells in urban areas must be 1:1 to 1:3. Third, the extraction and recharge of the water source heat pump in the metropolitan area will not affect the safety of the building. Finally, the analysis of groundwater quality tracking showed that GHP has little effect on groundwater quality.

This proves that the GHP application in Shenyang was guided by scientific research despite being a disruptive innovation. Additional study and monitoring led to the completion of technical regulations and codes.

Technology Development

After initial success with the ground source heat pumps, Shenyang has independently developed the *hybrid water source heat pump technology* and promoted the application of sewage source heat pump technology on a large scale.[78] The sewage source heat pump technology applies GHP to utilise the sewage water heat for house heating. GHP unit can be added to the existing coal-fired boiler room or central heating to combine coal-fired heating with GHP. Currently, this technology is being promoted in several large coal-fired heating enterprises in the city. The

[78] Interviewee 6

completed Shenyang Guohui Sewage Source Heat Pump Project can utilise 400,000 tons of reclaimed water daily. The hybrid technology has obtained a national patent.[79]

To ensure the safety and reliability of the GHP operation, Shenyang city supervises and manages the construction and operation of the ground source heat pump system by the "Shenyang City GHP System Construction and Application Management Measures", "Regulations on the Design of Heat Source Wells for GHP Systems" and "Notice on Further Strengthening the Quality Management of GHP System Engineering".[80]

Currently, any GHP project requires approval by the construction management office.[81] This policy was implemented after some GHP installed without prior geological analysis caused ecological disbalance.[82] Due to the relatively small size of the GHP industry in China, detailed regulations were missing.[83] Thus, some companies used it to decrease the construction cost during bidding and performed poorly afterwards. GHP installed with violation of regulations were charged with fines.[84]

Thus, the city government is involved in planning, designing, constructing and supervising GHP projects in the operational phase to acknowledge their importance for city development and guarantee long-lasting environmental impact.

[79] Interviewee 4
[80] Interviewee 10
[81] Ibid.
[82] Interviewee 4
[83] Ibid.
[84] Interviewee 9

Currently, any GHP project requires approval by the construction management office.[85] This policy was implemented after some GHP installed without prior geological analysis caused ecological disbalance.[86] Due to the relatively small size of the GHP industry in China, detailed regulations were missing.[87] Thus, some companies used it to decrease the construction cost during bidding and performed poorly afterwards. GHP installed with violation of regulations were charged with fines.[88]

3.4.4. Heat Pumps, Economy and Ideology: Demonstration Effects?

Since 1978, pilot projects have been a standard tool for implementing economic and social innovation in China. A pilot project is an experiment that introduces novel practices or any technological or institutional innovation in a selected location for a specific period. Unlike laboratory experiments with controlled conditions, socio-economic or socio-technical pilot projects are set under high uncertainty in complex environments. Special economic zones of Shenzhen, Zhuhai, and Shantou cities in Guangdong province and Xiamen in Fujian province are the earliest and very successful examples of a pilot project, which became a turning point in the county's economic development and later were expanded along the coastal area. Driven by a positive outlook, pilot projects are associated with high risks and unpredictable outcomes.

Intrinsically any system (should be environmental habitat, organisation or human being) is resistant to change and leans toward the status quo unless it is forced to alter by internal or external conditions. It means that innovation, by its nature, is a compelled action.

[85] Interviewee 10
[86] Interviewee 4
[87] Ibid.
[88] Interviewee 9

In a multi-party political system, the ruling party is motivated to innovate and implement policies for the public good to maximise its re-election prospects (Bove et al., 2013). While China has a formally multi-party system, the CCP has no competition in the political arena. Nonetheless, the CCP is continuously renewing itself, its institutions, policies and governance. The efforts are driven by the pursuit of efficiency, economic growth and social well-being. Indeed, the party's legitimacy to rule is closely tied to its ability to produce *economic goods* (Saich 1986).

However, innovation as a process or activity seems to be as relevant, if not more important, for legitimising the Communist rule than innovation outcomes. In other words, innovation in itself, disconnected from its results, is vital to the CCP's survival and prosperity. Innovation is a form of democratic participation, equal for all who plan a policy, implement it or are affected by the innovation process. I will support this argument by connecting the CCP's self-defined role in the historical process, technologism and redefinition of labour.

The CCP defines itself as a missing link between the past and the future and the broker between "traditional" and "advanced" culture (Holbig 2013). This ideological construct gives a dynamic impression. The party appears as an adjusting, ever-evolving organism rather than a rigid hierarchical structure. The boundaries of the past and the future, the traditional and the advanced, are constantly shifting, which creates an ever-lasting effect as if the CCP has always been and will always be.

Ideology is the core of any political party. The CCP's adaptive nature is produced and supported by its official ideology and language. Thus, the widespread use of *socialist/socialism* as an empty signifier guarantees the rhetorical coherence of official language and the CCP's monopoly over reproducing ideology (Holbig, 2013). The versatility of the official ideology validates the party's claim of innovativeness, which again is imagined as the driving force behind its historical mission to promote China’s national interest. The CCP has been relying on technology to carry out this mission.

Technologism, i.e. the perception of technology as an unquestioned good, is characteristic of the current Chinese political ideology. Science and technology have been central to the political discourse and the country's development since the establishment of the PRC. Technological borrowing (in particular reliance on the USSR in the 1950s) fostered the emergence of a new technocratic-managerial elite (Rensselaer W. Lee III 1972). But it also made this elite vulnerable to ideological attack during the Cultural Revolution. To a degree, many of those having scientific or technical backgrounds were forced to switch to manual labour or preferred to dissociate themselves from technical knowledge for personal safety. When Deng Xiaoping returned to power, his technocratic aspirations faced opposition within the government. Nonetheless, since the beginning of the reform and opening up, China’s development has been technology oriented.

In governance, using technology for urban development has two critical functions (León and Rosen 2020). First, high technologies become engines for urban economies by attracting investments and creating markets and jobs. Second, technologism reframes urban problems (economic, social, environmental, political) into technological issues to be addressed by technical solutions. Thus, the focus shifts from people or political institutions to technology, to its successes and failures. This is how, for example, *smart cities* became a household name in China.

Compared to Western conceptualisation, the Chinese concept of technological innovation is different. The Chinese idea of innovation is a successor to the concept of mass innovation in the Mao period, while in the West linear model of innovation is the most common approach to understanding the relation of science and technology to the economy (Godin 2006). The linear model portrays the process of innovation as composed of three main phases or sequential steps: basic and applied research, development, and production and diffusion. According to this model, innovation takes place in an isolated environment, being developed by industries and reaching society at its last step. Having become entrenched in discourses and policies with the great help of OECD statistics and methodological rules, the linear model became a social fact (Godin 2006). Thus, the change-producing activity occurs mainly in settings well removed, both physically and socially, from productive practice, which is not the case in China.

The Chinese concept of technological innovation is based on the Maoist dictum that practice governs the course of technological advance. Ideologically technology and labour were integrated to raise the worker above the level of an appendage of a machine (Rensselaer W. Lee III 1972). The CCP developed a concept of labour which stressed creativity and problem-solving as well as ordinary manual work. With labour being a source of ideas for technological innovation, technology was defined as a derivative of labour, giving practice, not theory, a guiding role in innovation. This ideological change in production relationships made workers masters, not slaves, of their machines. Practically speaking, workers' inventions and creations were encouraged and instrumental in restoring or improving the productive capacity of many enterprises. Besides, *practice as the mother of science* approach negated the hegemony of experts in the innovation process. It invited various participants, equated their roles in the process, and made technological innovation an inclusive collective action.

Accordingly, GHP implementation in Shenyang between 2006-2016 was meaningful and effective regardless of its technological and market success. It was a collective action of policymakers, bureaucrats, scientists, project developers, entrepreneurs, and citizens.

Technological innovation in the form of a pilot project invites participation, empowers and evokes a sense of belonging to the technological progress and historical process. Apart from attending to the material needs and building a wealthy nation, the CCP aspires to create a spiritual socialist civilisation (K. Brown and Bērziņa-Čerenkova 2018). Local technological innovation plays an essential role in this process.

IV. Conclusion

This research aimed to explain the logic behind decision-making on the GHP pilot project in Shenyang between 2006-2016 and evaluate its outcomes and impact on the city's sustainable development. It was argued that the geothermal heat pump pilot project in Shenyang was a necessary and sufficient contribution to the city's sustainable development. Interviews with stakeholders and policy document analysis led to the following conclusions.

The Shenyang GHP pilot project is the result of institutional pressure exerted on the local government to optimize the energy supply and reduce emissions. The combined effect of the binding planning system and cadre performance evaluation system resulted in institutional pressure. Higher authorities did not mandate the preference for a particular technology, the GHP. The Shenyang government made the decision based on local conditions, needs, and capacity.

The Shenyang government decoupled the tasks of emission reduction and energy structure optimisation. The former was achieved by relocating factories from the city to the outskirts. To solve the issue of energy restructuring, the municipality considered various renewable sources. There were limited conditions for exploring wind and solar energy in Shenyang. The gas heating alternative was considered but rejected as unsustainable because it would increase the city's dependence on gas supply from outside of the province. On the contrary, the local underground water resources were abundant. Especially after heavy industry relocation outside the city, Liaohe and Huhe River crossing Shenyang became affluent again. As a result, Shenyang Municipal Development and Reform Commission suggested to the city leaders promote water-source GHP technology as a low-carbon heating alternative.

Every GHP project involved four parties: the design company, the construction company, the supervision body and the GHP unit producer. Construction and supervision agents were primarily local, whereas most GHP manufacturers were from other provinces (Shandong, Shanghai, Beijing, Guangdong). There is no obvious pattern in the distribution of companies, no dominant player. Most companies were established in the 90s, so they do not appear to be shell companies. There were no officially stipulated bonus payments for local cadres to forcefully impose GHP. On the other hand, the mechanisms for cadre performance were a much more fundamental incentive.

The decline in GHP applications started in 2011 and the implementation eventually ceased. Deciding on promoting GHP in 2006, the Shenyang government had no intention to replace with them all existing coal boilers. The pilot project in Shenyang did not create the local GHP industry and did not mean to. However, it contributed to the low-carbon future within available resources and at minimal costs. The local bureaucrats expressed that the shift to alternative energy was inevitable, and the GHP pilot project was a doable step towards it.

The GHP pilot project was marginal to Shenyang's efforts to cut emissions during the 11th FYP. Nonetheless, the GHP pilot project was publicly promoted due to its social and political attractiveness. GHP aims at mitigating air pollution and serves a vital societal function by providing heating to citizens. GHP is a technological innovation associated with progress. Therefore, publicising the GHP pilot project benefited the city's image and promoted city leaders' careers. Both Shenyang majors who directly planned and implemented the GHP policy got announced to higher posts after their time in office was over, indicating that they fulfilled their obligations imposed by the central government.

Pilot projects are often a career growth engine. Officials use highly publicised pilot projects to seek political power and promotion, and the leader's position plays a crucial role in the decision-making process. Thus, local policy decision-making lies at the intersection of the central government's guidelines and local leaders' ambitions.

The Shenyang case study confirms the leading role of the planning system in China's policy-making and implementation. The plan-cadre nexus enacts person-based policy accountability instead of law-based and bureaucracy-based performance accountability. The Chinese planning system combines imperative, contractual, and indicative coordination features. In a way, a plan is a contract between local and national governments. Local governments negotiate performance targets with the central government and agree to follow the plan in exchange for attaining political power. The outcome of their work, in turn, legitimises the national government and the CCP rule. Environmental planning targets are the key tool for the centre to enforce sustainable agendas within local authorities.

Technological innovation is a common choice for meeting environmental planning targets. If we assume that environmental impact is a function of population size, resource use per person, and environmental impact per resource, there are three variables for manipulation: population size, consumption levels, and technological advancement. The decreasing ecological impact would mean excising control over population growth, slowing economic growth, or promoting technological innovation. The Rio Summit in 1992 showed governments' reluctance to compromise economic growth, stop boosting consumption or implement population growth-related policies, leaving technological innovation as the only solution to reduce the environmental impact of energy use. The leading economies have chosen the technocratic approach as a development paradigm.

Technologism, i.e. the perception of technology as an unquestioned good, is also characteristic of the current Chinese political ideology. Science and technology have been central to the political discourse and the country's development since the establishment of the PRC. Technological innovation invites participation, empowers and evokes a sense of belonging to the technological progress and historical process.

Advanced technologies function as engines for urban economies by attracting investments and creating markets and jobs. Moreover, technologism reframes urban problems (economic, social, environmental, political) into technical issues that technological solutions address. Thus, the focus shifts from people or political institutions to technology, to its successes and failures.

There are, nonetheless, limits and risks to pursuing sustainability through science and technology. Technological innovation for sustainability has to be designed with complexity and uncertainty that goes beyond the pure function of high efficiency and low carbon imprint
implementing sustainable technologies requires fundamentally restructuring the economic and industrial systems. The proliferation of a single technology will not result in sustainability. Besides, any technology coproduces environmentally harmful products. Only long-term exploitation can demonstrate the viability of the technology. The environmental outcome largely depends on the initial intent of the actors. Long-term decision-making and compound action of governments, communities, professionals and institutional drivers can make technology work for sustainability.

It is misleading to think that the government was ignorant and passive about environmental issues before the 11th five-year plan. The environmental agenda was gradually institutionalised through the establishment of administrative agencies, which were reorganised over time, gaining increasingly more independence, power, recourses and influence. The proportion of the environmental indicators in five-year plans has been progressively increasing. Despite the Chinese government's awareness of the ecological problems in the country, initially, there was no economic capacity to stop externalising the environmental costs to society and nature. The government's main concern was meeting the population's basic needs by providing them with food, income and work opportunities. In the first 20 years of the economic reforms, economic growth became the national and regional priority. This fired back once the national government turned towards sustainable development, as it met with non-compliance from local governments.

Partially, the reluctance of the local officials to submit to the environmental goals is caused by the specifics of regional financing and taxation in China. Local governments bare large proportions of their budgets and have to rely on their revenues. Internalising environmental costs would mean increasing their financial burden for them; that is why for as long as it was possible, they tried to ignore or avoid committing to any environmental indicators. This consequently postponed the beginning of China's active action for sustainability. The CCP has made sustainability integral to its planning regime. Meeting economic growth targets is not enough, for the development must be presented as sustainable.

A loser look at the idea of sustainability and its integration into China's planning system gives reason to assume that the GHP pilot project in Shenyang was not an environmental solution, but rather a management solution, that is a reaction aiming to support organisational processes. Thus, underlying principles of sustainability, as defined in UN processes, are internalised by the CCP as fundamental guiding principles for its development and adaptation. It applies that the driving force behind policy decision-making related to sustainability, low-carbon development, green economy, ecological civilization, etc. goes beyond environmental concerns and international commitments. The CCP regards such policies as obligatory and critical for its survival and resistance to historical forces. It also applies that according to the internal organizational logic, the GHP pilot project in Shenyang was indeed a necessary and sufficient contribution to sustainability, because it met organizational expectations expressed in Shenayng's 11th FYP.

Thus, sustainability theory treats human society, the economy and the natural environment as deeply interconnected and calls for a holistic approach to transformation. While the CCP claims to be a unifying force and the ultimate source of social welfare, as reflected by its strong network and the Party's involvement in all spheres of economic, political, and social life. Besides, sustainability implies that resources are scarce and limited. The CCP fully acknowledges resource scarcity through its efforts to promote economic, energy, and environmental security. China has made progress in the past 20 years toward achieving energy and food autonomy, including initiatives like the clean plate campaign to reduce food waste.

Another basic requirement for sustainability is long-term planning. As this research showed, planning is a dominant feature of the Chinese political system, which is proudly referred to as *scientific.* Despite dramatic socioeconomic and global changes, the ongoing continuity between the five-year plans is strong evidence of the plans' leading role in development. It is also argued that participation and engagement are central to the sustainability transition. Likewise, despite the absence of general elections, the CCP has always focused on population participation and mobilisation through the widespread party network, mass organisations, the *danwei* system in the past, and the *xiaoqu* housing model in the present. An unprecedented fundraising campaign in the aftermath of the Sichuan earthquake in 2008 or volunteer services during the COVID-19 pandemic is also a form of intense non-political engagement, approved or encouraged by the Party.

Principles of localisation and decentralisation are shared by sustainability and the Chinese state as well. Decentralisation became a key factor in the economic success of the Reforms of Opening. Admittedly, since the accession of Xi Jinping in 2013 the Chinese government has taken a trend towards decentralization. There is presumably a hope to compensate for the negative consequence of it through digital surveillance and big data application. Finally, sustainability urges for and offers control. Similarly, the CCP exercises control in the economic, political and social realms as a tool for preventing critical situations, but also for absorbing shocks. China's zero-COVID policy is a recent and vivid example of such an approach.

Apart from the underlying principles, sustainability has clearly defined areas, in which action must be taken to guarantee a successful transition, including peace and security, trends in population and urbanisation, population welfare, consumerism, globalisation, and climate change. Since the late 1970s, China has been proactive in all of these spheres. China's commitment to the Paris Agreement, mediation in the Ukraine crisis, refraining from open military conflicts, population control policies, and the nation's well-being as a proclaimed CCP's ultimate goal demonstrate this.

Strong structural similarities between sustainability and the CCP as a process of ongoing transformation make it logical to assume that they face the same challenges. The academic literature on sustainability states at least four challenges to achieving sustainability: interim assessment, allusive goals, institutional change, and ethics. Indeed, the CCP's remarkable transformation in the last 30 years revealed its struggles with self-assessment, internal discrepancies, self-reformation and legitimisation. How the Chinese Communist Party evolves in the future remains to be seen.

Appendix: List of Interviewees

Reference	Orgnaisation	Organisation name in English	Interview date and duration	Location
Interviewee 1	中国人民大学环境学院环境经济与管理系 环境政策与环境规划研究所	Renmin University of China Institute for Environmental Policy and Planning, School of Environment and Natural Resources	28.09.2015, 90 minutes	Beijing
Interviewee 2	第一摩码人居环境科技有限公司	The first Moma Habitat Environment Technology Co., Ltd.	22.10.2015, 60 minutes	Beijing
Interviewee 3	中国能源研究会地热专业委员会	Geothermal Committee of China Energy Research Society	27.11.2015, 50 minutes	Beijing
Interviewee 4	北京市华清地热开发有限责任公司	Beijing Huaqing Geothermal Development Company	7.12.2015, 50 munites	Beijing
Interviewee 5	沈阳市地源热泵协会	Shenyang Ground Source Heat Pump Association	8.12.2015, 90 minutes	Shenyang
Interviewee 6	沈阳环境科学研究院 沈阳环保规划局	Shenyang Academy of Environmental Science, Shenyang Environmental Protection Planning Bureau	20.06.2016, 40 minutes	Shenyang
Interviewee 7	沈阳市环境保护局	Shenyang Environmental Protection Bureau	21.06.2016, 90 minutes	Shenyang
Interviewee 8	沈阳市环境保护局	Shenyang Environmental Protection Bureau	21.06.2016, 30 minutes	Shenyang
Interviewee 9	沈阳市发展和改革委员会 资源节约与环境保护处	Shenyang Development and Reform Commission, Resource Conservation and Environmental Protection Department	22.06.2016, 30 minutes	Shenyang
Interviewee 10	沈阳市城市地下空间开发建设管理办公室	Shenyang Urban Underground Development and Construction Management Office	22.06.2016, 20 minutes	Shenyang
Interviewee 11	沈阳市地源热泵规划建设管理办公室	Shenyang Ground Source Heat Pump Planning and Construction Management Office	23.06.2016, 50 minutes	Shenyang
Interviewee 12	中国人民大学国际关系学院 中国人民大学国际能源战略研究中心	School of International Studies, Center for International Energy and Environment Strategy Studies	24.06.2016, 70 minutes	Beijing
Interviewee 13	北京节能环保促进会	Beijing Association to Promote Energy Conservation and Environmental Protection	21.07.2016, 90 minutes	Beijing
Interviewee 14	北京节能环保促进会	Beijing Association to Promote Energy Conservation and Environmental Protection	21.07.2016, 60 minutes	Beijing

References

Abbott, Kenneth W. 2012. “Engaging the Public and the Private in Global Sustainability Governance.” *International Affairs* 88(3).

Acemoglu, Daron. 2012. “Introduction to Economic Growth.” *Journal of Economic Theory* 147(2).

Acheampong, Alex O., Elliot Boateng, Mary Amponsah, and Janet Dzator. 2021. “Revisiting the Economic Growth–Energy Consumption Nexus: Does Globalization Matter?” *Energy Economics* 102.

Adams, William C. 2015. “Conducting Semi-Structured Interviews.” In *Handbook of Practical Program Evaluation: Fourth Edition*,.

Ahn, Yong Han, Annie R. Pearce, Yuhong Wang, and George Wang. 2013. “Drivers and Barriers of Sustainable Design and Construction: The Perception of Green Building Experience.” *International Journal of Sustainable Building Technology and Urban Development* 4(1): 35–45.

Alkaher, Iris, and Nurit Carmi. 2019. “Is Population Growth an Environmental Problem? Teachers’ Perceptions and Attitudes towards Including It in Their Teaching.” *Sustainability (Switzerland)* 11(7).

Anand, Sudhir, and Amartya Sen. 2000. “Human Development and Economic Sustainability.” *World Development* 28(12).

Angus, Ian H. 1980. “Toward a Philosophy of Technology.” *Research in Phenomenology* 10(1).

Anser, Muhammad Khalid, Majed Alharthi, Babar Aziz, and Sarah Wasim. 2020. “Impact of Urbanization, Economic Growth, and Population Size on Residential Carbon Emissions in the SAARC Countries.” *Clean Technologies and Environmental Policy* 22(4).

Arkhipov, Alexey Y., and Alexey N. Yeletsky. 2015. “Various Aspects of the Multipolarity within the World Economic System.” *Mediterranean Journal of Social Sciences* 6(36).

Assefa, G., and B. Frostell. 2007. “Social Sustainability and Social Acceptance in Technology Assessment: A Case Study of Energy Technologies.” *Technology in Society* 29(1): 63–78.

Van Audenhove, Leo, and Karen Donders. 2019. “Talking to People III: Expert Interviews and Elite Interviews.” In *The Palgrave Handbook of Methods for Media Policy Research*, ed. H., Puppis, M., Donders, K., Van Audenhove, L. Van den Bulck. Cham: Palgrave Macmillan.

Aung, Thiri Shwesin, Thomas B. Fischer, and Luan Shengji. 2020. “Evaluating Environmental Impact Assessment (EIA) in the Countries along the Belt and Road Initiatives: System Effectiveness and the Compatibility with the Chinese EIA.” *Environmental Impact Assessment Review* 81.

Avis, William Robert. 2019. “Urban Expansion in Nigeria.” *K4D Helpdesk Report 692. Brighton, UK: Institute of Development Studies.*

Ayala-Orozco, Bárbara et al. 2018. “Challenges and Strategies in Place-Based Multi-Stakeholder Collaboration for Sustainability: Learning from Experiences in the Global South.” *Sustainability (Switzerland)* 10(9).

Ayres, Robert U. 1995. “Life Cycle Analysis: A Critique.” *Resources, Conservation and Recycling* 14(3–4): 199–223.

Badland, Hannah et al. 2014. “Urban Liveability: Emerging Lessons from Australia for Exploring the Potential for Indicators to Measure the Social Determinants of Health.” *Social Science and Medicine* 111: 64–73.

Bagheri, Ali, and Peder Hjorth. 2007. “Planning for Sustainable Development: A Paradigm Shift towards a Process-Based Approach.” *Sustainable Development* 15(2).
Bai, Yang et al. 2016. “New Ecological Redline Policy (ERP) to Secure Ecosystem Services in China.” *Land Use Policy* 55.
Balzat, Markus, and Horst Hanusch. 2004. “Recent Trends in the Research on National Innovation Systems.” *Journal of Evolutionary Economics* 14(2): 197–210.
Bandura, Albert. 2007. “Impeding Ecological Sustainability through Selective Moral Disengagement.” *International Journal of Innovation and Sustainable Development* 2(1).
Baptista, Rui. 1999. “The Diffusion of Process Innovations: A Selective Review.” *International Journal of the Economics of Business* 6(1).
Barr, Stewart, Andrew Gilg, and Gareth Shaw. 2011. “Citizens, Consumers and Sustainability: (Re)Framing Environmental Practice in an Age of Climate Change.” *Global Environmental Change* 21(4): 1224–33.
Bartlett, Albert A. 1994. “Reflections on Sustainability, Population Growth, and the Environment.” *Population and Environment* 16(1).
Bartlett, Robert V., and Priya A. Kurian. 1999. “The Theory of Environmental Impact Assessment: Implicit Models of Policy Making.” *Policy and Politics* 27(4).
Basiago, Andrew D. 1995. “Methods of Defining ‘Sustainability.’” *Sustainable Development* 3(3): 109–19.
Becker, Christian U. 2011. Sustainability ethics and sustainability research *Sustainability Ethics and Sustainability Research*. Springer Science & Business Media.
Beder, Sharon. 1994. “The Role of Technology in Sustainable Development.” *IEEE Technology and Society Magazine* 13(4): 14–19.
Beermann, Jan. 2014. “Urban Partnerships in Low-Carbon Development: Opportunities and Challenges of an Emerging Trend in Global Climate Politics.” *urbe. Revista Brasileira de Gestão Urbana* 6: 170–83.
Bell, Stephen. 2011. “Do We Really Need a New ‘Constructivist Institutionalism’ to Explain Institutional Change?” *British Journal of Political Science* 41(4).
Van den Berg, Hendrik. 2016. Economic Growth and Development, Second Edition *Economic Growth and Development*. World Scientific Publishing Company.
van den Bergh, Jeroen C.J.M. 2010. “Externality or Sustainability Economics?” *Ecological Economics* 69(11).
Bi, Yuehong et al. 2009. “Comprehensive Exergy Analysis of a Ground-Source Heat Pump System for Both Building Heating and Cooling Modes.” *Applied Energy* 86(12): 2560–65.
Biedenweg, Kelly, Martha C. Monroe, and Annie Oxarart. 2013. “The Importance of Teaching Ethics of Sustainability.” *International Journal of Sustainability in Higher Education* 14(1).
Bijker, Wiebe E. 2009. “How Is Technology Made?-That Is the Question!” *Cambridge Journal of Economics* 34(1).
Bisengimana, Emmanuel et al. 2022. “The Frosting and Soil Imbalance Performance Issues of Building Heat Pumps: An Overview.” *Energy and Buildings* 273.
Blok, Vincent. 2021. “What Is Innovation? Laying the Ground for a Philosophy of Innovation.” *Techne: Research in Philosophy and Technology* 25(1).
Boas, Ingrid, Frank Biermann, and Norichika Kanie. 2016. “Cross-Sectoral Strategies in Global Sustainability Governance: Towards a Nexus Approach.” *International Environmental Agreements: Politics, Law and Economics* 16(3).
Bond, Alan, Angus Morrison-Saunders, and Jenny Pope. 2012. “Sustainability Assessment: The State of the Art.” *Impact Assessment and Project Appraisal* 30(1).

Boons, Frank, Carlos Montalvo, Jaco Quist, and Marcus Wagner. 2013. "Sustainable Innovation, Business Models and Economic Performance: An Overview." *Journal of Cleaner Production* 45: 1–8.
Borghesi, Simone, and Alessandro Vercelli. 2003. "Sustainable Globalisation." *Ecological Economics* 44(1).
Bornemann, Basil, and Holger Strassheim. 2019. "Governing Time for Sustainability: Analyzing the Temporal Implications of Sustainability Governance." *Sustainability Science* 14(4).
Bossel, Hartmut. 1999. Conservation Ecology *Indicators for Sustainable Development: Theory, Method, Applications*. Winnipeg: International Institute for Sustainable Development.
Bove, Vincenzo, Georgios Efthyvoulou, and Antonio Navas-Ruiz. 2014. "Political Cycles in Public Expenditure: Butter vs Guns." *Journal of Comparative Economics* .
Bowen, Glenn A. 2009. "Document Analysis as a Qualitative Research Method." *Qualitative Research Journal* 9(2): 27–40.
Boxer, Baruch, Geping Qu, and Woyen Lee. 1985. "Managing the Environment in China." *Pacific Affairs* 58(3).
Bringselius, Louise. 2018. "Efficiency, Economy and Effectiveness—but What about Ethics? Supreme Audit Institutions at a Critical Juncture." *Public Money and Management* 38(2).
Brown, Becky J., Mark E. Hanson, Diana M. Liverman, and Robert W. Merideth. 1987. "Global Sustainability: Toward Definition." *Environmental Management* 11(6): 713–19.
Brown, Kerry, and Una Aleksandra Bērziņa-Čerenkova. 2018. "Ideology in the Era of Xi Jinping." *Journal of Chinese Political Science* 23(3): 323–39.
Brundtland, Gro Harlem. 1987. "Our Common Future - Call for Action." *Environmental Conservation* 14(4).
den Butter, Frank A. G., and Marjan W. Hofkes. 2006. "A Neo-Classical Economic View on Technological Transitions." In *Understanding Industrial Transformation*, Dordrecht: Springer.
Byrne, John, Young Doo Wang, Bo Shen, and Xiuguo Li. 1994. "Sustainable Urban Development Strategies for China." *Environment & Urbanization* 6(1): 174–87.
Callon, Michel. 1994. "Is Science a Public Good?" *Science Technology and Human Values* 19(4).
———. 2012. "Society in the Making: The Study of Technology as a Tool for Sociological Analysis." In *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology: Anniversary Edition*.
Campos-Guzmán, Verónica, M. Socorro García-Cáscales, Nieves Espinosa, and Antonio Urbina. 2019. "Life Cycle Analysis with Multi-Criteria Decision Making: A Review of Approaches for the Sustainability Evaluation of Renewable Energy Technologies." *Renewable and Sustainable Energy Reviews* 104: 343–66.
Cao, Qianfa. 2016. "Chen Yun Kexu Fazhan Sixiang Taolun [On Chen Yun's Thought of Sustainable Development]." *Document Research Office of the Central Committee of the Communist Party of China*.
Caradonna, Jeremy. 2016. *Sustainability: A History*. New York, NY: Oxford University Press.
Carayon, Pascale. 2006. "Human Factors of Complex Sociotechnical Systems." *Applied Ergonomics* 37(4).
Cardno, Carol. 2018. "Policy Document Analysis: A Practical Educational Leadership Tool and a Qualitative Research Method." *Kuram ve Uygulamada Eğitim Yönetimi* 24(4): 623–40.
Carlaw, Kenneth I., and Richard G. Lipsey. 2003. "Productivity, Technology and Economic Growth: What Is the Relationship?" *Journal of Economic Surveys* 17(3).
Carlsson, B., and R. Stankiewicz. 1991. "On the Nature, Function and Composition of Technological Systems." *Journal of Evolutionary Economics* 1(2).

Cartier, Carolyn. 2015. "Territorial Urbanization and the Party-State in China." *Territory, Politics, Governance* 3(3).
Chan, Hon S, Koon-kwai Wong, K C Cheung, and Jack Man-keung Lo. 1995. "The Implementation Gap in Environmental Management in China : The Case of Guangzhou , Zhengzhou , and Nanjing." *Public Administration Review* : 333–40.
Chang, Yuan Chieh, and Ming Huei Chen. 2004. "Comparing Approaches to Systems of Innovation: The Knowledge Perspective." *Technology in Society* 26(1).
Chen, Jianming. 2020. "Chenyun Shengtai Huanjing Yu Dangdai Qishi [Chen Yun's Thought about Ecological Environment and Its Contemporary Enlightenment]." *Journal of Luoyang Normal University* 39(12): 1–4.
Chen, Jie, Danglun Luo, Guoman She, and Qianwei Ying. 2017. "Incentive or Selection? A New Investigation of Local Leaders' Political Turnover in China*." *Social Science Quarterly* 98(1).
Chen, Longqi, Tong Lai, and Lihong Zhou. 2020. "Collective Territoriality as a Major Barrier to Interagency Government Data Sharing in China: A Review of Existing Literature." In iConference 2020 Proceedings.
Chen, Xia et al. 2013. "Energy Saving and Emission Reduction of China's Urban District Heating." *Energy Policy* 55: 677–82.
Chen, Ye, Hongbin Li, and Li An Zhou. 2005. "Relative Performance Evaluation and the Turnover of Provincial Leaders in China." *Economics Letters* 88(3).
Cheney, Helen, Natalina Nheu, and Lorien Vecellio. 2004. "Sustainability as Social Change: Values and Power in Sustainability Discourse." *Sustainability and social science: Roundtable proceedings* : 225–46.
Cheung, P. T. 2005. "Guangzhou and Tianjin: The Struggle for Development in Two Chinese Cities Cities in China." In *Cities in Post-Mao China*, Routledge, 31–64.
Child, John, Yuan Lu, and Terence Tsai. 2007. "Institutional Entrepreneurship in Building an Environmental Protection System for the People's Republic of China." *Organization Studies* 28(7).
Childers, Daniel L. et al. 2014. "Advancing Urban Sustainability Theory and Action: Challenges and Opportunities." *Landscape and Urban Planning* 125.
China Vitae. 2003. "Qu Geping Biography." . www.chinavitae.com/biography/Qu_Geping/bio (October 10, 2022).
Cho, Youngsang, Junseok wang, and Daeho Lee. 2012. "Identification of Effective Opinion Leaders in the Diffusion of Technological Innovation: A Social Network Approach." *Technological Forecasting and Social Change* 79(1).
Christodouleas, John P. et al. 2011. "Short-Term and Long-Term Health Risks of Nuclear-Power-Plant Accidents." *New England Journal of Medicine* 364(24).
Clausen, Jens, and Klaus Fichter. 2019. "The Diffusion of Environmental Product and Service Innovations: Driving and Inhibiting Factors." *Environmental Innovation and Societal Transitions* 31.
Cloquell-Ballester, Vicente Agustín, Rafael Monterde-Díaz, Víctor Andrés Cloquell-Ballester, and María Cristina Santamarina-Siurana. 2007. "Systematic Comparative and Sensitivity Analyses of Additive and Outranking Techniques for Supporting Impact Significance Assessments." *Environmental Impact Assessment Review* 27(1).
Cohen, Wesley M., and Daniel A. Levinthal. 1989. "Innovation and Learning: The Two Faces of R & D." *The Economic Journal* 99(397).
Cole, Wade M. 2018. "Poor and Powerless: Economic and Political Inequality in Cross-National Perspective, 1981–2011." *International Sociology* 33(3).
Colsher, P. L., and R. B. Wallace. 1990. "Health and Social Antecedents of Relocation in Rural Elderly Persons." *Journals of Gerontology* 45(1).

Connor, Robin, and Stephen Dovers. 2004. Institutional Change for Sustainable Development *Institutional Change for Sustainable Development*.
Constantin, Margaux, Steve Saxon, and Jacky Yu. 2020. "COVID-19 and Reimagining the Tourism Economy | McKinsey." *McKinsey & Company* (08).
Cooke, P., M. G. Uranga, and G. Etxebarria. 1998. "Regional Systems of Innovation: An Evolutionary Perspective." *Environment and Planning A* 30(9).
Costanza, Robert, and Bernard C. Patten. 1995. "Defining and Predicting Sustainability." *Ecological Economics* 15(3): 193–96.
Coy, Dominique, Shirin Malekpour, Alexander K. Saeri, and Roger Dargaville. 2021. "Rethinking Community Empowerment in the Energy Transformation: A Critical Review of the Definitions, Drivers and Outcomes." *Energy Research and Social Science* 72.
Cui, Yuanlong et al. 2019. "Techno-Economic Assessment of the Horizontal Geothermal Heat Pump Systems: A Comprehensive Review." *Energy Conversion and Management* 191.
Dauvergne, Peter. 2010. The Shadows of Consumption *The Shadows of Consumption: Consequences for the Global Environment*. MIT Press.
Davenport, Sally, and David Bibby. 1999. "Rethinking a National Innovation System: The Small Country as 'SME." *Technology Analysis & Strategic Management* 11(3): 431–62.
Dawid, Herbert. 2006. "Agent-Based Models of Innovation and Technological Change." *Handbook of Computational Economics* 2: 1235–72.
Dear, Michael. 1992. "Understanding and Overcoming the NIMBY Syndrome." *Journal of the American Planning Association* 58(3).
Dernbach, John C. 2011. "Still Stumbling Toward Sustainability: U.S. National Governance, 2002-2007." *SSRN Electronic Journal*.
Ding, Sheng. 2010. "Analyzing Rising Power from the Perspective of Soft Power: A New Look at China's Rise to the Status Quo Power." *Journal of Contemporary China* 19(64).
Doloreux, D. 2002. "What We Should Know about Regional Systems of Innovation." *Technology in Society* 24(3).
Döringer, Stefanie. 2021. "The Problem-Centred Expert Interview". Combining Qualitative Interviewing Approaches for Investigating Implicit Expert Knowledge." *International Journal of Social Research Methodology* 24(3).
Dougherty, Deborah, and Danielle D. Dunne. 2011. "Organizing Ecologies of Complex Innovation." *Organization Science* 22(5).
Dovers, Stephen. 2004. TELA: Environment, Economy and Society *Institutions for Sustainability*. Canberra, ACT: Centre for Resource and Environmental Studies, The Australian National University.
Dovers, Stephen R., and John W. Handmer. 1992. "Uncertainty, Sustainability and Change." *Global Environmental Change* 2(4).
Duan, Juan. 2013. "Chen Yun de Xietiao Fazhan Guan Dui Ziyuan Xing Chengshi Panzhihua Ke Chixu Fazhan de Qishi [The Revelation of Chen Yun's View of Coordinated Development on Panzhihua's Sustainable Development]." *Journal of Lanzhou Commercial College* 29(1).
Duinker, Peter N., and Lorne A. Greig. 2007. "Scenario Analysis in Environmental Impact Assessment: Improving Explorations of the Future." *Environmental Impact Assessment Review* 27(3).
Dwyer, Catherine. 2011. "Systems Socio-Technical Systems Theory and Environmental Sustainability." *Sprouts: Working Papers on Information Systems* 11(3).
Eder, Klaus. 1996. *The Social Construction of Nature: A Sociology of Ecological Enlightenment*. London: Sage.
Edquist, Charles. 2010. "Systems of Innovation: Perspectives and Challenges." *African Journal of Science, Technology, Innovation and Development* 2(3): 14–45.

Eizenberg, Efrat, and Yosef Jabareen. 2017. "Social Sustainability: A New Conceptual Framework." *Sustainability (Switzerland)* 9(1).
Elzen, Boelie, Frank W. Geels, and Ken Green, eds. 2004. *System Innovation and the Transition to Sustainability*.
Engle, Nathan L. 2011. "Adaptive Capacity and Its Assessment." *Global Environmental Change* 21(2).
Enserink, Bert. 2000. "A Quick Scan for Infrastructure Planning: Screening Alternatives through Interactive Stakeholder Analysis." *Impact Assessment and Project Appraisal* 18(1).
Esty, Daniel C., and Andre Dua. 1997. Peterson Institute Press: All Books *Sustaining the Asia Pacific Miracle: Environmental Protection and Economic Integration*. Peterson Institute Press: All Books.
Evans, Annette, Vladimir Strezov, and Tim J. Evans. 2009. "Assessment of Sustainability Indicators for Renewable Energy Technologies." *Renewable and Sustainable Energy Reviews* 13(5): 1082–88.
Van Ewijk, Casper, and Sweder Van Wijnbergen. 1995. "Can Abatement Overcome the Conflict between Environment and Economic Growth?" *De Economist* 143(2).
Fagerberg, Jan. 2003. "Innovation: A Guide to the Literature."
Fagerberg, Jan, and Manuel M. Godinho. 2018. "Innovation, Economic Development and Policy." *Innovation, Economic Development and Policy: Selected Essays*: 185–213.
Fagerberg, Jan, and Martin Srholec. 2008. "National Innovation Systems, Capabilities and Economic Development." *Research Policy* 37(9): 1417–35.
Falkner, Robert. 2016. "The Paris Agreement and the New Logic of International Climate Politics." *International Affairs* 92(5).
Fan, C Cindy. 2006. "China's Eleventh Five-Year Plan (2006-2010): From 'Getting Rich First' to 'Common Prosperity.'" *Eurasian Geography and Economics* 47(6): 708–23.
Fan, Shenggen, and Connie Chan-Kang. 2005. "Road Development, Economic Growth, and Poverty Reduction in China." *Research Report of the International Food Policy Research Institute* (138).
Farla, Jacco, Jochen Markard, Rob Raven, and Lars Coenen. 2012. "Sustainability Transitions in the Making: A Closer Look at Actors, Strategies and Resources." *Technological Forecasting and Social Change* 79(6).
Fast, Stewart. 2013. "Social Acceptance of Renewable Energy: Trends, Concepts, and Geographies." *Geography Compass* 7(12).
Feenberg, Andrew. 2012. Questioning Technology *Questioning Technology*. Routledge.
Ferreira, João J.M., Cristina I. Fernandes, and Fernando A.F. Ferreira. 2020. "Technology Transfer, Climate Change Mitigation, and Environmental Patent Impact on Sustainability and Economic Growth: A Comparison of European Countries." *Technological Forecasting and Social Change* 150.
Fiksel, Joseph. 2003. "Designing Resilient, Sustainable Systems." *Environmental Science and Technology* 37(23).
———. 2006. "Sustainability and Resilience: Toward a Systems Approach." *Sustainability: Science, Practice and Policy* 2(2): 14–21.
Finnveden, Göran et al. 2009. "Recent Developments in Life Cycle Assessment." *Journal of Environmental Management* 91(1): 1–21.
Fischer, Frank. 2003. Reframing Public Policy: Discursive Politics and Deliberative Practices *Reframing Public Policy: Discursive Politics and Deliberative Practices*. Oxford University Press.
Fischer, Lisa Britt, and Jens Newig. 2016. "Importance of Actors and Agency in Sustainability Transitions: A Systematic Exploration of the Literature." *Sustainability (Switzerland)* 8(5).

Ford, Jeffrey D., Laurie W. Ford, and Angelo D'Amelio. 2008. "Resistance to Change: The Rest of the Story." *Academy of Management Review* 33(2).
Franklin, Alex, and Paul Blyton. 2013. *Researching Sustainability: A Guide to Social Science Methods, Practice and Engagement*. Routledge.
Fraser, Evan D.G. 2020. "The Challenge of Feeding a Diverse and Growing Population." *Physiology and Behavior* 221.
Freeman, Chris. 1995. "The National System of Innovation in Historical Perspective." *Cambridge Journal of Economics* 19(1): 5–24.
Freyre, Alisa et al. 2021. "How to Improve Effectiveness of Renewable Space Heating Programs by Better Understanding Homeowner—Installer Interactions." *Energies* 14(15).
Fuller, Douglas. 2019. EAI Working Paper *Searching for China's Technological Champions: What Past Structural Flaws and Policy Failures Tell Us about the Likelihood of Success for Current Policies*.
Fullerton, Don, and Gilbert E Metcalf. 1998. "Environmental Taxes and the Double-Dividend Hypothesis : Did You Really Expect Something for Nothing ?" *Chicago-Kent Law Review* 73(1).
Funtowicz, Silvio, Jerome Ravetz, and Martin O'Connor. 1998. "Challenges in the Use of Science for Sustainable Development." *International Journal of Sustainable Development* 1(1): 99–107.
Geels, Frank W. 2010. "Ontologies, Socio-Technical Transitions (to Sustainability), and the Multi-Level Perspective." *Research Policy* 39(4): 495–510.
———. 2012. "A Socio-Technical Analysis of Low-Carbon Transitions: Introducing the Multi-Level Perspective into Transport Studies." *Journal of Transport Geography* 24: 471–82.
Geels, Frank W. 2014. "Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective." *Theory, Culture & Society* 31(5): 21–49.
Geissdoerfer, Martin, Paulo Savaget, Nancy M.P. Bocken, and Erik Jan Hultink. 2017. "The Circular Economy – A New Sustainability Paradigm?" *Journal of Cleaner Production* 143.
General Administration of Quality Supervision. 2013. "The Technical Code for Water-Source Heat Pumps." https://www.chinesestandard.net/PDF.aspx/GBT19409-2013 (September 20, 2022).
General Administration of Quality Supervision, Inspection and Quarantine of the People Republic of China. 2003. "Water-Source Heat Pumps (GB/T19409-2003) ." https://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D7EC04D3A7E05397BE0A0AB82A (September 20, 2022).
Geng, Yong et al. 2013. "Regional Application of Ground Source Heat Pump in China: A Case of Shenyang." *Renewable and Sustainable Energy Reviews* 18(72): 95–102.
Gibbons, Stephen. 2015. "Gone with the Wind: Valuing the Visual Impacts of Wind Turbines through House Prices." *Journal of Environmental Economics and Management* 72.
Gilbert, Richard J. 2009. "Competition and Innovation." *Journal of Industrial Organization Education* 1(1): 1–23.
Gilley, Bruce. 2012. "Authoritarian Environmentalism and China's Response to Climate Change." *Environmental Politics* 21(2).
Godin, Benoît. 2006. "The Linear Model of Innovation: The Historical Construction of an Analytical Framework." *Science Technology and Human Values* 31(6): 639–67.
———. 2009. "National Innovation System." *Science, Technology & Human Values* 34(4): 476–501.

Goerner, Sally J., Bernard Lietaer, and Robert E. Ulanowicz. 2009. "Quantifying Economic Sustainability: Implications for Free-Enterprise Theory, Policy and Practice." *Ecological Economics* 69(1).

Gonzalez, Andrew, Patrick Thompson, and Michel Loreau. 2017. "Spatial Ecological Networks: Planning for Sustainability in the Long-Term." *Current Opinion in Environmental Sustainability* 29.

Goodland, Robert. 1995. "The Concept of Environmental Sustainability." *Annual Review of Ecology and Systematics* 26: 1–24.

de Gooyert, Vincent et al. 2016. "Sustainability Transition Dynamics: Towards Overcoming Policy Resistance." *Technological Forecasting and Social Change* 111: 135–45.

Gregson, Nicky. 2010. "The Shadows of Consumption: Consequences for the Global Environment Peter Dauvergne." *New Political Economy* 15(2).

Grinstein, Amir, and Petra Riefler. 2015. "Citizens of the (Green) World? Cosmopolitan Orientation and Sustainability." *Journal of International Business Studies* 46(6): 694–714.

Grum, Bojan, and Darja Kobal Grum. 2020. "Concepts of Social Sustainability Based on Social Infrastructure and Quality of Life." *Facilities* 38(11–12).

Grupp, Hariolf. 1992. Dynamics of Science-Based Innovation *Dynamics of Science-Based Innovation*.

Guha, Joydeep, and Bhaskar Chakrabarti. 2019. "Achieving the Sustainable Development Goals (SDGs) through Decentralisation and the Role of Local Governments: A Systematic Review." *Commonwealth Journal of Local Governance* 22: 1–21.

Gunarathne, Nuwan. 2019. "Sustainable Innovation Measurement: Approaches and Challenges." *Innovation for Sustainability*: 233–51.

Guo, Siyue et al. 2015. "Investigation and Analyses of Residential Heating in the HSCW Climate Zone of China: Status Quo and Key Features." *Building and Environment* 94: 532–42.

Gupta, Suraksha, Naresh K. Malhotra, Michael Czinkota, and Pantea Foroudi. 2016. "Marketing Innovation: A Consequence of Competitiveness." *Journal of Business Research* 69(12).

De Haan, Fjalar J. et al. 2014. "The Needs of Society: A New Understanding of Transitions, Sustainability and Liveability." *Technological Forecasting and Social Change* 85: 121–32.

Haberl, Helmut et al. 2011. "A Socio-Metabolic Transition towards Sustainability? Challenges for Another Great Transformation." *Sustainable Development* 19(1): 1–14.

Hall, Michael P., Neil A. Lewis, and Phoebe C. Ellsworth. 2018. "Believing in Climate Change, but Not Behaving Sustainably: Evidence from a One-Year Longitudinal Study." *Journal of Environmental Psychology* 56: 55–62.

Hall, N., P. Ashworth, and P. Devine-Wright. 2013. "Societal Acceptance of Wind Farms: Analysis of Four Common Themes across Australian Case Studies." *Energy Policy* 58: 200–208.

Hammami, Samiha Mjahed, Sahar Chtourou, and Abdelfattah Triki. 2016. "Identifying the Determinants of Community Acceptance of Renewable Energy Technologies: The Case Study of a Wind Energy Project from Tunisia." *Renewable and Sustainable Energy Reviews* 54: 151–60.

Han, Meiling et al. 2018. "City Branding in China's Northeastern Region: How Do Cities Reposition Themselves When Facing Industrial Decline and Ecological Modernization?" *Sustainability (Switzerland)* 10(1).

Hanna, S., and M. Munasinghe. 1995. "Property Rights and the Environment: Social and Ecological Issues." *Property rights and the environment: social and ecological issues*.

Hargreaves, Tom, Noel Longhurst, and Gill Seyfang. 2013. “Up, down, Round and Round: Connecting Regimes and Practices in Innovation for Sustainability.” *Environment and Planning A* 45(2): 402–20.
Heggelund, Gørild, and Ellen Bruzelius Backer. 2007. “China and Un Environmental Policy: Institutional Growth, Learning and Implementation.” *International Environmental Agreements: Politics, Law and Economics* 7(4).
Heilmann, Sebastian, and Oliver Melton. 2013. “The Reinvention of Development Planning in China, 1993-2012.” *Modern China* 39(6): 580–628.
Heilmann, Sebastian, and Elizabeth J. Perry, eds. 2020. Mao’s Invisible Hand *Mao’s Invisible Hand*. BRILL.
Hindriks, Frank, and Francesco Guala. 2021. “The Functions of Institutions: Etiology and Teleology.” *Synthese* 198(3).
von Hippel, Eric. 1976. “The Dominant Role of Users in the Scientific Instrument Innovation Process.” *Research Policy* 5(3).
Hobden, Christine. 2021. Citizenship in a Globalised World *Citizenship in a Globalised World*.
Hodgson, G. 2007. “What Are Institutions?” *Voprosy Ekonomiki* 2007(8).
Holbig, Heike. 2013. “Ideology after the End of Ideology. China and the Quest for Autocratic Legitimation.” *Democratization* 20(1): 61–81.
Hou, C., H. Chen, and R. Long. 2022. “Coupling and Coordination of China’s Economy, Ecological Environment and Health from a Green Production Perspective.” *International Journal of Environmental Science and Technology* 19(5).
Howells, Jeremy. 2009. “Regional Systems of Innovation?” In *Innovation Policy in a Global Economy*,.
Howley, Peter, Mark Scott, and Declan Redmond. 2009. “Sustainability versus Liveability: An Investigation of Neighbourhood Satisfaction.” *Journal of Environmental Planning and Management* 52(6): 847–64.
Hu, Angang. 2013. “The Distinctive Transition of China’s Five-Year Plans.” *Modern China* 39(6): 629–39.
Huang, Philip C.C. 2013. “Development ‘Planning’ in Present-Day China-System, Process, and Mechanism: Dialogues among Western and Chinese Scholars, VI.” *Modern China* 39(6): 575–79.
Huesemann, Michael H. 2003. “The Limits of Technological Solutions to Sustainable Development.” *Clean Technologies and Environmental Policy* 5(1): 21–34.
Hughes, Agatha C., and Thomas P. Hughes. 2011. Systems, Experts, and Computers *Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World War II and After*. MIT Press.
Hughes, Patrick J. 2008. Program *Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers*.
Huttrer, Gerald W. 1997. “Geothermal Heat Pumps: An Increasingly Successful Technology.” *Renewable Energy* 10(2–3): 481–88.
Huynen, Maud M.T.E., Pim Martens, and Henk B.M. Hilderink. 2005. “The Health Impacts of Globalization: A Conceptual Framework.” *Globalization and Health*.
Ijäs, Asko, Markku T. Kuitunen, and Kimmo Jalava. 2010. “Developing the RIAM Method (Rapid Impact Assessment Matrix) in the Context of Impact Significance Assessment.” *Environmental Impact Assessment Review* 30(2).
Intarakumnerd, Patarapong, Pun-arj Chairatana, and Tipawan Tangchitpiboon. 2002. “National Innovation System in Less Successful Developing Countries: The Case of Thailand.” *Research Policy* 31(8): 1445–57.

Itard, Laure, and Gerda Klunder. 2007. “Comparing Environmental Impacts of Renovated Housing Stock with New Construction.” *Building Research and Information* 35(3): 252–67.
Ives, Christopher D. et al. 2017. “Human–Nature Connection: A Multidisciplinary Review.” *Current Opinion in Environmental Sustainability* 26–27.
Jacka, Tamara. 2009. “Cultivating Citizens: Suzhi (Quality) Discourse in the PRC.” *Positions* 17(3).
Jahiel, Abigail R. 1998. “The Organization of Environmental Protection in China.” *The China Quarterly* (156): 757–87.
Jalonen, Harri. 2011. “The Uncertainty of Innovation: A Systematic Review of the Literature.” *Journal of Management Research* 4(1).
Jamieson, Dale. 1998. “Sustainability and Beyond.” *Ecological Economics* 24(2–3): 183–92.
Jarzebski, Marcin Pawel et al. 2021. “Ageing and Population Shrinking: Implications for Sustainability in the Urban Century.” *Urban Sustainability* 1(1).
Jensen, Charlotte Louise, Gary Goggins, Inge Røpke, and Frances Fahy. 2019. “Achieving Sustainability Transitions in Residential Energy Use across Europe: The Importance of Problem Framings.” *Energy Policy* 133.
Joerges, Bernward. 2019. The Development of Large Technical Systems *Large Technical Systems: Concepts and Issues*. Routledge.
Johnson, Hazel, and Gordon Wilson. 1999. “Institutional Sustainability as Learning.” *Development in Practice* 9(1–2).
Johnson, Thomas. 2010. “Environmentalism and NIMBYism in China: Promoting a Rules-Based Approach to Public Participation.” *Environmental Politics* 19(3).
Johnston, Paul, Mark Everard, David Santillo, and Karl-henrik Robèrt. 2007. “Reclaiming the Definition of Sustainability.” *Environmental Science and Pollution Research* 14(1): 60–66.
van der Kamp, Denise, Peter Lorentzen, and Daniel Mattingly. 2017. “Racing to the Bottom or to the Top? Decentralization, Revenue Pressures, and Governance Reform in China.” *World Development* 95.
Kampschulte, Andrea. 1999. “«Image» as an Instrument of Urban Management.” *Geographica Helvetica* 54(4): 229–41.
Kanbur, Ravi, and Xiaobo Zhang. 2005. “Fifty Years of Regional Inequality in China: A Journey through Central Planning, Reform, and Openness.” *Review of Development Economics* 9(1).
Kang, Le, and Ming Li. 2011. “Shijun Ma: Keeping on Exploring New Areas to Meet the Challenge of Human and Social Demands.” *Protein and Cell* 2(2): 90–91.
Karppinen, Kari, and Hallvard Moe. 2019. “Texts as Data I: Document Analysis.” In *The Palgrave Handbook of Methods for Media Policy Research*, Springer International Publishing, 249–62.
Kates, Robert W., and Thomas M. Parris. 2003. “Long-Term Trends and a Sustainability Transition.” *Proceedings of the National Academy of Sciences of the United States of America* 100(14): 8062–67.
Kavian, Soheil et al. 2020. “Exergy, Economic and Environmental Evaluation of an Optimized Hybrid Photovoltaic-Geothermal Heat Pump System.” *Applied Energy* 276: 115469.
Kawall, Jason. 2004. “Searching for Sustainability: Interdisciplinary Essays in the Philosophy of Conservation Biology.” *Conservation Biology* 18(2).
Kemp, Rene. 1994. “Technology and the Transition to Environmental Sustainability: The Problem of Technological Regime Shifts.” *Futures* 26(10): 1023–46.
———. 2010. “Sustainable Technologies Do Not Exist!” *Ekonomiaz* 75(3): 2–17.

Kern, Florian, and Adrian Smith. 2008. “Restructuring Energy Systems for Sustainability? Energy Transition Policy in the Netherlands.” *Energy Policy* 36(11).
Keys, Noni, Dana C. Thomsen, and Timothy F. Smith. 2010. “Opinion Leaders and Complex Sustainability Issues.” *Management of Environmental Quality: An International Journal* 21(2): 187–97.
Khooshie, Ranee, Panjabi Lal, and Ranee K Panjabi. 1993. “Can International Law Improve the Climate-An Analysis of the United Nations Framework Convention on Climate Change Signed at the Rio Summit in 1992.” *N.C.J. Int’l L. & Com. Reg* 18.
Kiely, Ray. 2005. Industrialization & Developmen *Industrialization & Development*. UCL Press.
Kim, Eunjin, Heather Shoenberger, and Yuan Sun. 2021. “Living in a Material World: Sponsored Instagram Posts and the Role of Materialism, Hedonic Enjoyment, Perceived Trust, and Need to Belong.” *Social Media and Society* 7(3).
Kline, Stephen J., and Nathan Rosenberg. 2009. “An Overview of Innovation.” *Studies on Science and the Innovation Process*: 173–203.
Kostka, Genia, and William Hobbs. 2012. “Local Energy Efficiency Policy Implementation in China: Bridging the Gap between National Priorities and Local Interests.” *China Quarterly* (211): 765–85.
Kostka, Genia, and Jonas Nahm. 2017. “Central-Local Relations: Recentralization and Environmental Governance in China.” *China Quarterly* 231: 567–82.
Lafferty, William M., and Katarina Eckerberg, eds. 2013. From Earth Summit to Local Agenda 21: Working Towards Sustainable Development *From Earth Summit to Local Agenda 21: Working towards Sustainable Development*. Routledge.
Laforet, Sylvie. 2011. “A Framework of Organisational Innovation and Outcomes in SMEs.” *International Journal of Entrepreneurial Behaviour and Research* 17(4).
Lakner, Christoph, Daniel Gerszon Mahler, Mario Negre, and Espen Beer Prydz. 2022. “How Much Does Reducing Inequality Matter for Global Poverty?” *Journal of Economic Inequality*.
Lande Official Website. “Company History.” *2022*. http://www.landac.net.cn/about/gongsijieshao.htm (September 28, 2022).
Landry, Pierre F. 2003. “The Political Management of Mayors in Post-Deng China.” *Copenhagen Journal of Asian Studies* (17).
Lau Leby, Jasmine, and Ahmad Hariza Hashim. 2010. “Liveability Dimensions and Attributes: Their Relative Importance in the Eyes of Neighbourhood Residents.” *Journal of Construction in Developing Countries* 15(1): 67–91.
Lee, Jeong-dong, and Chansoo Park. 2006. “Research and Development Linkages in a National Innovation System: Factors Affecting Success and Failure in Korea.” *Technovation* 26(9): 1045–54.
Leiserowitz, Anthony A., Robert W. Kates, and Thomas M. Parris. 2006. “Sustainability Values, Attitudes, and Behaviors: A Review of Multinational and Global Trends.” *Annual Review of Environment and Resources* 31: 413–44.
León, Luis F.Alvarez, and Jovanna Rosen. 2020. “Technology as Ideology in Urban Governance.” *Annals of the American Association of Geographers* 110(2): 497–506.
Leon-Soriano, Raúl, María Jesús Muñoz-Torres, and Ricardo Chalmeta-Rosaleñ. 2010. “Methodology for Sustainability Strategic Planning and Management.” *Industrial Management and Data Systems* 110(2).
Leopold, LB, FE Clarke, BB Hanshaw, and Balsley. 1971. “Procedure for Evaluating Environmental Impact.” *US Geological Survey Circular*.
Lewis, Joanna L. 2007. “China’s Strategic Priorities in International Climate Change Negotiations.” *Washington Quarterly* 31(1).

Li, Daitian, Zheng Liang, Fredrik Tell, and Lan Xue. 2021. "Sectoral Systems of Innovation in the Era of the Fourth Industrial Revolution: An Introduction to the Special Section." *Industrial and Corporate Change* 30(1).
Li, Kewen et al. 2015. "Comparison of Geothermal with Solar and Wind Power Generation Systems." *Renewable and Sustainable Energy Reviews* 42.
Li, Lili, and Araz Taeihagh. 2020. "An In-Depth Analysis of the Evolution of the Policy Mix for the Sustainable Energy Transition in China from 1981 to 2020." *Applied Energy* 263.
Li, Xingdao. 2007. "Chen Yun Huanjing Baohu Sixiang Tanxi [Analysis of Chen Yun's Thought on Environmental Protection]." *Xueshu lunwen* 199.
Li, Yun, Yanbin Li, Pengfei Ji, and Jing Yang. 2015. "The Status Quo Analysis and Policy Suggestions on Promoting China's Hydropower Development." *Renewable and Sustainable Energy Reviews* 51: 1071–79.
Liang, Xuan et al. 2016. "PM2.5 Data Reliability, Consistency, and Air Quality Assessment in Five Chinese Cities." *Journal of Geophysical Research* 121(17).
Liaoning Provincial People's Congress. 2003. "Regulations on Shenyang Air Pollution Prevention and Control ." http://www.npc.gov.cn/npc/c1220/200806/0ff8e92615054d1881bf1204239cdaa9.shtml (September 20, 2022).
Lindberg, Marie Byskov, Jochen Markard, and Allan Dahl Andersen. 2019. "Policies, Actors and Sustainability Transition Pathways: A Study of the EU's Energy Policy Mix." *Research Policy* 48(10): 1–15.
Ling, Chen. 2018. Journal of East Asian Studies *Manipulating Globalization:* Stanford University Press.
Liu, Dawei, and Hang Xu. 2018. "The Politics of Curtailment: Multi-Level Governance and Solar Photovoltaic Power Generation in China." *Environmental Politics* 27(5): 852–71.
Liu, Lingxuan, Bing Zhang, and Jun Bi. 2012. "Reforming China's Multi-Level Environmental Governance: Lessons from the 11th Five-Year Plan." *Environmental Science & Policy* 21: 106–11.
Liu, Mingxing, Binwen Song, and Ran Tao. 2006. "Perspective on Local Governance Reform in China." *China and World Economy* 14(2).
Liu, Mingyue, Xiaolong Feng, Sangui Wang, and Huanguang Qiu. 2020. "China's Poverty Alleviation over the Last 40 Years: Successes and Challenges." *Australian Journal of Agricultural and Resource Economics* 64(1): 209–28.
Liu, Yansui, and Yang Zhou. 2021. "Territory Spatial Planning and National Governance System in China." *Land Use Policy* 102.
Livermore, Michael A. 2014. "Cost-Benefit Analysis and Agency Independence." *University of Chicago Law Review* 81(2).
Lo, Kevin. 2015. "How Authoritarian Is the Environmental Governance of China?" *Environmental Science and Policy* 54.
Long, Xianling, and Xi Ji. 2019. "Economic Growth Quality, Environmental Sustainability, and Social Welfare in China - Provincial Assessment Based on Genuine Progress Indicator (GPI)." *Ecological Economics* 159.
Longhurst, Robyn. 2013. "Semi-Structured Interviews and Focus Groups. Key Methods in Geography." *Journal of Chemical Information and Modeling* 53(9).
Longo, Stefano B. et al. 2021. "Sociology for Sustainability Science." *Discover Sustainability* 2(1).
Lorenzoni, Irene et al. 2006. "Cross-National Comparisons of Image Associations with 'Global Warming' and 'Climate Change' among Laypeople in the United States of America and Great Britain." *Journal of Risk Research* 9(3): 265–81.

Lozano, Rodrigo. 2008. “Envisioning Sustainability Three-Dimensionally.” *Journal of Cleaner Production* 16(17): 1838–46.
Lu, Yuan, Eric W.K. Tsang, and Mike W. Peng. 2008. “Knowledge Management and Innovation Strategy in the Asia Pacific: Toward an Institution-Based View.” *Asia Pacific Journal of Management* 25(3).
Lundvall, Bengt-Åke. 1992. “National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning.” *London, Pinter*.
———. 1998. “Why Study National Systems and National Styles of Innovation?” *Technology Analysis and Strategic Management* 10(4): 403–22.
Lundvall, Bengt-Åke, Björn Johnson, Esben Sloth Andersen, and Bent Dalum. 2002. “National Systems of Production, Innovation and Competence Building.” *Research Policy* 31: 213–31.
Lv, Bingyang, Yongzheng Liu, and Yan Li. 2020. “Fiscal Incentives, Competition, and Investment in China.” *China Economic Review* 59.
Lv, Wen Dong, Dan Tian, Yuan Wei, and Rui Xue Xi. 2018. “Innovation Resilience: A New Approach for Managing Uncertainties Concerned with Sustainable Innovation.” *Sustainability (Switzerland)* 10(10).
Lyon, David. 2004. “Globalizing Surveillance: Comparative and Sociological Perspectives.” *International Sociology* 19(2).
Ma, Wenting, Martin de Jong, Mark de Bruijne, and Daan Schraven. 2020. “Economic City Branding and Stakeholder Involvement in China: Attempt of a Medium-Sized City to Trigger Industrial Transformation.” *Cities* 105.
Ma, Yunfeng et al. 2021. “Air Pollutant Emission Characteristics and HYSPLIT Model Analysis during Heating Period in Shenyang, China.” *Environmental Monitoring and Assessment* 193(1).
Macher, Ken. 1988. “Empowerment and the Bureaucracy.” *Training & Development Journal* 42(9).
MacKenzie, Donald. 1984. “Marx and the Machine.” *Technology and Culture* 25(3).
Malerba, Franco. 2005. “Sectoral Systems of Innovation: A Framework for Linking Innovation to the Knowledge Base, Structure and Dynamics of Sectors.” *Economics of Innovation and New Technology* 14(1–2).
Man Li, Rita Yi et al. 2021. “The Impact of Sustainability Awareness and Moral Values on Environmental Laws.” *Sustainability (Switzerland)* 13(11).
Mandelik, Yael, Tamar Dayan, and Eran Feitelson. 2005. “Issues and Dilemmas in Ecological Scoping: Scientific, Procedural and Economic Perspectives.” *Impact Assessment and Project Appraisal* 23(1).
Maohong, Bao. 2004. “Environmental History in China.” *Environment and History* 10(4).
Marc, Alexandre. 2016. “Conflict and Violence in the 21st Century: Current Trends as Observed in Empirical Research and Statistics.” *Fragility, Conflict and Violence for the World Bank Group*. https://www.un.org/pga/70/wp-content/uploads/sites/10/2016/01/Conflict-and-violence-in-the-21st-century-Current-trends-as-observed-in-empirical-research-and-statistics-Mr.-Alexandre-Marc-Chief-Specialist-Fragility-Conflict-and-Violence-World-Bank-Group.pd. (September 20, 2022).
Marcuse, Peter. 1988. “Sustainability Is Not Enough.” *American Journal of Alternative Agriculture* 3(2–3): 128–30.
Marshall, Julian D., and Michael W. Toffel. 2005. “Framing the Elusive Concept of Sustainability: A Sustainability Hierarchy.” *Environmental Science and Technology* 39(3).
Marshall, R. Scott, Mark Cordano, and Murray Silverman. 2005. “Exploring Individual and Institutional Drivers of Proactive Environmentalism in the US Wine Industry.” *Business Strategy and the Environment* 14(2).

Martínez, E. et al. 2009. “Life Cycle Assessment of a Multi-Megawatt Wind Turbine.” *Renewable Energy* 34(3): 667–73.

McKenzie, Stephen. 2004. University of South Australia *Social Sustainability: Towards Some Definitions*.

McMichael, A. J., C. D. Butler, and Carl Folke. 2003. “New Visions for Addressing Sustainability.” *Science* 302(5652).

Mcmillan, John, and Barry Naughton. 1992. “How to Reform a Planned Economy: Lessons from China.” *Oxford Review of Economic Policy* 8(1).

McNabb, David E. 2019. “The Population Growth Barrier.” In *Global Pathways to Water Sustainability*, Cham: Palgrave Macmillan.

Meadowcroft, James. 2009. “What about the Politics? Sustainable Development, Transition Management, and Long Term Energy Transitions.” *Policy Sciences* 42(4): 323–40.

Mebratu, Desta. 1998. “Sustainability and Sustainable Development: Historical and Conceptual Review.” *Environmental Impact Assessment Review* 18(6).

Meex, Elke et al. 2018. “Requirements for Applying LCA-Based Environmental Impact Assessment Tools in the Early Stages of Building Design.” *Building and Environment* 133: 228–36.

Mertha, Andrew C. 2005. “China’s ‘Soft’ Centralization: Shifting Tiao/Kuai Authority Relations.” *China Quarterly* (184): 791–810.

Metcalfe, J. S. 1994. “Evolutionary Economics and Technology Policy.” *Economic Journal* 104(425).

Meuser, Michael, and Ulrike Nagel. 2009. “The Expert Interview and Changes in Knowledge Production.” In *Interviewing Experts*, London: Palgrave Macmillan.

Millar, Carla et al. 2012. “Sustainability and the Need for Change: Organisational Change and Transformational Vision.” *Journal of Organizational Change Management* 25(4).

Miller, Seumas. 2003. “Social Institutions.” In *Realism in Action*, Dordrecht: Springer.

———. 2009. The Moral Foundations of Social Institutions: A Philosophical Study *The Moral Foundations of Social Institutions: A Philosophical Study*.

Ministry of Construction. 2005. “Technical Code for Ground-Source Heat Pump System.” https://www.chinesestandard.net/PDF/English.aspx/GB50366-2005 (September 20, 2022).

———. 2009. “Technical Code for Ground-Source Heat Pump System.” . http://cnspc.sinopec.com/cnspc/Resource/Pdf/GB%2050366-2005.pdf (September 20, 2022).

Ministry of Ecology and Environment. 2018. “History.” https://www.mee.gov.cn/zjhb/jgls/lsyg/ (October 10, 2022).

Moe, Hallvard, and Kari Karppinen. 2011. “What We Talk about When We Talk about Document Analysis.” *Trends in Communication Policy Research: New Theories, Methods and Subjects*.

Moore, Jason W. 2017. “The Capitalocene, Part I: On the Nature and Origins of Our Ecological Crisis.” *Journal of Peasant Studies* 44(3).

Morgan, Richard K. 2012. “Environmental Impact Assessment: The State of the Art.” *Impact Assessment and Project Appraisal* 30(1): 5–14.

Morrison-saunders, Angus, and Ross Marshall. 2007. “EIA Follow Up International Best Practice Principles.” *IAIA Special Publication Series No. 6* (6).

Mulder, Peter, and Jeroen C.J.M. van den Bergh. 2001. “Evolutionary Economic Theories of Sustainable Development.” *Growth and Change* 32(1).

Mulder, Peter, Henri L.F. De Groot, and Marjan W. Hofkes. 2001. “Economic Growth and Technological Change: A Comparison of Insights from a Neo-Classical and an Evolutionary Perspective.” *Technological Forecasting and Social Change* 68(2).

Naderifar, Mahin, Hamideh Goli, and Fereshteh Ghaljaie. 2017. "Snowball Sampling: A Purposeful Method of Sampling in Qualitative Research." *Strides in Development of Medical Education* 14(3).
National Development and Reform Commission of the PRC. 2004. "China Medium and Long Term Energy Conservation Plan." https://www.ndrc.gov.cn/xxgk/jd/jd/200506/t20050628_1183006.html?code=&state=123 (September 20, 2022).
———. 2007. "Medium and Long-Term Development Plan for Renewable Energy in China." http://cn.chinagate.cn/economics/2007-09/10/content_8851366.htm (September 20, 2022).
National Energy Administration. 2005. "Renewable Energy Industry Development Guidance Catalogue."
Naughton, Barry. 2014. "China's Economy: Complacency, Crisis & the Challenge of Reform." *Daedalus* 143(2).
Neacsu, Marius. 2009. "The City Image and the Local Public Administration: A Working Tool in Urban Planning." *Transylvanian Review of Administrative Sciences* 5(27): 172–88.
Nelson, Richard R, and Sidney G Winter. 1977. "In Search of Useful Theory of Innovation." *Research Policy* 6: 36–76.
Nidumolu, Ram, C K Prahalad, and M R Rangaswami. 2009. "Why Sustainability Is Now the Key Driver of Innovation." *Harvard Business Review* 87(9): 57–64.
Obach, Brian, Michael N. Dobkowski, and Isidor Wallimann. 2003. "On the Edge of Scarcity: Environment, Resources, Population, Sustainability, and Conflict." *Contemporary Sociology* 32(6).
Öberg, Christina, and Allen T. Alexander. 2019. "The Openness of Open Innovation in Ecosystems – Integrating Innovation and Management Literature on Knowledge Linkages." *Journal of Innovation and Knowledge* 4(4).
O'Connor, Gina Colarelli, and Mark P. Rice. 2013. "New Market Creation for Breakthrough Innovations: Enabling and Constraining Mechanisms." *Journal of Product Innovation Management* 30(2).
Oelschlaeger, Max. 1979. "The Myth of the Technological Fix." *The Southwestern Journal of Philosophy* 10(1): 43–53.
Oerlemans, Leon A.G., Marius T.H. Meeus, and Frans W.M. Boekema. 1998. "Do Networks Matter for Innovation? The Usefulness of the Economic Network Approach in Analysing Innovation." *Tijdschrift voor Economische en Sociale Geografie* 89(3).
Omri, Anis. 2020. "Technological Innovation and Sustainable Development : Does the Stage of Development Matter?" *Environmental Impact Assessment Review* 83.
Oreg, Shaul. 2003. "Resistance to Change: Developing an Individual Differences Measure." *Journal of Applied Psychology* 88(4).
O'Riordan, Timothy. 2013. *The Transition to Sustainability: The Politics of Agenda 21 in Europe*. : Routledge.
Orr, David W. 2002. "Four Challenges of Sustainability." *Conservation Biology* 16(6): 1457–60.
Owen, Anthony D. 2006. "Renewable Energy: Externality Costs as Market Barriers." *Energy Policy* 34(5).
Pardo Del Val, Manuela, and Clara Martínez Fuentes. 2003. "Resistance to Change: A Literature Review and Empirical Study." *Management Decision* 41(2).
Parrilli, Mario Davide, and Henar Alcalde Heras. 2016. "STI and DUI Innovation Modes: Scientific-Technological and Context-Specific Nuances." *Research Policy* 45(4): 747–56.
Patel, Parimal, and Keith Pavitt. 1994. "National Innovation Systems: Why They Are Important, and How They Might Be Measured and Compared." *Economics of Innovation and New Technology* 3(1): 77–95.

Paul, Arpan, and Joy Sen. 2020. “A Critical Review of Liveability Approaches and Their Dimensions.” *Geoforum* 117: 90–92.
Perez, Carlota. 2009. “Technological Revolutions and Techno-Economic Paradigms.” *Cambridge Journal of Economics* 34(1).
Pezzey, John. 1992. “Sustainability : An Interdisciplinary Guide.” *Environmental Values* 1(4): 321–62.
Du Pisani, Jacobus A. 2006. “Sustainable Development – Historical Roots of the Concept.” *Environmental Sciences* 3(2): 83–96.
Pye, Lucian W. et al. 1999. “China Joins the World: Progress and Prospects.” *Foreign Affairs* 78(5).
Qu Geping. 1982. “Environmental Protection in China.” *Environmental Conservation* 9(1): 31–33.
Ramos-Escudero, Adela et al. 2021. “Spatial Analysis of Indicators Affecting the Exploitation of Shallow Geothermal Energy at European Scale.” *Renewable Energy* 167.
Ran, Ran, and Yan Jian. 2021. “When Transparency Meets Accountability.” *China Review* 21(1).
Raskin, Paul, Michael Chadwick, Tim Jackson, and Gerald Leach. 1996. Stockholm Environment Institute *The Sustainability Transition: Beyond Conventional Development*.
Ratner, Blake D. 2004. “‘Sustainability’ as a Dialogue of Values: Challenges to the Sociology of Development.” *Sociological Inquiry* 74(1).
Rees, William. 2010. “What’s Blocking Sustainability? Human Nature, Cognition, and Denial.” *Sustainability: Science, Practice, and Policy* 6(2).
Rensselaer W. Lee III. 1972. “Ideology and Technical Innovation in Chinese Industry, 1949-1971.” *Asian Survey* 12(8): 647–61.
Risheng, Guo. 2012. “Progress of China’s Agenda 21.” *Chinese Journal of Population Resources and Environment* 10(3).
Romer, Paul M. 1994. “The Origins of Endogenous Growth.” *Journal of Economic Perspectives* 8(1).
Rosenau, James N. 2017. “Globalization and Governance: Bleak Prospects for Sustainability.” In *Challenges of Globalization*, Routledge.
Sachs, Jeffrey D. 2012. “From Millennium Development Goals to Sustainable Development Goals.” *The Lancet* 379.
Sáez Blázquez, Cristina et al. 2019. “Technical Optimization of the Energy Supply in Geothermal Heat Pumps.” *Geothermics* 81(4): 133–42.
Saha, Devashree. 2009. “Factors Influencing Local Government Sustainability Efforts.” *State and Local Government Review* 41(1).
Saich, Tony. 1986. “Linking Research to the Productive Sector: Reforms of the Civilian Science and Technology System in Post-Mao China.” *Development and Change* 17: 3–33.
Salminen, Airi, Katri Kauppinen, and Merja Lehtovaara. 1997. “Towards a Methodology for Document Analysis.” *Journal of the American Society for Information Science* 48(7): 644–55.
Sanner, Burkhard, Constantine Karytsas, Dimitrios Mendrinos, and Ladislaus Rybach. 2003. “Current Status of Ground Source Heat Pumps and Underground Thermal Energy Storage in Europe.” *Geothermics* 32(4): 579–88.
Sasanpour, Farzaneh. 2017. “Livable City One Step towards Sustainable Development.” *Journal of Contemporary Urban Affairs* 1(3): 13–17.
Scerri, Andy, and Paul James. 2009. “Communities of Citizens and ‘indicators’ of Sustainability.” *Community Development Journal* 45(2): 219–36.

Schienke, Erich W. 2012. "'Ecocity China': An Ethos Under Development." In *Philosophy of Engineering and Technology*, Dordrecht: Springer.
Schnitzer, Monika. 2000. "The Process of China's Market Transition (1978-1998): The Evolutionary, Historical, and Comparative Perspectives." *Journal of Institutional and Theoretical Economics* 156(1).
Schrempf, Benjamin, David Kaplan, and Doris Schroeder. 2013. "National, Regional, and Sectoral Systems of Innovation – An Overview." *Report for FP7 Project "Progress", progressproject.eu.*
Searle, John. 2005. "What Is an Institution?" *Journal of Institutional Economics* 1: 1–22.
Seghezzo, Lucas. 2009. "The Five Dimensions of Sustainability." *Environmental Politics* 18(4): 539–56.
Self, Stuart J., Bale V. Reddy, and Marc a. Rosen. 2013. "Geothermal Heat Pump Systems: Status Review and Comparison with Other Heating Options." *Applied Energy* 101: 341–48.
Shafer, C. Scott, Bong Koo Lee, and Shawn Turner. 2000. "A Tale of Three Greenway Trails: User Perceptions Related to Quality of Life." *Landscape and Urban Planning* 49(3–4).
Shafiee, Shahriar, and Erkan Topal. 2009. "When Will Fossil Fuel Reserves Be Diminished?" *Energy Policy* 37(1).
Sharifi, Ayyoob, Dahlia Simangan, Shinji Kaneko, and Hassan Virji. 2021. "The Sustainability–Peace Nexus: Why Is It Important?" *Sustainability Science* 16(4).
Shearman, Richard. 1990. "The Meaning and Ethics of Sustainability." *Environmental Management* 14(1).
Shenyang Government. 2005a. "Shenyang 11th Five-Year Plan." http://www.gov.cn/ztzl/2005-11/23/content_106914.htm (September 20, 2022).
———. 2005b. "Shenyang Land Use Plan for 2006-2020 ." . https://www.mnr.gov.cn/gk/ghjh/201811/t20181101_2324704.html (September 20, 2022).
———. 2005c. "The Basic Situation of Adjustment and Transformation of Shenyang's Old Industrial Base." http://drc.changchun.gov.cn/sygzdt/200508/t20050822_1283321.html (September 20, 2022).
———. 2006a. "Implementation Opinions on Comprehensively Promoting Construction and Application of Ground Source Heat Pump Systems ." http://www.shenyang.gov.cn/web/assembly/action/browsePage.do?channelID=1158644667228&contentID=1165816507758 (September 20, 2020).
———. 2006b. "Notice on Distributing the Responsibilities of the 11th Five-Year Plan for the Economic and Social Development of Shenyang City ." http://www.shenyang.gov.cn/web/assembly/action/browsePage.do?channelID=1158644667228&contentID=1172740593986 (September 20, 2020).
———. 2007. "Measures of Shenyang Municipality for the Administration of Construction and Application of GHP Systems." http://www.moj.gov.cn/pub/sfbgw/flfggz/flfggzdfzwgz/200712/t20071214_137122.html (September 20, 2020).
Simonen, Kathrina. 2014. "Life Cycle Assessment." *Life Cycle Assessment* 45(1): 1–159.
Singh, Rajesh Kumar, H. R. Murty, S. K. Gupta, and A. K. Dikshit. 2012. "An Overview of Sustainability Assessment Methodologies." *Ecological Indicators* 15(1).
Siudek, Tomasz, and Aldona Zawojska. 2014. "Competitiveness in the Economic Concepts, Theories and Empirical Research." *Oeconomia* 13(1).
Skoulikaris, Charalampos, and Antigoni Zafirakou. 2019. "River Basin Management Plans as a Tool for Sustainable Transboundary River Basins' Management." *Environmental Science and Pollution Research* 26(15).

Smink, Magda M., Marko P. Hekkert, and Simona O. Negro. 2015. "Keeping Sustainable Innovation on a Leash? Exploring Incumbents' Institutional Strategies." *Business Strategy and the Environment* 24(2).
Snell, Tim, and Richard Cowell. 2006. "Scoping in Environmental Impact Assessment: Balancing Precaution and Efficiency?" *Environmental Impact Assessment Review* 26(4).
Social Research Association. 2021. "Research Ethics Guidance." https://the-sra.org.uk/common/Uploaded%20files/Resources/SRA%20Research%20Ethics%20guidance%202021.pdf (October 6, 2022).
Soete, Luc, Bart Verspagen, and Bas Ter Weel. 2010. 2 Handbook of the Economics of Innovation *Systems of Innovation*. North-Holland.
Soini, Katriina, and Joost Dessein. 2016. "Culture-Sustainability Relation: Towards a Conceptual Framework." *Sustainability (Switzerland)* 8(2).
Solow R. 1993. Presentation at Woods Hole *Sustainability: An Economist's Perspective*.
Song, Qijiao, Tianle Liu, and Ye Qi. 2021. "Policy Innovation in Low Carbon Pilot Cities: Lessons Learned from China." *Urban Climate* 39.
Southworth, Michael. 1985. "Shaping the City Image." *Journal of Planning Education and Research* 5(1): 52–59.
Spangenberg, Joachim H. 2005. "Economic Sustainability of the Economy: Concepts and Indicators." *International Journal of Sustainable Development* 8(1–2).
Stahel, W. R. 1997. "The Service Economy: 'Wealth without Resource Consumption'?" *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 355(1728).
Standing Committee of the National People's Congress. 2005. "Renewable Energy Law of the People's Republic of China." http://www.npc.gov.cn/zgrdw/englishnpc/Law/2007-12/13/content_1384096.htm (September 20, 2022).
Standing Committee of the National People's Congress of China. 2018. "Energy Conservation Law of the People's Republic of China ." . http://www.npc.gov.cn/zgrdw/englishnpc/Law/2009-02/20/content_1471608.htm (September 20, 2022).
State Council of China. 2006. "11th Five-Year Plan." http://www.gov.cn/gongbao/content/2006/content_268766.htm (September 19, 2022).
State Planning Commission. 2000. "Critical Points of Renewable Energy Industry Development Plan 2000-2015."
Steele, Wendy. 2011. "Strategy-Making for Sustainability: An Institutional Learning Approach to Transformative Planning Practice." *Planning Theory and Practice* 12(2).
Stephens, Jennie C. 2019. "Energy Democracy: Redistributing Power to the People through Renewable Transformation." *Environment* 61(2).
Stigka, Eleni K., John A. Paravantis, and Giouli K. Mihalakakou. 2014. "Social Acceptance of Renewable Energy Sources: A Review of Contingent Valuation Applications." *Renewable and Sustainable Energy Reviews* 32: 100–106.
Strommen, Erik F., and Bruce Lincoln. 1992. "Constructivism, Technology, and the Future of Classroom Learning." *Education and Urban Society* 24(4).
Subramanian, Vrishali et al. 2016. "Sustainable Nanotechnology Decision Support System: Bridging Risk Management, Sustainable Innovation and Risk Governance." *Journal of Nanoparticle Research* 18(4).
Swilling, Mark, and Eve Annecke. 2012. "Just Transitions Explorations of Sustainability in an Unfair World Introduction: On Becoming Visible." *UCT Press* 6(1).
Tang, Li, and Philip Shapira. 2011. "Regional Development and Interregional Collaboration in the Growth of Nanotechnology Research in China." *Scientometrics* 86(2).

Tapsuwan, Sorada, Claire Mathot, Iain Walker, and Guy Barnett. 2018. “Preferences for Sustainable, Liveable and Resilient Neighbourhoods and Homes: A Case of Canberra, Australia.” *Sustainable Cities and Society* 37: 133–45.

The State Council The People’s Republic of China. 2006. “The National Medium- and Long-Term Program for Science and Technology Development (2006-2020).” http://www.gov.cn/gongbao/content/2006/content_240244.htm (September 20, 2022).

Thornton, Patricia M. 2013. “The Advance of the Party: Transformation or Takeover of Urban Grassroots Society?” *China Quarterly* (213): 1–18.

Tian, Zhihua, Yanfang Tian, Yang Chen, and Shuai Shao. 2020. “The Economic Consequences of Environmental Regulation in China: From a Perspective of the Environmental Protection Admonishing Talk Policy.” *Business Strategy and the Environment* 29(4).

Tibbs, Hardin. 2011. “Changing Cultural Values and the Transition to Sustainability.” *Journal of Futures Studies* 15(3): 13–32.

Todorov, Vladislav, and Dora Marinova. 2011. “Modelling Sustainability.” *Mathematics and Computers in Simulation* 81(7): 1397–1408.

Tonelli, Flavio, Steve Evans, and Paolo Taticchi. 2013. “Industrial Sustainability: Challenges, Perspectives, Actions.” *International Journal of Business Innovation and Research* 7(2).

Tsai, Wen Hsuan, and Xingmiu Liao. 2020. “Mobilizing Cadre Incentives in Policy Implementation: Poverty Alleviation in a Chinese County.” *China Information* 34(1): 45–67.

Tsoutsos, Theocharis, Niki Frantzeskaki, and Vassilis Gekas. 2005. “Environmental Impacts from the Solar Energy Technologies.” *Energy Policy* 33(3): 289–96.

von Tunzelmann, G.N. 1996. “Firms, Markets and Economic Change: A Dynamic Theory of Business Institutions.” *Research Policy* 25(6).

Turner, Billie Lee et al., eds. 1997. *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years*. : Cambridge University Press.

Ulriksen, Marianne S., and Nina Dadalauri. 2016. “Single Case Studies and Theory-Testing: The Knots and Dots of the Process-Tracing Method.” *International Journal of Social Research Methodology* 19(2): 223–39.

Uyarra, Elvira, and Kieron Flanagan. 2013. “Reframing Regional Innovation Systems: Evolution, Complexity and Public Policy.” In *Re-Framing Regional Development*, Routledge.

Valcárcel-Aguiar, Beatriz, Pilar Murias, and David Rodríguez-González. 2018. “Sustainable Urban Liveability: A Practical Proposal Based on a Composite Indicator.” *Sustainability (Switzerland)* 11(1).

Varun, I. K. Bhat, and Ravi Prakash. 2009. “LCA of Renewable Energy for Electricity Generation Systems-A Review.” *Renewable and Sustainable Energy Reviews* 13(5).

Vollenbroek, Frans A. 2002. “Sustainable Development and the Challenge of Innovation.” *Journal of Cleaner Production* 10(3): 215–23.

Walker, K. J. 1979. “Ecological Limits and Marxian Thought.” *Politics* 14(1).

Wallis, Cara. 2020. Technomobility in China *Technomobility in China*. New York University Press.

Wals, Arjen E J, and Frans Lenglet. 2016. “Sustainability Citizens: Collaborative and Disruptive Social Learning.” *Sustainability Citizenship in Cities - Theory and practice* (May): 52–66.

Wan, Jun et al. 2022. “A Brief Overview of the 13th Five-Year Plan for the Protection of Ecological Environment.” *Environmental Strategy and Planning in China*: 57–85.

Wang, Alex L. 2013. “The Search for Sustainable Legitimacy: Environmental Law and Bureaucracy in China.” *Harvard Environmental Law Review* 37(2).

Wang, Jinpeng. 2018. "Reform of China's Environmental Governance: The Creation of a Ministry of Ecology and Environment." *Chinese Journal of Environmental Law* 2(1).
Wang, Nannan, and Yen Chiang Chang. 2014. "The Evolution of Low-Carbon Development Strategies in China." *Energy* 68: 61–70.
Wang, Yan, Richard K. Morgan, and Mat Cashmore. 2003. "Environmental Impact Assessment of Projects in the People's Republic of China: New Law, Old Problems." *Environmental Impact Assessment Review* 23(5): 543–79.
Ward, Hugh. 2008. "Liberal Democracy and Sustainability." *Environmental Politics* 17(3): 386–409.
Watson, Goodwin. 1971. "Resistance to Change." *American Behavioral Scientist* 14(5): 745–66.
Weaver, Paul et al. 2017. Sustainable Technology Development *Sustainable Technology Development*. Routledge.
Wei, Houkai. 2014. *Zhongguo Chengshi Hangzheng Dengji Yu Guimo Zengzhang [Administrative Hierarchy and Growth of City Scale in China]*.
Weisser, Daniel. 2007. "A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies." *Energy* 32(9): 1543–59.
Werbach, Adam. 2011. "Strategy for Sustainability." *Strategic Direction* 27(10).
Wesley, Jared J. 2010. *Qualitative Document Analysis in Political Science*.
Wheeler, Stephen M. 2000. "Planning for Metropolitan Sustainability." *Journal of Planning Education and Research* 20(2).
White, Mark A. 2013. "Sustainability: I Know It When I See It." *Ecological Economics* 86: 213–17.
Wilkinson, Adrian, Malcolm Hill, and Paul Gollan. 2001. "The Sustainability Debate." *International Journal of Operations and Production Management* 21(12).
Witt, Ulrich. 2016. "What Is Specific about Evolutionary Economics?" In *Rethinking Economic Evolution*, Edward Elgar Publishing.
Wolsink, Maarten. 2012. "Wind Power: Basic Challenge Concerning Social Acceptance." *Encyclopedia of Sustainability Science and Technology* 17.
Wong, Tai Chee, and Ran Liu. 2017. "Developmental Urbanism, City Image Branding and the 'Right to the City' in Transitional China." *Urban Policy and Research* 35(2): 210–23.
Wood, Graham, and Julia Becker. 2005. "Discretionary Judgement in Local Planning Authority Decision Making: Screening Development Proposals for Environmental Impact Assessment." *Journal of Environmental Planning and Management* 48(3).
World Wide Fund For Nature. 2001. " Father of Environmental Protection in China to Receive WWF's Highest Award." https://wwf.panda.org/wwf_news/?2354/Father-of-environmental-protection-in-China-to-receive-WWFs-highest-award (October 10, 2022).
Wu, Fulong. 2015. Paperboard Packaging *Planning for Growth: Urban and Regional Planning in China*. Routledge.
Wu, Jie, Shuaihe Zhuo, and Zefu Wu. 2017. "National Innovation System, Social Entrepreneurship, and Rural Economic Growth in China." *Technological Forecasting and Social Change* 121: 238–50.
Wüstenhagen, Rolf, Maarten Wolsink, and Mary Jean Bürer. 2007. "Social Acceptance of Renewable Energy Innovation: An Introduction to the Concept." *Energy Policy* 35(5): 2683–91.
Xiao, Qingyang, Zongwei Ma, Shenshen Li, and Yang Liu. 2015. "The Impact of Winter Heating on Air Pollution in China." *PLoS ONE* 10(1).
Xie, Guanghua, Jianlin Chen, Ying Hao, and Jing Lu. 2021. "Economic Policy Uncertainty and Corporate Investment Behavior: Evidence from China's Five-Year Plan Cycles." *Emerging Markets Finance and Trade* 57(10).

Xie, Zhenhua. 2020. “China’s Historical Evolution of Environmental Protection along with the Forty Years’ Reform and Opening-Up.” *Environmental Science and Ecotechnology* 1.
Xiong, Chengcheng, and Mohd Sayuti Hassan. 2022. “Renewable Heat Policy in China: Development, Achievement, and Effectiveness.” *Sustainability* 14(15): 9297.
Xiwei, Zhong, and Yang Xiangdong. 2007. “Science and Technology Policy Reform and Its Impact on China’s National Innovation System.” *Technology in Society* 29(3): 317–25.
Xue, Lan, and Kuotsai Tom Liou. 2012. “Government Reform in China: Concepts and Reform Cases.” *Review of Public Personnel Administration* 32(2).
Yang, Lu, Xin Liu, Qun Gai, and Yuning Zuo. 2021. “Evaluation and Analysis of Comprehensive Benefit of Ground Source Heat Pump in Cold Area.” *IOP Conference Series: Earth and Environmental Science* 760(1).
Yin, Robert K. 1992. “The Case Study Method as a Tool for Doing Evaluation.” *Current Sociology* 40(1): 121–37.
You, Tian, and Hongxing Yang. 2020. “Feasibility of Ground Source Heat Pump Using Spiral Coil Energy Piles with Seepage for Hotels in Cold Regions.” *Energy Conversion and Management* 205.
Yu, Siming et al. 2020. “Adoption and Implementation of Sustainable Development Goals (SDGs) in China-Agenda 2030.” *Sustainability (Switzerland)* 12(15).
Yuan, Zengwei, Jun Bi, and Yuichi Moriguichi. 2006. “The Circular Economy: A New Development Strategy in China.” *Journal of Industrial Ecology* 10(1–2).
Zhang, Dongbao. 2016. “Chen Yun de Kequ Fazhan Sixiang [Chen Yun’s Sustainable Development Thought].” *Shanghai dangshi yu dangjian* 3.
Zhang, Fang, Chuanyong Zhang, and John Hudson. 2018. “Housing Conditions and Life Satisfaction in Urban China.” *Cities* 81: 35–44.
Zhang, Guangrui, ed. 2011. *Green Book of China’s Tourism 2011: China Tourism Development Analysis and Forecast*. COTRI China Outbound.
Zhang, Junfeng, and Kirk R. Smith. 2007. “Household Air Pollution from Coal and Biomass Fuels in China: Measurements, Health Impacts, and Interventions.” *Environmental Health Perspectives* 115(6).
Zhang, Kunmin, and Zongguo Wen. 2008. “Review and Challenges of Policies of Environmental Protection and Sustainable Development in China.” *Journal of Environmental Management* 88(4): 1249–61.
Zhang, Linling, Ruyin Long, Wenbo Li, and Jia Wei. 2020. “Potential for Reducing Carbon Emissions from Urban Traffic Based on the Carbon Emission Satisfaction: Case Study in Shanghai.” *Journal of Transport Geography* 85.
Zhang, Pan. 2021. “Target Interactions and Target Aspiration Level Adaptation: How Do Government Leaders Tackle the ‘Environment-Economy’ Nexus?” *Public Administration Review* 81(2).
Zhang, Yang. 2018. “Allies in Action: Institutional Actors and Grassroots Environmental Activism in China.” In *Research in Social Movements, Conflicts and Change*, Emerald Publishing Limited.
Zhao, Pengjun. 2015. “The Evolution of the Urban Planning System in Contemporary China: An Institutional Approach.” *International Development Planning Review* 37(3).
Zheng, Keyan, Yiping Mo, and Ling Chen. 2015. “Twenty Years of Geothermal Heat Pumps in China.” *World Geothermal Congress 2015*: 2–5.
Zheng, Yongnian. 2009. The Chinese Communist Party as Organizational Emperor: Culture, reproduction, and transformation *The Chinese Communist Party as Organizational Emperor: Culture, Reproduction, and Transformation*. Routledge.

Zheng, Yulian, Allan Walker, and Shuangye Chen. 2013. “Change and Continuity: A Critical Analysis of Principal Development Policy in Mainland China (1989-2011).” *Educational Management Administration and Leadership* 41(4).
Zhou, Mi et al. 2022. “Environmental Benefits and Household Costs of Clean Heating Options in Northern China.” *Nature Sustainability* 5(4): 329–38.
Zhou, Sophie, and Sjak Smulders. 2021. “Closing the Loop in a Circular Economy: Saving Resources or Suffocating Innovations?” *European Economic Review* 139.
Zimmermann, Klaus F., Gokhan Karabulut, Mehmet Huseyin Bilgin, and Asli Cansin Doker. 2020. “Inter-Country Distancing, Globalisation and the Coronavirus Pandemic.” *World Economy* 43(6).
Zucman, Gabriel. 2019. “Global Wealth Inequality.” *Annual Review of Economics* 11.
Van Der Zwaan, A. H. 1975. “The Sociotechnical Systems Approach: A Critical Evaluation.” *International Journal of Production Research* 13(2).

DOI: 10.17185/duepublico/78135
URN: urn:nbn:de:hbz:465-20230523-153012-4