Title	Dilemmas for China: Energy, economy and environment
Author(s)	Tang, Xu; McLellan, Benjamin C.; Snowden, Simon; Zhang, Baosheng; Höök, Mikael
Citation	Sustainability (2015), 7(5): 5508-5520
Issue Date	2015-05-06
URL	http://hdl.handle.net/2433/214447
Right	© 2015 by the authors; licensee MDPI, Basel, Switzerland. This is an open access article distributed under the Creative Commons Attribution License (CC BY) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
Type	Journal Article
Textversion	publisher

Sustainability **2015**, *7*, 5508-5520; doi:10.3390/su7055508

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Communication

Dilemmas for China: Energy, Economy and Environment

Xu Tang [1,*], Benjamin C. McLellan [2], Simon Snowden [3], Baosheng Zhang [1] and Mikael Höök [4]

1 School of Business Administration, China University of Petroleum, Beijing 102249, China; E-Mail: bshshysh@cup.edu.cn

2 Graduate School of Energy Science, Kyoto University, Yoshida-honmachi, Sakyo-ku, Kyoto 606-8501, Japan; E-Mail: b-mclellan@energy.kyoto-u.ac.jp

3 Management School, University of Liverpool, L69 7ZH Liverpool, UK; E-Mail: simon.snowden@googlemail.com

4 Global Energy Systems, Department of Earth Sciences, Uppsala University, Villavägen 16, SE-752 36 Uppsala, Sweden; E-Mail: mikael.hook@geo.uu.se

* Author to whom correspondence should be addressed; E-Mail: tangxu@cup.edu.cn; Tel.: +86-10-8973-1507; Fax: +86-10-8973-1752.

Academic Editor: Vincenzo Torretta

Received: 8 February 2015 / Accepted: 28 April 2015 / Published: 6 May 2015

Abstract: China's current national policies promote high levels of economic growth, transforming China into a "world factory", but at a high cost in terms of energy and the environment. At the same time, this growth and transformation also forms the backbone of China's economy, underpinning social stability. China faces a dilemma to reconcile its economy, energy system and environmental security. Each aspect of this triad is discussed in this study to illuminate the challenges faced by China, and China's dilemma in energy, economy and environment is analyzed from the perspective of its participation in current global supply chains. While China must import a significant proportion of its energy and a large proportion of primary materials, a large share of these imports are returned to the global market as industrial exports. China is bound by its own course of action and unable to radically change its position for the foreseeable future as the road to economic development and employment stability is through policies built on exports and shifting development models, presenting a tough socio-economic trade-off. China's growth challenges are discussed as an example of challenges more broadly faced in the developing world. China's success or failure in achieving a sustainable developmental pattern will inevitably have a significant influence on the global environment.

Keywords: energy-economy-environment; energy security; Chinese economy; embodied energy; international trade

1. Introduction

China is an excellent example of the current crises faced by the rapidly developing and emerging economies of the world, but with close to 20% of global population, it is a country that stands alone in its potential to show the benefits and failures, challenges and enablers of development. It can be argued that China's unique size and nature as a centrally-planned economy may make it less of a representative example of the developing world, but we would argue that many of the decisions that must be made remain as representative challenges for the rest of the developing world. In this paper, we seek to broadly examine some of the key, intertwined challenges that affect the ability of developing nations to establish sustainable development transitions, drawing on the case of China.

The sustainable development of developing countries is largely posited on the goal of attaining higher standards of living (including such development goals as high educational participation, good health and longevity), underpinned by improved economic performance. This economic performance in turn has largely been based to date on an industrialization pattern very similar to the path that the developed countries followed, though certain technological steps are being omitted, and the path is often being compressed in time (what took the developed countries over 200 years is being achieved in perhaps half that time in some developing nations). Importantly, economic growth requires energy and resources, which are largely being sought from non-renewable energy technologies and potentially the over-exploitation of natural resources. Thus, economic growth has largely come at a cost to the environment, which at some point, must either be rectified or present unavoidable barriers to further development. China's success or failure in achieving a sustainable developmental pattern may serve as an example for the remainder of the developing world and will inevitably have a significant influence on the global environment.

The energy, economy and environment (E^3) issue is an intricate problem, where three separate strands intertwine in a complex knot. From the perspective of academic research, coordinated development of E^3 in China has attracted much attention, especially subsequent to 2000. Current research can be divided into three areas: (1) establishing macro-simulation models, such as computable general equilibrium (CGE) models, to optimize energy utilization by economic policies on the premise that environmental conditions remain unchanged or even improve [1,2]; (2) establishing evaluation indices and systems to assess the coordinated development of the E^3 system [3,4]; and (3) establishing econometric models to study the co-integration relationship of the E^3system [5]. Ma *et al.* [6] undertook a comprehensive literature review on the co-integration of the energy and economic system in China, observing that most existing studies demonstrate a causal relationship between national aggregate energy consumption and national aggregate economic growth in China. Although research on the E^3 issue in China has attracted much attention in the current academic literature, the conflicting relationships between and within the energy, the economic and the environmental sectors of China still lack clear elucidation. This paper will first review each aspect of the E^3 triad to illuminate the dilemmas faced by China when interacting with the rest of the world and then will discuss the reasons why it is difficult for China to address these E^3 dilemmas.

2. Three "E's" of China: Energy, Economy and Environment Challenges

2.1. Energy Context

Coal dominates current energy consumption in China, accounting for 66.0% of the total energy consumed in 2013 [7]. China is the world's largest coal producer, with Chinese coal production, as a proportion of global output, growing from 16.2% in 1981 to nearly 50% in 2013 [8]; however, growth in consumption since 2003, when China was a major world coal exporter (second only to Australia), has meant that since 2009, China has become a net coal importer. According to the General Administration of Customs of China [9], China imported 290 million metric tons (Mt) of coal in 2012, making it the largest importer of coal in the world. Recent studies have questioned the longevity of China's domestic coal reserves [10,11] and identified China's "peak coal" status [12–14]. Oil accounted for only 17.8% of China's total energy consumption in 2013, far lower levels than those of the OECD countries, lower even than the world average. However, China's oil consumption in absolute terms is the second largest in the world with the degree of dependence on foreign oil reaching 58% in 2013. The largest oil fields in China (Daqing and Shengli) have already reached their peak production [15,16], leaving only limited possibilities for increased domestic oil production. Natural gas makes up only a few percent of China's energy system, even though gas demand is growing rapidly [17], and studies indicate that China's domestic gas resources cannot be developed rapidly enough to match this surge in demand [18]. This will lead China into future reliance on gas imports and competition with the EU and other international actors for available exports.

Continued depletion of "easy" fossil energy will force producers to develop more challenging hydrocarbon deposits (e.g., shale oil and deep-water oil) with increased costs in both economic, environmental and energy terms. The energy cost for producing fossil energy is increasing, and the energy return on investment (EROI) is declining in China. Hu *et al.* [19] pointed out that the EROI for China's oil and natural gas production sector fluctuated from 12–14:1 in the mid-1990s and declined to 10:1 in 2007–2010. EROI for the coal production sector has declined from 35:1 in 1995–1997 to about 27:1 in 2010. The predicted EROI of both sectors will continue to decline until 2020. A declining EROI implies that more and more energy output would have to be devoted simply to obtaining energy. While currently, the EROI is still significantly higher than the limitation of one (at or below which the extraction of energy resource is effectively a loss of energy), it must be considered that this limit may eventually be reached. The rate of approach to this limit is an important forecasting parameter to which close attention should be paid. Although it is anticipated that the cost of fuel will closely parallel the EROI on a global basis, the domestic price of extraction has the potential to remain hidden as imports are increased.

China may obtain additional energy resources through overseas cooperation or acquisition of external resources, where strong finances and a distinctive political attitude, with government and industry in close cooperation, enable China to develop resources that few Western companies could or would invest in. However, it should be noted that there are difficulties and risks due to political instability in many resource-rich locations, such as the Middle East and North Africa, continuing in the wake of the Arab Spring. China's expansion into the global oil and gas industry, while in part focused on obtaining sufficient domestic supply, has been argue to potentially harm international energy security rather than improving it [20].

Thus, on the supply side, energy in China is still largely fossil-fuel based, and growth in domestic demand further threatens the country's self-sufficiency, although its financial capability enables energy security to be maintained at present. However, such factors as the near (or perhaps passed) peak in domestic oil and coal production and the decreasing EROI should give pause to policy makers to seriously consider the implications of the consumption of depleting resources within a longer term sustainability perspective. Self-sufficiency or energy security as a goal in itself should direct policy towards investment in renewable energy resources in the mid-term, but currently, cost and capacity limitations are constraining rapid expansion, particularly in order to meet the exceedingly high energy growth rates of the current economic development strategy. On the demand side, rapid growth in the industrial sector has supported a vital export-oriented economy, which the government is now aiming to focus more on internal markets.

2.2. Economic Aspects

China's economic growth has driven and been fuelled by a large energy requirement. It is questionable whether China can stop this pattern of demand for fossil energy through changes to its economic structure, with findings in recent years indicating sustained and rapid growth in China's energy demand [21–29]. This outlook is unlikely to change even considering anthropogenic climate change in the long term, although a potential for the reduction of the impact through an improved energy mix, industrial structural adjustments and enhanced technological developments cannot be rejected [30]. Concurrently, significant energy is still required to support further economic growth. Thus, the peak of energy consumption is expected to occur later than the peak production year for both oil [31] and coal [10]. Two observations can further illuminate this phenomenon. The first is the rapid expansion of China's automobile fleet. Fast economic development has brought continuous improvement in people's living standards, and these rising living standards manifest themselves in a booming demand for automobiles. Over the last 10 years, the total number of civil vehicles increased from 20.5 million in 2002 to 120.9 million in 2012 with an average annual growth rate of 19.4%. Among these, the total number of registered private vehicles increased from 9.7 million to 93.1 million with an average annual growth rate of 25.4% over the same period [32]. China's GDP per capita has already reached over 6700 USD in 2013, permitting a growing medium-high and medium income population to acquire and use automobiles. Transportation will continue to consume more energy, especially oil, since other forms of energy cannot yet substitute for oil as a transportation fuel at the scope and scale required.

The second observation relates to the heterogeneous levels of economic development witnessed throughout China. In a vast country such as China, there are both historic and geographic reasons for regional differences in economic development [33–35]. Some eastern regions of China have already entered a stage of economic development comparable to moderately-developed countries, presenting a gradually stabilized energy consumption trend. In contrast, the majority of the central and western regions are still undergoing extensive economic growth. These regions reflect the initial stages of industrialization focused on low-level construction/manufacturing, typical of patterns of earlier industrialization in the eastern areas of China. Therefore, China's energy consumption and energy-related CO_2 emissions have different profiles depending on the region being examined [36]. Since the regional difference in economic development in China is considerable, demand could be expected to rise dramatically as standards of living rise in areas of low GDP per capita [37].

2.3. Environmental Concerns

There are many key environmental impacts attributable to energy production and consumption, including anthropogenic climate change, particulate emissions and water pollution. Energy production and consumption have become one of the main reasons for environmental deterioration in China. In recent years, serious haze has become the dominant environmental issue for not only the government, but also the Chinese public [38]. Most air pollution in China results from coal combustion, which is the source of 90% of SO_2 emissions, 70% of dust emissions and 67% of NO_x emissions [39]. A coal-dominated energy structure is the major reason for this atmospheric pollution [40]. Anthropogenic global warming is perhaps the most important global issue of the 21st century [41], and nearly 72.5% of China's total CO_2 emissions were from coal in 2010 [40]. Coal will continue to dominate China's energy consumption and production system in the foreseeable future, challenging the government in its pursuit of a greenhouse gas abatement policy in the short-to-medium term [42]. On the international stage, this makes China appear to be one of the main perpetrators of anthropogenic global warming and places the nation's diplomats in a tough position caught between demands to decarbonize and domestic calls for more energy to sustain economic development. Developing alternative energy is certainly an option in theory, but will take time and significant investment to realize the benefits [43]. Moreover, China's use of coal for construction minerals (cement and steel) is currently exceedingly difficult to substitute for renewable alternatives anywhere in the world; thus, these key materials of development are almost unavoidable emitters of greenhouse gases [44]. China's national energy policy has also plunged its renewable industrial development into a passive state [45]. Recent amendments to this policy have mitigated some of the problems [46], although it is still too early to fully evaluate the effectiveness of these changes in promoting non-fossil energy sources. According to the Chinese government's renewable energy medium- and long-term development plans [47], non-fossil fuel energy will account for 15% of total energy use in 2020. Even if this target can be achieved successfully, fossil fuels will still be the main source for China's energy consumption mix. Depletion of conventional fossil fuels can potentially trigger increased economic pressure to develop unconventional hydrocarbon resources, ranging from shale gas to oil sands. However, the EROI is less for these resources, and hence, the carbon footprint is also higher than more conventional hydrocarbon sources, making the emission problem even worse [48]. It is likely that unconventional oil and gas will be affected by future climate change mitigation initiatives [49].

3. China's Dilemmas in Energy, Economy and Environment

3.1. China's Development Model and E^3 Dilemmas

China initiated an open-door policy with economic reform in 1978. A capital-intensive, export-oriented economy has led to spectacular economic growth, lifting millions of Chinese people out of poverty. However, it has also given rise to unprecedented levels of energy consumption and environmental pollution. This has been claimed to pose a threat to energy and environmental security [50]. Environmental hazards have spread far beyond the cities, and rural environmental issues are increasingly acute [51]. China's environmental sustainability index remains among one of the lowest in the world, despite government efforts to reduce further deterioration in the environment [52].

China's dilemma in energy, economy and environment can be analyzed from the perspective of its participation in current global supply chains. China is one of the countries furthest upstream in global supply chains, primarily producing raw materials and low-level manufactured goods for export. In fact, international exports have been a primary driver for China's economic growth over the last decade, especially since accession to the World Trade Organization in 2001.

While China must import a significant proportion of its energy and a large proportion of primary materials, a large share of these imports is returned to the global market as industrial exports. Kahrl and Roland-Holst [53] point out that since 2002, the energy required to generate exports have been the largest source of energy demand growth in China. Therefore, as a "world factory", China distributes a lot of embodied energy to other countries through inexpensive "made in China" products, and this embodied energy has tended to increase over time [54]. Taking embodied oil as an example, China's net oil exports embodied in international trade were estimated to be 78.69 million tons (Mt) in 2011, while they were only 24.83 Mt in 1997 and 28.99 Mt in 2002 [55]. Many countries benefit from China's embodied energy exports: the U.K., for example, has been the largest net embodied energy importer since 2008 and this accounts for 43% of the U.K.'s total net embodied fossil energy imports [56]. In a manner similar to that of embodied energy, globalized trade has numerous implications for the environment, since trade creates a mechanism by which consumers can shift the environmental pollution associated with their consumption to different parts of the world. China has paid a high environmental price for its export capacity. Research shows that rapid growth in China's exports is a key determinant in China's rising CO_2 emissions and that Chinese consumption-based CO_2 emissions are much less than production-based emissions [57–61]. In the current global supply chain context, production methodologies encourage leakages through trade that may do more to displace than to reduce CO_2 emissions [62]. Besides CO_2 emissions, an explosive expansion of exports also brings many other environmental problems. Total quantities of wastewater, sulfur dioxide and solid waste embodied in exports have increased dramatically from 1997–2007 [63].

3.2. Shifting Development Models Present a Tough Trade-Off in China

The percentage of China's economic production that was domestically consumed decreased from 62.3% in 2000 to 51.8% in 2012, despite the many policies aimed at stimulating domestic consumption since 2000 [64]. China's economic growth is essentially a development trap based on a model dependent on exports, and China exports much embodied energy and CO_2 emissions as a part of this trade. This reduces both economic development and divests purchasing countries of some of their environmental costs, raising the issue of who should be responsible for these export overheads. The Chinese government reasonably wants importers to cover some, if not all, of these costs [65]; and economists would argue that an effective carbon taxation scheme with full cost pass-on to the consumer would be one method of achieving this. The domestic implications of imposing an effective environmental tax or stricter regulations on emissions (combined with effective monitoring and full pass-on of costs to consumers) may cause significant hardship to the populous and difficulty for the government. At the same time, such a long-sighted policy would impact the global competitiveness of Chinese products, effecting their income from trade and potentially slowing growth and development. It is proving to be very challenging to find solutions to this problem from a broad and balanced perspective [65], but it should also be noted that this is an economic development model that China has chosen to follow, not forced on it by others. Net exports of embodied energy and CO_2 emissions are the inevitable results of China's present economic development model, and this model creates many job opportunities for China, which have been important for successive Chinese governments. For example, China's international exports dropped dramatically during the global economic crises in 2009, and about 20 million migrant workers in coastal regions lost their jobs directly and had to return to their hometowns in rural regions according to Chinese government statistics [66]. This would be exacerbated if indirect unemployment was considered. China needs to make the trade-off between reducing embodied energy exports and changing the current development model of exporting resource-intensive products. One method could be to first rank the export sectors from the perspective of trade-off costs and then gradually reducing embodied energy exports starting with sectors with a relatively low trade-off cost on unemployment.

3.3. The Fourth "E": Equity

As mentioned earlier, there are large disparities in the level of development across different regions of China. This has significant implications for a fourth "E", namely equity. Such disparities in living standards and opportunities are key drivers of tensions between regions. Moreover, the inequity of trade in embodied emissions that China sees with the importers of her goods is mirrored in the regions of the nation. Economic progress in the east has depended on the degradation of environments in the central and western regions. At the same time, opportunity is not being traded back to these regions with lower levels of income prevalent. The government's integrity will be tested by the performance on such distributive issues.

3.4. Sustainability Considerations

The E^3 dilemma, from a relatively short-term perspective, offers insights into the political difficulties of balancing the growth and environmental implications of rapidly-expanding economies. However, it also highlights the limitations of short-term planning in the face of long-term growth targets and environmental constraints. Domestic energy supply in China using fossil fuels is already insufficient to meet domestic demand, and reliance on imports is growing rather than declining. While unconventional resources of fossil fuels, e.g., shale oil, might alleviate the self-sufficiency temporarily, the decreasing EROI and the peaking of domestic resource production should act as clear indicators that the ultimate trajectory is unsustainable. While imports of fossil fuels can alleviate concerns over this issue for some time, the parallel growth of demand in other developing countries and the subsequent increasing competition for resources must ultimately drive prices up, bringing the issue finally into the field of vision of politicians. While the current rate of growth could not easily be met by renewable energy technologies (capacity expansion is slower on an absolute scale than conventional technologies), it is also apparent that renewable energy holds solutions to two of the three E's: environment and energy. It has been widely argued that grid parity is being reached in many markets around the world for renewables, such as wind and solar [67]; China and other developing countries still face affordability challenges for such technologies. The economic component is therefore still lagging. The timing of rapid expansion into renewables should be considered closely by the government of China, particularly since the country possesses many of the critical mineral resources [68] and the manufacturing facilities to produce these technologies for domestic use (although currently, they are mostly exported). Ultimately, sustainability for China from the E^3 perspective must take adequate account of resource depletion, and perhaps, more effective internalization of the current costs of environmentally-damaging energy technologies is one potential approach to shift the balance of affordability in favor of cleaner alternatives.

4. Conclusions

Countries inevitably face conflicting policy choices surrounding economic growth, energy resource utilization and environmental degradation when pursuing rapid development [69,70]. China's current national policies have promoted economic growth, and whilst transforming China into a "world factory", this growth has come at a high energy and environmental cost. This E^3 dilemma that China faces has been outlined and examined in this paper; however, it is very difficult for China to find easy solutions to this complicated problem in the short term. At present, China is bound by its own course of action and unable to radically change its position for the foreseeable future, as the road to economic development and employment stability is through policies built on exports. Therefore, a trade-off between China's net exports of embodied energy and CO_2 emissions and their contributions to economic development and employment stability for the population should be sought quantitatively, and such studies are to be encouraged in the future. China should understand that it is not a simple restructuring task to reduce the embodied energy export, even if such reforms are motivated in the best interests of future prosperity and sustainable development. China cannot bear the whole trade-off cost if it wishes to reduce embodied energy exports, because of its large economy and population base, which ultimately necessitates long-term reform. Furthermore, China cannot ensure its own energy and environmental security alone and isolated from the international community, especially considering the bonds of global trade that tie the rest of the world to China. This intersection of energy, economy and environmental issues has crossed both the geographic and socioeconomic boundaries of sovereign states.

From China's perspective, it should identify balanced policies that offer the best trade-off between these components. Since China cannot complete a low-cost industrialization process in energy and environmental terms in the same manner that the developed countries did, China needs to carefully review and inspect the fossil energy-dependent industrialized society that has arisen, as the environmental and energy self-sufficiency concerns are real sustainability issues for the nation in the long term. We recommend that such debates and studies in today's developing context should be encouraged in China, as they will be conducive in developing a better understanding of how to solve those complicated problems, problems that not only China must confront, but that are significant concerns for future global development.

Acknowledgments

We thank Gail Tverberg for helpful comments. The authors also would like to give many thanks to the National Natural Science Foundation of China (Project Nos. 71303258, 71373285), the National Social Science Funds of China (Project No. 13&ZD159), the Research Fund for the Doctoral Program of Higher Education of China (Project No. 20120007120015), the MOE (Ministry of Education in China) Project of Humanities and Social Sciences (Project No. 13YJC630148), Special Fund Project for Beijing Excellent Doctoral Dissertation Supervisor(Project No. 20121141402)and the Science Foundation of China University of Petroleum, Beijing (Project No. BJ-2011-03), for sponsoring this joint research.

Author Contributions

Xu Tang designed the study, wrote the manuscript and revised it until its final version. Benjamin C. McLellan revised the manuscript. Simon Snowden participated in designing the study. Baosheng Zhang supervised the whole work and edited the manuscript. Mikael Höök provided good advice throughout the paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Wei, Y.M.; Wu, G.; Liu, L.C.; Fan, Y. Progress in modeling for energy-economy-environment complex system and its applications. *Chin. J. Manag.* **2005**, *2*, 159–170.
2. Zhang, S.W. Review of the status quo and future development of energy-economy-environment models. *Energy Technol. Econ.* **2010**, *2*, 43–49.
3. Zhao, T.; Li, X.Y. Research on the coordinating evaluation model for energy-economy-environment system. *J. Beijing Inst. Technol.* **2008**, *2*, 11–16.
4. Fan, Z.Q.; Cao, M. Measurement and evaluation of coordinate developmental state of energy-economy-environment system. *Forecasting* **2005**, *4*, 66–70.
5. Song, J.K.; Jia, J.T. Research on the dynamic cointegration of energy-economy-environment system of China-the econometric analysis based on VEC model. *J. Ind. Technol. Econ.* **2012**, *8*, 46–52.
6. Ma, H.Y.; Oxley, L.; Gibson, J. China's energy economy: A survey of the literature. *Econ. Syst.* **2010**, *2*, 105–132.
7. National Bureau of Statistics of China. Total Consumption of Energy and Its Composition. In *China Statistical Yearbook*; China Statistics Press: Beijing, China, 2013.
8. BP. BP Statistical Review of World Energy. Available online: http://www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review-2014/BP-statistical-review-of-world-energy-2014-full-report.pdf (accessed on 24 June 2014).

9. General Administration of Customs of China. Customs Statistics. Available online: http://www.customs.gov.cn/publish/portal0/tab44604/module109000/info414072.htm (accessed on 21 January 2013).
10. Lin, B.Q.; Liu, J.H. Estimating coal production peak and trends of coal imports in China. *Energy Policy* **2010**, *38*, 512–519.
11. Höök, M.; Zittel, W.; Schindler, J.; Aleklett, K. Global coal production outlooks based on a logistic model. *Fuel* **2010**, *11*, 3546–3558.
12. Tao, Z.P.; Li, M.Y. What is the limit of Chinese coal supplies—A STELLA model of Hubbert Peak. *Energy Policy* **2007**, *6*, 3145–3154.
13. Lin, B.Q.; Liu, J.H.; Yang, Y.C. Impact of carbonintensity and energysecurityconstraints on China's coal import. *Energy Policy* **2012**, *48*, 137–147.
14. Wang, J.L.; Feng, L.Y.; Tverberg, G.E. An analysis of China's coal supply and its impact on China's future economic growth. *Energy Policy* **2013**, *57*, 542–551.
15. Tang, X.; Zhang, B.S.; Höök, M.; Feng, L.Y. Forecast of oil reserves and production in Daqing oilfield of China. *Energy* **2010**, *7*, 3097–3102.
16. Höök, M.; Bardi, U.; Feng, L.Y.; Pang, X.Q. Development of oil formation theories and their importance for peak oil. *Mar. Pet. Geol.* **2010**, *9*, 1995–2004.
17. Li, J.C.; Dong, X.C.; Shangguan, J.; Höök, M. Forecasting the growth of China's natural gas consumption. *Energy* **2011**, *3*, 1380–1385.
18. Lin, B.Q.; Wang, T. Forecasting natural gas supply in China: Production peak and import trends. *Energy Policy* **2012**, *49*, 225–233.
19. Hu, Y.; Hall, C.A.S.; Wang, J.Y.; Feng, L.Y.; Poisson, A. Energy Return on Investment (EROI) of China's conventional fossil fuels: Historical and future trends. *Energy* **2013**, *54*, 352–364.
20. Leung, G.C.K. China's energy security: Perception and reality. *Energy Policy* **2011**, *3*, 1330–1337.
21. Lu, X.; Lei, S. Household energy demand of China towards a well-off society by 2020. *Energy Procedia* **2011**, *5*, 1676–1681.
22. Liu, J.; Chen, W.Y.; Liu, D.S. Scenario analysis of China's future energy demand based on TIMES model system. *Energy Procedia* **2011**, *5*, 1803–1808.
23. Zhang, H.B.; Zhong, N. Forecast of Energy Demand in the Next Decade. *Energy Procedia* **2011**, *5*, 2536–2539.
24. Yu, S.W.; Wei, Y.M.; Wang, K. APSO–GA optimal model to estimate primary energy demand of China. *Energy Policy* **2012**, *42*, 329–340.
25. Yu, S.W.; Wei, Y.M.; Wang, K. China's primary energy demands in 2020: Predictions from an MPSO–RBF estimation model. *Energy Convers. Manag.* **2012**, *61*, 59–66.
26. Yu, S.W.; Zhu, K.J. A hybrid procedure for energy demand forecasting in China. *Energy* **2012**, *1*, 396–404.
27. You, J. China's challenge for decarbonized growth: Forecasts from energy demand models. *J. Policy Model.* **2013**, *4*, 652–668.
28. Shan, B.G.; Xu, M.J.; Zhu, F.G.; Zhang, C.L. China's Energy Demand Scenario Analysis in 2030. *Energy Procedia* **2012**, *14*, 1292–1298.
29. Feng, L.Y.; Hu, Y.; Hall, C.A.; Wang, J.L. *The Chinese Oil Industry: History and Future*; Springer: New York, NY, USA, 2012; ISBN 978-1-4419-9409-7.

30. Fan, Y.; Xia, Y. Exploring energy consumption and demand in China. Energy **2012**, *1*, 23–30.
31. Feng, L.Y.; Tang, X.; Zhao, L. Reasonable Planning of Oil Production in China Based on Peak Oil Model. *Pet. Explor. Dev.* **2007**, *4*, 497–501.
32. National Bureau of Statistics of China. Possession of Private Vehicles. In *China Statistical Yearbook*; China Statistics Press: Beijing, China, 2013.
33. Cheng, J.Y.; Zhang, M.J. Regional differences and sustainable development in China. *J. Chin. Polit. Sci.* **1999**, *1*, 1–50.
34. Arayama, Y.; Miyoshi, K. Regional Diversity and Sources of Economic Growth in China. *World Econ.* **2004**, *10*, 1583–1607.
35. Liu, J.Y.; Zhang, Q.; Hu, Y.F. Regional differences of China's urban expansion from late 20th to early 21st century based on remote sensing information. *Chin. Geogr. Sci.* **2012**, *1*, 1–14.
36. Li, H.N.; Mu, H.L.;Zhang, M.; Gui S.S. Analysis of regional difference on impact factors of China's energy-Related CO_2 emissions. *Energy* **2012**, *1*, 319–326.
37. Ito, T.; Chen, Y.Q.; Ito, S.; Yamaguchi, K. Prospect of the upper limit of the energy demand in China from regional aspects. *Energy* **2010**, *12*, 5320–5327.
38. Li, M.N.; Zhang, L.L. Haze in China: Current and future challenges. *Environ. Pollut.* **2014**, *6*, 85–86.
39. Chen, W.Y.; Xu, R.N. Clean coal technology development in China. *Energy Policy* **2010**, *5*, 2123–2130.
40. Boden, T.A.; Marland, G.; Andres, R.J. *Global, Regional, and National Fossil-Fuel CO_2 Emissions*; Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy: Oak Ridge, TN, USA, 2013.
41. IPCC. Climate Change 2007—Fourth Assessment Report. Available online: http://www.ipcc.ch/ (accessed on 17 November 2007).
42. Bloch, H.; Rafiq, S.; Salim, R. Coal consumption, CO_2 emission and economic growth in China: Empirical evidence and policy responses. *Energy Econ.* **2012**, *2*, 518–528.
43. Höök, M.; Li, J.C.; Johansson, K.; Snowden, S. Growth rates of global energy systems and future outlooks. *Nat. Resour. Res.* **2012**, *1*, 23–41.
44. McLellan, B.C.; Corder, G.D.; Giurco, D.P.; Ishihara, K.N. Renewable energy in the minerals industry: A review of global potential. *J. Clean. Product.* **2012**, *32*, 32–44.
45. Zhang, P.D.; Yang, Y.L.; Shi, J.; Zheng, Y.H.; Wang, L.S.; Li, X.R. Opportunities and challenges for renewable energy policy in China. *Renew. Sustain. Energy Rev.* **2009**, *2*, 439–449.
46. Schuman, S.; Lin, A. China's renewable energy law and its impact on renewable power in China: Progress, challenges and recommendations for improving implementation. *Energy Policy* **2012**, *51*, 89–109.
47. NDRC (National Development and Reform Commission). Renewable Energy Medium and Long-Term Development Plan. Available online: http://www.gov.cn/zwgk/2007-09/05/content_738243.htm (accessed on 5 September 2007).
48. Brandt, A.R.; Farrell, A.E.Scraping the bottom of the barrel: greenhouse gas emission consequences of a transition to low-quality and synthetic petroleum resources. *Clim. Chang.* **2007**, *3–4*, 241–263.
49. Chan, G.; Reilly, J.; Paltsev, S.; Chen, Y.-H.H. The Canadian oil sands industry under carbon constraints. *Energy Policy* **2012**, *50*, 540–550.

50. Xue, P.L.; Zeng, W.H. Policy issues on the control of environmental accident hazards in China and their implementation. *Procardia Environ. Sci*. **2010**, *2*, 440–445.
51. Wang, C.M.; Lin, Z.L. Environmental Policies in China over the Past 10 Years: Progress, Problems and Prospects. *Procedia Environ. Sci.* **2010**, *2*, 1701–1712.
52. Liu, J.G.; Diamond, J. Revolutionizing China's environmental protection. *Science* **2008**, *319*, 37–38.
53. Kahrl, F.; Roland-Holst, D. Energy and exports in China. *China Econ. Rev.* **2008**, *4*, 649–658.
54. Liu, H.T.; Xi, Y.M.; Guo, J.; Li, X. Energy embodied in the international trade of China: An energy input–output analysis. *Energy Policy* **2010**, *8*, 3957–3964.
55. Tang, X.; Snowden, S.; Höök, M. Analysis of energy embodied in the international trade of UK. *Energy Policy* **2013**, *57*, 418–428.
56. Tang, X.; Zhang, B.S.; Feng, L.Y.; Snowden, S.; Höök, M. Net oil exports embodied in China's international trade: An input–output analysis. *Energy* **2012**, *1*, 464–471.
57. Lin, B.Q.; Sun, C.W. Evaluating carbon dioxide emissions in international trade of China. *Energy Policy* **2010**, *1*, 613–621.
58. Yan, Y.F.; Yang, L.K. China's foreign trade and climate change: A case study of CO_2 emissions. *Energy Policy* **2010**, *1*, 350–356.
59. Ma, S.Z.; Chen, Y. Estimation of China's Embodied CO_2 Emissions during 2000–2009. *China World Econ.* **2011**, *6*, 109–126.
60. Xu, M.; Li, R.; Crittenden, J.C.; Chen, Y.S. CO_2 emissions embodied in China's exports from 2002 to 2008: A structural decomposition analysis. *Energy Policy* **2011**, *11*, 7381–7388.
61. Erik, D.; Pei, J.S.; Yang, C.H. Trade, production fragmentation, and China's carbon dioxide emissions. *J. Environ. Econ. Manag.* **2012**, *1*, 88–101.
62. Pan, J.H.; Phillips, J.; Chen, Y. China's balance of emissions embodied in trade: Approaches to measurement and allocating international responsibility. *Oxford Rev. Econ. Policy* **2008**, *2*, 354–376.
63. Zhang, C.; Beck, M.B.; Chen, J.N. Gauging the impact of global trade on China's local environmental burden. *J. Clean. Product.* **2013**, *54*, 270–281.
64. National Bureau of Statistics of China. Gross Domestic Product by Expenditure Approach. In *China Statistical Yearbook*; China Statistics Press: Beijing, China, 2013.
65. Zhang, Z.X. Who should bear the cost of China's carbon emissions embodied in goods for exports? *Miner. Econ.* **2012**, *2–3*, 103–117.
66. Chinese Central Leading Group on Financial and Economic Affairs. About 20 Million Migrant Workers in China Lost Their Jobs and Back Home due to Financial Crisis. Available online: http://news.sohu.com/20090202/n262012610.shtml (accessed on 2 February 2009).
67. Breyer, C.; Gerlach, A. Global overview on grid-parity. *Prog. Photovolt.* **2013**, *21*, 121–136.
68. McLellan, B.; Corder, G.; Ali, S. Sustainability of rare earths—An overview of the state of knowledge. *Minerals* **2013**, *3*, 304–317.
69. Apergis, N.; Payne, J.E. The causal dynamics between coal consumption and growth: evidence from emerging market economies. *Appl. Energy* **2010**, *6*, 1972–1977.

70. Singh, K. India's emissions in a climate constrained world. *Energy Policy* **2011**, *6*, 3476–3482.