



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

How would big data support societal development and environmental sustainability? Insights and practices

Citation for published version:

Song, M, cen, L, zheng, Z, fisher, R, Liang, X, wang, Y & Huisingh, D 2016, 'How would big data support societal development and environmental sustainability? Insights and practices', *Journal of Cleaner Production*, vol. 142, pp. 489-500. <https://doi.org/10.1016/j.jclepro.2016.10.091>

Digital Object Identifier (DOI):

[10.1016/j.jclepro.2016.10.091](https://doi.org/10.1016/j.jclepro.2016.10.091)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Published In:

Journal of Cleaner Production

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

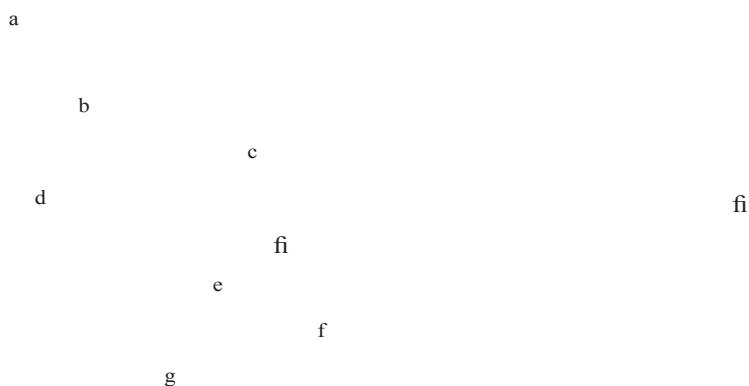
Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



How would big data support societal development and environmental sustainability? Insights and practices

Malin Song ^{a, 1}, Ling Cen ^b, Zhixia Zheng ^c, Ron Fisher ^d, Xi Liang ^e, Yutao Wang ^f,
Donald Huisingh ^g



Abstract

The theme of this Special Volume (SV) focuses on improving natural resource management and human health to ensure sustainable societal development. Natural resources have been exploited unduly regardless of the consequences, which has resulted in inappropriate management natural resources and has caused severe environmental degradation. Contributions in this SV addressed improved environmental management, utilization, and allocation of natural resources; evaluation of sustainable natural resource management; pollution prevention and treatment; and evaluation and suggestions for improved natural resource-related policies. The authors presented an inspiring panorama of the initiatives that have been developed throughout the world for sustainable natural resource management and improve societal development. Theoretically, new approaches to bridge the gaps between the economic development and environmental protection were increasingly dominant. Empirically, many of the papers provided case studies of regions in China and other regions. The authorship reflected growing collaboration between researchers from many different countries or universities. While the great diversity of contributions on the topic reflected the wealth of insights generated on the topic in recent years, there is much more that must be done to achieve societal sustainability in natural resource management.

Key Words

Natural resource management, big data assessment tools, Sustainable societal development, Pollution prevention
Cleaner production, Environmental protection, Sustainable societies

¹ Corresponding author.

E-mail addresses: songmartin@163.com, songml@aufe.edu.cn (M. Song).

1. Introduction and context

Environmental issues related to resources, bio-diversity, food security, climate changes and global population growth are a few of the crucial, inter-connected dimensions that must be addressed in increasingly effective, systematic and holistic ways with the objective of preventing crises such as the 2013 giant, multi-regional smog that evolved in China. That smog event and subsequent severe air quality problems, combined with severe water and soil pollution problems have elicited positive responses from many within the Chinese Government, industry, academia and by citizens more broadly.

This Special Volume (SV) was envisioned, planned and developed to help China and other nations globally, to be able to make improved decisions for prevention and correction of problems, based upon the evolving analytical power of 'Big Data.'

In the broader historical context our natural resources had evolved for millions of years before humans began using them. Those resources were rich in biodiversity and geodiversity, and human society was/is totally dependent upon local, regional, and global ecosystems. However, current world population has exceeded seven billion, and is projected to reach nine billion in the near future. Growth of the human population has surpassed the carrying-capacity of global eco-systems and has caused bio- diversity losses, resource exhaustion, atmospheric, water and soil pollution and dramatic global climate changes (Cherniwchan, 2012).

It is predicted that climate change will severely affect not only the diverse ecosystems upon which agriculture, forestry, and fisheries are dependent, but also industry, commerce, personal residences, and transportation, upon which all societies in developing and developed countries are dependent. Climate change is and will increasingly be directly related to food and water insecurity and other demands upon ecosystems of which boundaries have already been surpassed. Thus, challenges related to climate changes are attracting increasing attention globally from research scholars, governments, businesses, religious groups, environmental NGOs and other social leaders.

In global economic competition, every country tends to pursue short-term economic growth rather than also being responsible for the long-term, sustainable management of global eco-system resources. This is particularly notable in most developing countries. They usually seek to maximize, short-term agricultural and industrial transformations with little attention the longer-term consequences and impacts upon society and upon the eco-systems upon which all of us are totally interdependent.

During the development process, governments and companies often exploit minerals, forests and grasslands, wetlands, rivers, lakes and the ocean in totally unsustainable ways. Although they may achieve short-term benefits, the worldwide environmental problems such as serious atmospheric and water pollution, reduction of tropical forests and land desertification are resulting in rapid decline of the global eco-system's carrying capacity and are also causing rapid increases in the global greenhouse gases, which are causing increases in global atmospheric and

oceanic temperatures.

As illustrative of this, the environmental and human health burdens have been externalized upon Chinese society during recent decades, due to a narrow focus upon rapid economic development (Wong, 2013). In China, the industry-caused smog pollution issues, which mainly resulted from emissions from coal-fired power plants, industrial processes, and transportation-related sources, have dramatically increased in the last two decades. In recent years, the smog issues have become more severe and widespread throughout China (Wang et al., 2014). This is seriously threatening human health as atmospheric concentrations of particulate matter 2.5 (PM 2.5) soar, regularly to concentrations far above The World Health Organization's 'safe air' standards. The PM 2.5 particulates are absorbed through the lungs and cause asthma, lung diseases, and heart attacks. Such problems are also increasingly prevalent in India and other developing countries.

Dealing with increasingly serious resource and environmental problems is a task that should be shared by the whole international society. At the first World Climate Conference that was held in Geneva in 1979, climate change was first put on the agenda as an issue that should be addressed by the world. Since then, most countries in the world have formulated and are beginning to implement some relevant resource, industry, trade and environmental policies that are designed to seek to slow-down and to reverse the global climate change processes. Fortunately, a number of important international standardization institutions are developing illustrative governmental and corporate policy frameworks, which if implemented, can help societies to make the urgently needed transitions to post-fossil carbon societies.

Such policy frameworks are designed to encourage sustainable management of natural resources by systematically implementing cleaner production and sustainable consumption. The importance of improved sustainable natural resource management is being increasingly realized by policy makers as evidenced by the inclusion of such emphases in research and policies (Sterner and Coria, 2011). For example, Chinese leaders are increasingly committed to developing and implementing strategies of societal sustainable development, which are designed to help to ensure that ecosystems are managed in sustainable ways to fulfill the needs of present and future generations on the planet.

Many Chinese policies have been developed and implemented to improve the sustainability and effectiveness of natural resource management. For example, legislation such as the 'Water Law of the People's Republic of China' that was passed on October 1, 2002, and the 'Property Law of the People's Republic of China' that was passed on March 16, 2007, are focused on implementing sustainable natural resource management.

In this context, the evolving science of Big Data can potentially be used to help scientists, policy makers, and city planners to develop and implement policies, strategies, and practices that will internalize currently externalized environmental and human health burdens on society. Data concerning resource management such as hydrogeological data, environmental surveillance data, economic statistics and meteorological data are not only in large quantity but are also complex temporally and spatially. Types and formats of data are diversified and countless

ties interconnections exist within and among these data, which make it difficult or impossible for traditional data analysis methods to be used to adequately analyze them. Hence, Big Data approaches are needed to effectively and efficiently manage and analyze them in order to fulfill the demands for storing, querying and analyzing the data so as to facilitate better decision-making. When Big Data are properly used and analyzed, the results can be more reliable, integral and safe. Therefore, such analyses can help governments and societies to make effective progress at the local, regional, national and global levels in transitioning to become truly sustainable, post-fossil carbon societies.

Cleaner production in the era of Big Data will increasingly depend upon the support of Big Data analyses. In summary, under the pressure of shortages of natural resources and increasingly severe air, water and land quality, with increasing species diversity losses, with dramatically severe climate changes impacts, with continuing human population growth at the rate of a net increase of 70,000,000 per year on planet earth, and with increasing threats of social upheavals and wars, there will be increasing interest in learning how Big Data concepts and approaches can be used to help developed and developing countries learn how to prevent and to correct environmental and human health challenges through cleaner production and by focusing on prevention rather than upon pollution control, pollutant treatment, or pollutant dilution. Relevant, Big Data can be used to adjust production plans or policies, including environmental and resource data pertaining to holistic, and integrative management of minerals, minimization of soil erosion, prevention and/or reduction of water pollution, reduction of geomorphologic and climatological changes. Though proper collection and usage of Big Data, analysts can find the relevance among them through correlation analysis. Thus, causality and necessity among data can be found and accurate predictions and better judgments and decisions can be made. This can result in improved effectiveness in sustainable natural resource management, and will help to reduce risks to human health and negative impacts upon ecosystems and will provide reliable guidance in socio-ecological environmental protection work. Big data can be used to help societies achieve improved and sustainable input-output ratios and performance-price ratios and to improve human and ecosystem health. Learning how to protect human and ecosystem health by improving natural resource management is one of the most important research topics throughout the world. The mismanagement of natural resources has caused and will cause increasing risks to human survival.

To address these challenges, this SV contains more than sixty articles, which are focused upon expanded and improved approaches to restore and to maintain nature's dynamic ecosystems and to improve human health, both of which are essential for sustainable societal development (Schilling and Chiang, 2011; Sparling, 2014). Authors of articles in this SV encouraged researchers to build upon and to continuously develop new and more effective Big Data models and methods for improved environmental resource management for screening, analyzing and implementing better decision-support tools to predict short and long-term trends and consequences. Insights gained from those predictions can be used in decision-making to develop better governmental and corporate policies, procedures, indicators and feedback loops for sustainable short and long-term management of natural and human resources.

The contributions of the authors of this SV introduced in the subsequent paragraphs of this introductory article, focus upon ways that Big Data can be integrated with other approaches, so that society can develop and use new approaches and management insights to prevent and/or to solve ecological and human health crises and thereby

maintain sustainable and healthy ecosystems in the short and long-term future, for all.

2. Themes in this Special Volume

2.1 Natural resource utilization and management

There are nine papers in the theme of natural resource utilization and management. Alternative approaches for sustainably managing natural resources are proposed to help policy makers, scientists, and industrialists develop and implement policies and strategies to protect and sustainably manage natural resources. Lin and Lin (2017) evaluated the efficiency of energy consumption of the heating industry in China. Li et al. (2017a) studied the forestry resources efficiency to investigate Chinese forest resources. In addition, Li and Liu developed a spatiotemporal dynamic analysis of forest ecosystem services by using Big Data. Xiao et al. (2016) investigated optimal farmland conversion in China under the double restraints of economic growth and resource protection through a theoretical model. Hou et al. (2017) studied cooking fuel in rural China. Wang and Lin (2017) studied natural gas usage by applying a panel unit root and heterogeneous panel co-integration method. Jiang et al. (2017) analysed spatiotemporal changes of coal fires (e.g. coal seams, open-cast coal mines, coal heaps, and coal waste piles) located in Wuda of China. Both Chen et al. (2017a) and Wang and Ye (2017) focused their work on fossil energy consumption.

1) Lin and Lin in their ‘Evaluating energy conservation in China's Heating industry’ studied the relationships between energy consumption and other factors, such as GDP and urban population density based on co-integration technology. They found that for every 1% GDP growth could cause 2.24% increase in energy consumption, every 1% growth of urban population density decreased energy consumption by 0.56% and 1% growth of central heating areas was associated with 0.36% decline of energy consumption. They believed that the Big Data analysis method could be employed in the supply systems of heating, which would help cities with dense populations to save energy.

2) Li, Hao, and Chi in their ‘Evaluation on China’s forestry resources efficiency based on big Data’ collected provincial data in China and evaluated efficiency of forestry resources management based on Big Data theory. Their results showed that the status quo of technologies are the main obstacle to the improvement in efficiency of forestry resource management. It is important to increase the investment in science and technology and to improve operation and management of administrative departments for better forestry resources utilization.

3) Xiao, Wu, Wang, and Liang in their ‘Optimal farmland conversion in China under double restraints of economic growth and resource protection’ used a set of panel data of 31 Chinese provinces from 1997 to 2013 to study the effects of farmland conversion on economic growth. In their paper, they used a theoretical model to analyse the optimal proportion of farmland conversion. The conclusion showed that there were excessive farmland losses and farmland conversion. Relevant policies encouraged economic growth but neglected the ecological and social costs of farmland resources. It is urgent to establish the market of unified urbane rural construction land, through which to protect farmland and to reduce excessive farmland conversion to non- agricultural uses.

- 4) The fourth contribution to this theme was written by Hou, Tang, Ma, Liu, Wei, and Liao. In 'Cooking Fuel Choice in Rural China: Results from Microdata. They used a large-scale survey data to research the fuel choice in China's rural household cooking. The results showed that many factors such as distance to market, educational background, coal price, and female labour participation had effects on determining the fuel choices of households. They also found that there were great differences among regions: Forty percent of the rural households preferred solid fuels in south eastern coastal areas, while in north eastern areas, the figure exceeded 80%.
- 5) Wang and Lin, in their 'China's natural gas consumption peak and factors analysis: A regional perspective', studied the influencing factors of natural gas consumption in China based on a set of panel data. The results showed that energy Kuznets curve can be used to fit the relationship between per capita natural gas consumption and economic development level. There was a great difference of potential gas consumption among regions and gas population rate (proportion of population using natural gas of total population) played a more important role on determining gas consumption than GDP.
- 6) Jiang, Jia, Chen, Deng, and Rao contributed the article 'Using spatiotemporal remote sensing data to assess the status and effectiveness of the underground coal fire suppression efforts during 2000e2015 in Wuda, China'. Using the data of the Wuda coal-mining region of China from 2000 to 2015, they studied the spatiotemporal changes of coal fires, evaluated the fire protection project CFSP, and provided solutions for coal energy producers and environmental decision-makers. They documented that this fire protection project was very successful although the removed overburden led to destruction of coalfield landscape. Further evaluation of fire suppression activities was necessary due to environmental impacts and costs.
- 7) The contribution 'Regional Differences in China's Fossil Energy Consumption: An Analysis for the Period 1997e2013' by Chen, Wu, Wen, Cheng, and Wang studied regional differences in the per capita consumption of fossil-fuel based energy by applying annual and cumulative consumption Gini indexes and the deviation index. Based on the panel data of 30 Chinese provinces from 1997 to 2013, they found that Gini ratio of fossil energy consumption had been below 0.3 in recent years. What drove down the overall Gini index was the change of per capita energy consumption across 30 Chinese provinces from 1997 to 2013. One of the novelties of their paper is that they focused on cumulative energy consumption rather than upon the annual flows of energy consumption that is common in the existing literature.
- 8) Li and Liu's 'Spatiotemporal dynamic analysis of forest ecosystem services using 'big data': A case study of Anhui province, central-eastern China' evaluated the quantity and value of forest ecosystem services in Anhui province by using the data from 2009 to 2014. They first illustrated the changes of forest ecosystem services, and then built an assessment model to study the changing trends of value of forest ecosystem services, in which they took spatial heterogeneity, scarce resources, and social development into account. They found that the overall value of forest ecosystem services would exceed previous estimations if spatiotemporal visualization was used.

9) In 'Forecasting Chinese carbon emissions from fossil energy consumption using nonlinear grey multivariable models', Wang and Ye predicted the carbon emission from fossil energy consumption by combining the power exponential terms with multivariable grey model. After solving two nonlinear programming models, they obtained the predicted results, which helped in the formulation of energy and environment policies.

In summary, the authors of the articles in this section studied how natural resources, such as forestry and fossil fuels were utilized in China. Some authors focused on a certain industry (such as the heating industry), some authors focused on certain regions of China (such as Anhui, Wuda, and rural China), and some authors studied all of China. These authors investigated the current situation of natural resource management and provided suggestions to make improvements in the sustainable management of all natural resources in the short and long term. Human beings must now face their responsibilities for making such improvements in natural resource management.

2.2 Evaluation of sustainable natural resource management

The ten papers in the second theme focused upon sustainability in resource management. They considered sustainable utilization of natural resources, such as water resources (Sun et al., 2017) and land resources (Li et al., 2017c); industrial development in the building industry (Zhang et al., 2017a) and transportation industry (Li et al., 2017b); regional economic development in the Poyang Lake Eco-Economics Zone (Zhang and Chen, 2017), in the Hadaqi Industrial Corridor (Wan et al., 2017), and in China's Beijing-Tianjin-Hebei region (Xie et al., 2017a). Some authors focused upon sustainable supply chain management (Wu et al., 2017a), sustainable products management (Hazen, 2017), and corporate management sustainability (Tseng, 2017).

1) In their 'Sustainable utilization of water resources in China: A system dynamics model', Sun, Liu, Shang, and Zhang modeled the supply and demand of water and the gap between them from 2005 to 2020. They changed parameter values to detect the changes of key variables under different development programs. The results showed that a balanced development program was preferable to others, which attained not only economic growth but also resource conversion. According to their finding, they recommended that improving water supply instead of controlling demand was a good solution to bridge the gap between supply and demand.

2) In the paper 'A big data analytics architecture for cleaner manufacturing and maintenance processes of complex products', Zhang, Shan, Liu, and Si combined Big Data analytics with service-driven patterns to obtain an overall architecture of analytics, which could help them to manufacture in a cleaner manner. They found that their method could overcome most previous weakness and was beneficial to customers, manufacturers, and the environment, and could provide a theoretical basis for sustainable production by manufacturing enterprises.

3) In the paper 'Sustainability Characteristics of China's Poyang Lake Eco- Economics Zone in the big data environment', Zhang and Chen analysed the environmental and sustainable characteristics of Poyang Lake Eco-Economic Zone by using a new DEA method. That is, they proposed a global non-radial directional distance function model, which could overcome the shortcomings of traditional methods. The empirical results obtained

from the new method provided several policy implications, such as it was necessary to establish a pollutant emission trading system in China and to encourage technology innovation for energy saving and emissions reduction.

4) To help to ensure ecological, social, and economic sustainability, Wan, Zhang, Qi, Li, Chen, and Zang developed the paper 'A study of regional sustainable development based on GIS/RS and SD model d case of Hadaqi Industrial Corridor'. Based on GIS/RS technology and a systematic dynamics model, the authors empirically studied the Hadaqi industrial corridor that is located in northeast China. They verified that predatory development of re- sources and unreasonable development practices had led to ecological deterioration and that these factors were more decisive than population growth. In addition, they documented that the Hadaqi industrial corridor is a typical area of high intensity interactions between people and nature. Therefore, PRED (population stabilization, improved resource management, improved environmental protection, and sustainable development) should be promoted step-by-step to achieve the coordinated development of social development and protection of the ecological environment.

5) In the fifth paper, 'Toward Sustainability: Using Big Data to Explore the Decisive Attributes of Supply Chain Risks and Uncertainties', Wu, Liao, Tseng, Lim, Hu, and Tan discussed how to effectively utilize resources and investments for light-emitting diode (LED) firms in seeking sustainability. They found that managers must adopt several controls for improving production areas that are located in the core problem quadrant when firms provide flexible capacity and achieve beneficial effects through alignment and congruence. There were many other attributes located in the first quadrant, which can help firms mitigate risks, including margin improvement, employee education, skills development, and labour relations.

6) Xie, He, and Xie, in their paper 'Exploring the factors influencing ecological land change for China's Beijing-Tianjin-Hebei Region using big data', studied the factors influencing ecological land change in China's Beijing-Tianjin-Hebei region from 2000 to 2005. The results showed that there were wide differences in effects among different type of factors. Four variables including Slope type, Soil organic matter (SOM) content, farmer's population percentage, and Landform type, significantly affected the forestland coverage changes. Altitude, distance to the primary road, and GDP per capita were important factors that influenced sustainability in grasslands. Farmer's population percentage, GDP per capita, and altitude were key variables to wetland changes. Lastly, natural and socioeconomic factors can exert effects on ecological land management changes.

7) In the paper 'Sustainability performance for China's Transportation Industry under the Environmental Regulation', Li, Meng, and Yao studied total factor productivity in the transportation industry based on the non-radial directional distance function model, which revealed the direction of undesirable output vector. They constructed a revised Malmquist-Luenberger index to verify the 'Porter Hypothesis' in the transportation industry and compared different performance of total factor productivity under different intensities of regulation.

8) In the paper 'Dynamic analysis of ecological environment combined with land cover and NDVI changes and implications for sustainable urban-rural', Li, Cao, and Long studied the ecological environment change of the

Mu Us sandy land. Through their empirical study, some interesting results were obtained. For example, land cover changed moderately during 1990e2010, 10% of the land was converted from one usage pattern to another. More importantly, it was found that the normalized differences in vegetation index (NDVI) values showed an evident increase of about 0.0076 per year, during the period 2000e2004, which was lower than that of Shaanxi-Gansu-Ningxia region, but greatly exceeded those of the Northeast China, North China and Northwest China Shelter Forests and the upper reaches of the Yellow River. By analysing the ecological performance index, mainly based on land cover and NDVI indicators, four categories of grids were identified for accurate ecological restoration. In addition, the authors of this paper provided suggestions for improvements, such as water and land resource management improvements should be considered when conducting urban-rural development and coal exploitation.

9) In Hazen's paper 'Perceived Quality of Remanufactured Products: Construct and Measure Development', the author proposed a rigorous instrumental development process consisting of five sequential data-collection efforts from three different countries to conceptualize and define a multidimensional construct, and to develop a content-valid and reliable instrument. The main contribution of this paper was that it established the definition of Quality of Remanufactured Products and an associated Quality of Remanufactured Products measure, which was a direct response to the calls for research on consumer perceptions and on other, remanufactured production market-related issues.

10) To help solve the sustainability issues within corporations, in the paper 'Using social media and qualitative and quantitative information scales to benchmark corporate sustainability', Tseng proposed certain models to evaluate a Taiwanese circuit board manufacturing firm by considering social media as a part of the decision-making process. Specifically, the author developed a hybrid method to evaluate the weights of the aspects and attributes as described by qualitative and quantitative data. The results showed that to acquire benefits from sustainable design, a code of conduct and eco-products, firms must increase their exchanges across corporate functions when dealing with these unexplored sustainability activities.

In summary, natural resources play crucial roles in demographic, social, and economic development. Regional development is often focused upon rapidly improving an area's economy; however, it is inevitable that this development will adversely influence the ecosystem. Therefore, it is important for manufacturing enterprises to achieve sustainable production and to improve their sustainable competitive advantages within the context of sustainable management of ecological resources and human resources. The authors of these papers focused upon the topic improved environmental regulations to achieve sustainable societal developments. Policy implications, including establishing and enforcing the pollutant emission trading system in China as well as encouraging technology innovations for natural resource saving and emissions reductions, were proposed for decision-makers to achieve sustainable societal development.

2.3 Natural resource allocations and utilization

This interesting theme is comprised of eleven papers that are grouped into two subthemes. One subtheme addressed

the natural resource allocations and utilization with consideration of energy while the papers in the other sub-theme did not consider energy dimensions.

2.3.1. Natural resource allocations and utilization without considering energy

There are five papers in this subtheme, which address the manufacturing industry (Gong et al., 2017; Lu et al., 2017) and agriculture (Deng et al., 2017a; Deng et al., 2017b, c) in China, and the international economy (Wu et al., 2017b).

1) Gong, Guo, Zhang, and Cheng in their ‘An approach for evaluating cleaner production performance in iron and steel enterprises involving competitive relationships’ evaluated the environmental performance in iron and steel enterprises by using a new method. In order to capture the competitive relationship, authors specified a nonlinear programming model. Then the cleaner production performance could be obtained by the evidential reasoning (ER) approach based on aggregate evaluation information. They provided a numerical example to demonstrate how to use these methods.

2) Lu, Liu, Zhang, Li, Lu, Ma, Shen, and Zhu, in their ‘Improved production and quality of biocrude oil from low-lipid high-ash macroalgae *Enteromorpha prolifera* via addition of crude glycerol’, focused on biocrude production from *Enteromorpha prolifera* (Ep) with crude glycerol and Ep with glycerol, in comparison to production from Ep alone, and considered production at different reaction temperatures (240 °C–360 °C). The addition of crude glycerol significantly improved biocrude production as well as reduced the oil's nitrogen content. Elemental analyses indicated that the nitrogen content of biocrude oil from Ep with crude glycerol was nearly 1% lower than under other conditions and similar to that of petroleum.

3) Deng, Gibson, and Wang, in their ‘Quantitative measurements of the interaction between net primary productivity and livestock production in Qinghai Province based on the data fusion technique’, applied simultaneous equations to estimate the relationships between livestock production and net primary productivity based on data of Qinghai Province of China. The results showed that there was a bidirectionally positive relationship between them. Existence of natural reserves, temperature, sunshine hours, relative humidity, and rainfall had positive effects on livestock production. Although grazing density had a negative effect on it, the authors argued that it is essential to maintain an appropriate grazing density for sustainable livestock farming.

4) Deng, Gibson, and Wang also presented ‘Management of trade-offs between cultivated land conversions and land productivity in Shandong Province’, in which they researched the cultivated land conversion and land productivity in Shandong Province of China based on Estimation System of Land Production (ESLP) model. The results showed that land productivity was unevenly distributed in Shandong Provinces. Productivity in the western area was the highest and that in regions where cultivated land conversion occurred, the productivity was relatively lower. In addition, the estimation results show that the overall trend of land productivity was in a downward trend as the built-up land area increased from 2003 to 2010.

5) Wu, Geng, and Liu, in their 'Trends of natural resource footprints in the BRIC countries', focused on the resource footprints of biomass, fossil fuels, minerals, and water based on BRIC countries from 1995 to 2008. Through a global and multiregional input-output model, the authors found that these countries consumed one third of the global resources during 1995e2008 and that there was fast growth of per capita resource footprint in BRIC countries, which was higher than the world average value. The rate of resource footprint increase was higher than domestic extraction in China. Regarding resource productivity, there was a large gap among BRIC countries, with Russia being the highest and then followed by Brazil.

2.3.2 Natural resource allocations and utilization considering energy

There are six papers in this subtheme that took account of carbon emission (Zhou et al., 2017a; Zhang et al., 2017c; Zhu et al., 2017; Zhou et al., 2017b) and resource intensities (Zhang et al., 2017b; Wei and Li, 2017).

- 1) Zhou, Zhang, Zhou, and Zhou, in their 'A comparative study on decoupling relationship and influence factors between China's regional economic development and industrial energy related carbon emissions', analysed the decoupling relationships between industrial energy-related carbon emissions and economic growth in China. The authors applied Big Data analysis and the Tapio extended model to study the data of eight major regions from 1996 to 2012. They found that there were weak decoupling relations in most regions and energy consumption decoupling factors had consistent positive effects on industrial carbon emission decoupling that were greater than the emission factors. Furthermore, the overall technological level of carbon emission reduction in China was low and backwards, having few contributions to economic growth and industrial energy carbon emission decoupling. In addition, economic intensity had significant positive effects on carbon emissions and such effects were weaker in developed areas than in other regions.
- 2) Zhang, Pan, Yan, and Pan's 'Convergence Analysis of Regional Energy Efficiency in China based on Large-dimensional Panel Data Model' used panel data of 30 provinces in China during 2000e2014 to evaluate the energy efficiency and evaluation results indicated that there was significant spatial autocorrelation and clear spatial effects on China's regional energy efficiency. Between 2000 and 2014, China's regional energy efficiency exhibited both absolute b-convergence and conditional b-convergence, but the rate of the latter was higher than the former after other variables were controlled, such as the initial conditions of economic development level, the foreign direct investment, and governmental influences. Finally, the empirical evidence indicated that industrial transfer's contributed to the improvement in the convergence of regional energy efficiency in China since 2004.
- 3) Zhu, Wu, Li, and Xiong, in their 'China's regional natural resource allocation and utilization: A DEA-based approach in a big data environment', evaluated the efficiency of natural resource utilization in mainland China. They proposed a new method, SBM-DEA model, to analyse a set of panel data of 26

provinces from 2005 to 2012. Drawing support from the development of Big Data, they constructed production technology according to previously observed production data. Empirical study showed that most provinces performed well in terms of efficiency in utilizing natural resources. From a sub-regional perspective, the eastern area performed the best, followed by the central and western areas. Their study documented that at least half of the 26 provincial regions could reduce their natural resource consumption while keeping their consumption constant.

- 4) In 'Energy Efficiency and Congestion Assessment with Energy Mix Effect: The Case of APEC Countries', Zhou, Meng, Bai, and Cai adopted a DEA model to evaluate the energy efficiency and congestion by using the data of Asia-Pacific Economic Cooperation (APEC) countries from 1995 to 2013, and then a multiple linear model was estimated. The empirical results showed that nearly twenty percent of energy waste was caused by energy congestion (reducing energy input results in an increase in one or more outputs without worsening other inputs or outputs) and energy inefficiencies in developing countries were lower than in developed ones. Energy consumption and industrial value added per GDP exerted positive effects on energy congestion, but the effect of GDP per capita was negative. Finally, several policy recommendations were given for improving energy usage efficiency.
- 5) Zhang, Hao, Chang, Pan, and Tang, in their 'Energy-based resource intensities of industry sectors in China', constructed an eco-thermodynamic input-output model for explaining the sector-specific resource intensities in China. They found that resource intensities varied greatly across Chinese industry sectors, which were documented by the ratio of resource consumption to economic capital generation. Resource exploiting sectors of non-metallic minerals and metallic ores ranked the first in energy intensities. Sectors relying less on primary natural resources such as the service sectors had the smallest energy to money ratios. Combined resource intensities with their structures of industry sectors facilitated identification of the opportunities for reducing resource intensities as well as for improving ecological sustainability.
- 6) Wei and Li contributed the paper 'Resource misallocation in Chinese manufacturing enterprises: evidence from firm-level data', which studied resource misallocations, that is, energy and labour inputs were preferable in China. By using a simultaneous system of equations, they found non-coal energy inputs were more productive than coal and coal-related fuels. Although non-coal energy is more environmental-friendly, its costs were higher. Further, empirical results indicated that there was significant resource misallocation in manufacturing enterprises. Labour was underpaid while energy was overpaid, on average, compared with their marginal productivity. There was a wide difference in the pattern of energy misallocations across subsectors.

In summary, authors of articles contained in this theme argued that natural resource allocations and utilization in different fields should be focused upon reductions in wastage and can be improved by employing various improvement approaches. Cleaner production performance improvements in the iron and steel enterprises should

be implemented. Choices of production modes in agriculture should be optimized and CO₂ emissions in China and other developing countries should be reduced. Additional research is needed to understand the inter-relationships between energy consumption and economic development in APEC countries and on the energy-based resource intensities of industry sectors in China. Approaches that can be used to allocate and utilize all resources more effectively should be developed further, and the scope should not be limited to a focus upon natural resources.

2.4 Pollution prevention, treatment and environmental efficiency

The twelve papers within this theme are mainly about pollution treatment and prevention as well as upon improvement in environmental efficiency. For example, environmental efficiency improvement studies were performed by Chen and Jia (2017), He et al. (2017), Liu et al. (2017a), Liu et al. (2017b). The two papers about emission permits allocation were contributed by An et al. (2017) and Ji et al. (2017). The remaining six papers about pollution treatment and prevention were authored by Wang et al. (2017a), Chen et al. (2017b), Luo et al. (2017), Xie et al. (2017b), Huang et al. (2017b), and Louhghalam et al. (2017).

- 1) The paper ‘[Environmental efficiency evaluation of China's industrial sector based on the SBM-DEA model](#)’ by Chen and Jia, calculated the industrial environmental efficiencies of 31 provinces in China from 2008 to 2013. By adopting an SBM-DEA model that considers undesirable outputs, the authors found that environmental efficiencies in most regions were low except for Beijing, Jiangsu, and Guangdong. No increasing trend in environmental efficiencies was found during this period. There are large differences in environmental efficiencies across China.
- 2) Through the paper ‘[the synthetic geo-ecological environmental evaluation of a coastal coal-mining city using spatiotemporal big data: A case study in Longkou, China](#)’, He, Gu, Wang, and Zhang evaluated geological and ecological environmental quality of Longkou based on spatiotemporal Big Data. The authors applied a digital elevation model (DEM), and the precipitation and interpolation processing to generate factor layers and developed a synthetic evaluation index system. Clear specializations of zonality can be reflected by the spatial distribution of geo-ecological environmental quality, which showed that the quality of coastal coal mine areas was poor while that in inland and mountainous area of Nanshan Mountain was good. It proved that the proposed model that combined AHP with GIS in this paper was an effective means for evaluating regional geo-ecological environmental quality.
- 3) In the paper ‘[Environmental efficiency evaluation of land transportation sector in China based on the parallel SBM-DEA model](#)’, Liu, Zhang, Zhu, and Chu studied the resource utilization and environmental efficiency of land transportation sector in China. The authors proposed a framework based upon a parallel SBM-DEA model, which took resource utilization and CO₂ emissions into account. By adopting this framework, the environmental efficiency and the technology efficiency of the land transportation sector was evaluated. The results showed that Anhui's land transportation ranked first among all provinces. However, the average overall environmental and technological efficiency of the land transportation sector was poor.

- 4) Based on a cross-efficiency DEA model, Liu, Chu, Yin, and Sun, in the paper ‘DEA cross-efficiency evaluation considering undesirable output and ranking priority: A case study of eco-efficiency analysis of coal-fired power plants’, proposed a model for efficiency evaluation considering both undesirable outputs and cross-efficiency measures. Then a ranking priority model was proposed considering the decision-making units' intentions of pursuing the best ranking positions. An aggressive model was developed to guarantee the uniqueness of the optimal solution. Finally, by using the proposed approach, eco-efficiency performance improvements of coal-fired power plants were evaluated in a Big Data environment, and results showed that most coal-fired power plants in China were not performing well.
- 5) An, Wen, Xiong, Yang, and Chen studied the topic of carbon dioxide emission permits in ‘[Carbon dioxide emission permits allocation in a Big Data environment](#)’. They evaluated the efficiency of DMU in a Big Data environment by using a new DEA approach. This was the first time to set carbon dioxide emission permits for each decision-making unit with the minimum costs was used. The new method, presented by the authors of this article, has an advantage compared with methods in other literature, which is, considering the cost that each decision-making unit should pay. Hence, this approach can be used to allocate the CDE permits with the minimum cost.
- 6) In the paper ‘[Robust multi-criteria AEP for emission permits allocation in a Big Data environment](#)’, Ji, Sun, Wang, and Yuan proposed a new approach, robust multi-criteria AEP, to address the allocation issue of emission permits, which extended the classic DEA theory and provided tractability in analysing real-world large data sets. This method helped the researchers to determine the lowest total group-level pollutant emissions when group-level outputs are fixed. In addition to obtaining an optimal allocation plan for emission permits, the proposed approach can be used to calculate the optimal emission standard and the optimal total number of permits to be allocated.
- 7) The paper ‘[Carbon emission coefficient of conventional energy based on the Jiangsu Statistical Yearbook](#)’, written by Wang, Xie, and Yang, calculated the carbon emission coefficient of conventional energy based on the Jiangsu Statistical Yearbook. The authors investigated decoupling relationships between economic growth and carbon emissions of transportation in Jiangsu Province with the consideration of electricity. In addition, the transportation sector performed well in reducing pollution and carbon emission in Jiangsu Province after the Eleventh Five-Year Plan. However, there are more potential way to make improvements in low-carbon development.
- 8) Chen, Shao, Tian, Xie, and Yin, in the paper ‘[Spatial Durbin model in 116 cities of China during 2006e2012](#)’, studied the effects of air pollution on public health by using a spatial Durbin model in 116 cities of China during 2006e2012. They measured the public health through lung cancer mortality and respiratory disease mortality, which were collected from 161 websites of mortality-monitored locations in China, and measured air pollution by industrial emissions of sulfur dioxide and soot from corresponding cities. This study separated the local and neighboring effects of air pollution on public health based on the estimation of direct and indirect effects of air pollution. The empirical results provided evidence of the adverse impacts of air pollution and of its spatial spillover effects on public health. That study needs to

be replicated based upon the 2013e2016 data at the end of this year to determine the trends during and after the incredibly severe smog in 2013.

- 9) In the paper ‘Analysis on Spatial-temporal Features of Taxi Emissions from Big Data Informed Travel Patterns: A Case of Shanghai, China’, Luo, Dong, Dou, Zhang, Ren, Li, Sun, and Yao applied Big Data analysis on GPS data of taxis to analyze the energy consumption and emissions of taxis in Shanghai. They focused on the spatial and temporal features of energy consumption and pollutants and found a dual-core cyclic structure distribution of energy consumption and emission. Through the analyses of emission distribution of taxis combined with Big Data techniques, the authors were able to help policy-makers understand travel patterns and related environmental implications in the Shanghai metropolis and then to make policies on infrastructure systems, demand side management, and the promotion of low-carbon lifestyles.
- 10) The paper ‘Effect Analysis of Air Pollution Control in Beijing Based on an Odd-And-Even License Plate Model’ by Xie, Tou, and Zhang, by taking Beijing as an example, constructed an odd-and-even license plate model to quantitatively describe the pollution level caused by vehicle exhausts, and then studied the actual effect of the license plate limitation rule. Through analysis of the relationships between the license plate limitation rule and the urban air pollution control, it was found that the former had a positive impact on the latter in the short term since license plate limitation rule has gradually become the norm.
- 11) In the paper ‘Carbon Emission Flow from Self-Driving Tours and Its Spatial Relationship with Scenic Spots – A Traffic-related Big Data Method’, Huang, Cao, Jin, Yu, and Huang adopted data mining technology and method of tour traffic carbon emission flow analysis to analyse self-driving tour carbon emission flow in 2014. They found that regions that have high expressway traffic and self-driving tour traffic were mostly located along the Yangtze River, while other regions were mostly located in northern Jiangsu. Regions that have high self-driving tour traffic are located in Nanjing, Suzhou, Wuxi, and Changzhou. Lastly, there was no evidence that carbon emissions from self-driving tours had a significantly positive impact on the grades of scenic spots.
- 12) The last paper of this section, ‘Carbon Management of Infra-structure Performance: Integrated Big Data Analytics and Pavement-Vehicle Interactions’ was written by Louhghalam, Akbarian, and Ulm, who performed a comprehensive network-scale analysis, which provided an estimate of total excessive CO₂ emissions that was associated with pavement roughness and deflection. Computationally efficient pavement vehicle interactions models were used as they are easy to implement and require a minimum amount of input parameters. The authors employed Monte Carlo simulation scheme to find the confidence bounds of excessive fuel consumption and the corresponding CO₂ emissions when facing missing data and uncertainty of input variables. The contribution of proposed approach was closing a gap by integrating the network-level phase-using environmental impact in pavement Life Cycle Assessment. Finally, efficient and easy-to-implement model-based approaches for large data analytics can help agencies make more economically and environmentally sustainable network-level decisions.

With the green economy becoming more important, environmental protection and pollution prevention have

become an increasingly important activity in the whole world, especially for China. These papers focus on three main topics, namely environmental efficiency evaluation, emission permits allocation, and pollution treatment and prevention, to comprehensively analyse and solve environmental problems. Through these papers, decision-makers can comprehensively understand the problems they are facing and address these problems computationally.

The theme of Natural Resource-Related Policies and their Effects is addressed by twelve papers. These authors studied the current situation and proposed some natural resource-related policies for country leaders to develop, implement, and monitor the impacts of new generations of better policies.

- 1) Kung, Zhang, and Chang, in their ‘*Impacts of Natural Resource-Related Policies and their Effects on Bioenergy Production and GHG Emissions Reduction in Taiwan*’, employed the Big Data method, a mathematical programming model, as well as a dynamic structural equation model to examine promotion policies in bioenergy production and GHG (greenhouse gas) emissions reduction in Taiwan. The results showed that prices of coal and GHG had negative effects upon ethanol production and positive effects upon electricity production. Empirical results indicated that: (1) the GHG prices is more effective than the coal price in the sense of reducing the ethanol production; (2) the gasoline price has a negative impact on contemporary electricity production; (3) the coal and GHG prices have positive impacts on contemporary electricity production; (4) the gasoline price, coal price, GHG price and GHG emissions reductions have a significant positive impact on contemporary welfare.
- 2) Li, Qiao, and Shi, in their ‘*The aggregate effect of air pollution regulation on CO₂ mitigation in China's manufacturing industry: An econometric analysis*’, applied a theoretical framework of co-benefits to study how air pollution regulations affected CO₂ mitigation in China. Based on industrial aggregate data of 18 manufacturing sectors from 1991 to 2010, their study showed that more stringent regulations of SO₂ cause more CO₂ emissions when the output effect was eliminated. In addition, SO₂ regulation provides a reference for regulating other air pollutants.
- 3) In the contribution ‘*Relationship between landscape diversity and crop production: A case study in the Hebei province of China based on multi-source data integration*’, Deng, Gibson, and Wang studied the Hebei province's landscape diversity and its effects on crop production as clarified via Big Data analytical approaches. The empirical study showed that there was a positive ecological effect of landscape diversity on crop production. Therefore, it is important to adhere to a certain level of landscape diversity if crop production is to be sustained.

- 4) Yang, Wang, and Shi, in their article ‘[The impact of the carbon market on the economic growth of China](#)’, explored the goal of the Chinese government for a win-win situation between economic development and environmental protection. They argued that it was mainly the fixed capital investment that bolstered China's economic growth and that increases of human capital investment could reduce combustion of fossil fuels. The authors proposed the conditions for China to meet the goal and found that technological progress was the key to achieve both economic growth and carbon emission reduction.
- 5) The paper by Cao and Wang, ‘[The impact of the carbon market on the economic growth of China](#)’, proposed a method to measure green technology progress to verify the effect of opening up upon China's green technology progress. They found that by enhancing the supervision on exporting enterprises, China could use exports to bolster its domestic economy. Moreover, imports from developed countries could improve China's green technology and, its ability to innovate and cultivate human talents, could be enhanced.
- 6) Huang, Fu, and Qi, in their ‘[The impact of the carbon market on the economic growth of China](#)’, estimated the influences of restrictions on air quality by using a new empirical strategy. They found that driving restrictions had effects in the short run, but such effect would fade out gradually, which was helpful to understand the effectiveness of current driving restriction policies and may help policy-makers to achieve better results in the future.
- 7) Wang, Deng, Wang, and Zhang contributed ‘[The impact of the carbon market on the economic growth of China](#)’, in which the market clearing model was developed based on the market equilibrium principle. The degree of power market deregulation was measured by using the free transaction ratio. It was found that transaction ratios exerted significant effects on the operation of power systems and that the optimal transaction ratio could be determined.
- 8) In the contribution ‘[The impact of the carbon market on the economic growth of China](#)’ fi
[The impact of the carbon market on the economic growth of China](#)’, Liu, Guo, and Fan studied the behavior and performance of emitting companies that participated in the European Union Emission Trading Scheme (EU ETS). Authors measured the efforts by the after-action factor of trading performance and found that emission level, industrial sector, and trading requirements had significant effects on companies’ trading performance.
- 9) Liu and Wu, in their ‘[The impact of the carbon market on the economic growth of China](#)’
[The impact of the carbon market on the economic growth of China](#)’, employed Social Accounting Matrix (SAM) model to identify price impacts and transmitting paths of imposing greenhouse gas emission taxes. According to Big Data analyses from the first national census of pollution sources, sources of emissions of CO₂ and non-CO₂ greenhouse gases were compared, showing that prices in all sectors had the greatest increase in the CO₂ emissions tax scenario as compared to CH₄ and N₂O emissions tax scenarios. The authors suggested that CH₄ and N₂O emission reduction should be considered more by China.
- 10) Zhang and Huisingh in the paper ‘[The impact of the carbon market on the economic growth of China](#)’
[The impact of the carbon market on the economic growth of China](#)’, studied techno-economic characters of geological CO₂ storage options, including CO₂ transportation, geological storage approaches and CO₂ leakage monitoring. They believed that deep saline aquifers had strong capacities and were easily located near CO₂ emission sites as compared with other technologies such as depleted oil/gas reservoirs and coal seams. The main barriers to the implementation of carbon storage schemes included high

costs, severe energy penalty, safety and reliability, and policy uncertainties, etc.

11) In the paper ‘[The impact of the public-private partnership model on the urban sewage treatment projects in China](#)’, Yang, Long, Cui, Zhu, and Chen adopted the public-private partnership model to study urban sewage treatment projects, concerning the relationships between responsibility and authority, benefit sharing, and risk sharing. From perspectives of governments, enterprises, intermediary agencies, and public groups, the authors analysed these issues in detail. It was found that the relationship between government and market was the key to the implementation of public-private partnership models in urban sewage treatment projects.

12) Liu and Zhang, in their ‘[The impact of corporate governance on social responsibility information disclosure and enterprise value](#)’, explored the relationships among corporate governance, social responsibility information disclosure and enterprise value based on the data of listed companies with high pollution during 2008e2014. The empirical results showed that there was a downward trend of social responsibility information disclosure, and social responsibility was able to exert positive effect on firm's long-term values. The authors documented that efficient corporate governance could help to facilitate improved management and disclosure of social responsibility information.

In summary, the authors of these twelve papers measured and analysed both positive and negative effects of these policies, especially on carbon emissions. They addressed how policies that related to natural resources were developed and how their effects on resource utilization were measured. Big data analytical approaches were used in these works to comprehensively analyse the dynamic changes of natural resources and the effects of related policies. In particular, they investigated how processes had changed, especially before and after policies of natural resource management were implemented. Significantly, these papers provided governments and/or companies with useful information for the development and implementation of proactive, human health and environmental protection policies.

2.6.

In response to this SV's call for papers, some scholars submitted studies of the Green Supply Chain Management (GSCM) in the Big Data environment. They focused on the optimization of GSCM (Zhao et al., 2017), forecasted efficiency of green suppliers (Shabanpour et al., 2017), and sustainability of GSCM (Papadopoulos et al., 2017; Dubey et al., 2017).

1) Shabanpour, Yousefi, and Saen's paper ‘[The impact of green supply chain management on the efficiency of green suppliers](#)’ integrated dynamic DEA with artificial neural networks (ANN) to evaluate the efficiency of green suppliers in the future. First, ANN was employed to obtain forecasted data including inputs, outputs, and links of green suppliers. Then dynamic DEA was applied to analyse the forecasted data mentioned above to obtain good efficiency values of green suppliers in the past, present, and future simultaneously.

- 2) Papadopoulos, Gunasekaran, Dubey, Altay, Childe, and Fosso-Wamba, in their paper ‘[Supply chain resilience in the era of Big Data](#)’, used Big Data analyses and results suggested that trust, information sharing, and public-private partnership were critical enablers of resilience in supply chain networks. The article contributed to the literature on resilience in supply chain networks for sustainability in that: (i) it demonstrated how to use Big Data analysis to test and to propose particular frameworks under the environments of resilient supply chains for sustainability; (ii) it argued that swift trust, public private partnerships, and quality information sharing link to resilience in supply chain networks; and (iii) it used the context of Nepal, in the actual process of disaster relief activities, to provide contemporaneous perceptions of the phenomenon when it took place.
- 3) Dubey, Gunasekaran, Papadopoulos, Childe, Shibin, and Wamba, in their ‘[Sustainable supply chain management in the era of Big Data](#)’, introduced literature on driving forces of sustainable supply chain management (SSCM) and adopted the Total Interpretive Structural Modeling (TISM) and MICMAC analysis to test a framework that extrapolates SSCM driving forces and their relationships, which depicted how the driving forces were distributed in different levels and how a particular driving force could influence the others through transitive links.

Resonating with previous themes, these four papers highlighted that green supply chain management in a sustainability context in terms of both resource utilization and economic development is crucial. To be specific, they provided an optimization model and sustainable technology selection decision-making model for Green Supply Chain Management, and forecast efficiency of green suppliers by a new method in the Big Data environment. Furthermore, they highlighted further research directions in sustainability. They contributed, not only in the area of green supply chain management, but also in new directions of sustainability development.

3. Discussion

The variety of papers presented in this SV demonstrated numerous approaches and empirical analyses available in the environment of Big Data to improve natural resource management and human health to ensure sustainable societal development. Most importantly, the articles of this SV showed that the environment of Big Data have made changes in the study of economic development and resource utilization. Resources, especially natural resources, have been utilized more and more to support the improvement of society. In recent years, wasting of natural resources and emission of CO₂ and of other greenhouse gases have been growing steadily, making it vital to find and to implement improved way to reduce and to manage them in sustainable ways for the short and long-term future. Because of this, Big Data analytical approaches can provide ways to deal with these problems. The improvement of natural resource utilization, improved energy efficiency, enhanced environmental efficiency and protection, and sustainability could all be achieved, with the aid of tools of Big Data.

This SV presented an inspiring panorama of initiatives that have been developed throughout the world for

sustainable societal development and for their resonance in the research world. Cases in this SV came from many regions of the world, although most of the articles were from China. It is interesting to note that many papers were co-authored by Chinese and non-Chinese authors, suggesting a growing collaboration in this field. However, these collaborations have largely focused on the collection of interesting and useful empirical examples so far and many challenges remain in terms of methodology development in the field of applying Big Data to solve and to prevent problems pertaining to environmental management and human survival upon planet earth.

At this point, the themes showed a variety of emerging research traditions. For instance, some new approaches were increasingly designed to bridge the gap between the economic development and environmental protection. Similarly, some frameworks emerged as powerful heuristics to address changes, such as connecting farmland conversion in China to the double constraints of economic growth and resource protection. Some new approaches and theories could offer valuable insights to help us to understand multi-level processes of change.

In addition to theoretical insights, most of the papers in this SV provided case studies of regions in China. For example, they studied cases in agriculture such as the cooking fuel choices in rural China, cases in transportation, such as the environmental efficiency of land transportation in China, cases in energy consumption, such as eco-efficiency analyses of coal-fired power plants, cases in regional economic development, such as China's regional natural resource allocation and utilization, cases in carbon dioxide emission, such as the allocation of carbon dioxide emission permits with minimum cost for Chinese provinces, and cases in international situations, such as trends of natural resource footprints in the BRIC countries. All of these case studies were meaningful for improving natural resource utilization and economic development.

Notions of governance were strongly represented in Theme 5. The theme of 'natural resource related policies and their effects' provided more insights into policy effects that emerged recently but reflected powerful changes in society. Because many countries have developed and implemented natural resource-related policies, including energy policies, it is crucial to measure and to analyse both positive and negative effects of these policies. The findings of these studies will help country leaders to develop, implement, and monitor the impacts of new generations of more holistic policies. Papers on this topic addressed how policies concerning sustainable natural resource management were developed and how their effects on resource utilization were measured. For example, in this SV, Kung et al. (2017) studied the promotion policies for renewable energy and their effects in Taiwan. The work of Cao and Wang (2017) verified the influence China's opening up policy has had on green technology progress. Luo et al. (2017) analysed energy consumption and emissions by taxies and their spatial-temporal distribution in Shanghai.

This SV illustrated that scholars need to consider how we can more effectively help us to transition to truly sustainable societies. Certainly additional research is needed to solve the numerous challenges in we need to address. For example, most studies presented in this SV were focused on cases in China only, which should be broadened to cover other geographical regions. The benefits of research to improve the efficiency of natural resource management is not limited to China but can enrich many other countries Including both developed countries and developing countries. There is much room for contributions to improve and to apply the research

methodologies used by the authors of the articles in this SV in other contexts. Such research is needed to help societies make the transition to sustainable, post-fossil carbon societies.

References

- An, Q., Wen, Y., Xiong, B., Yang, M., Chen, X., 2017. Allocation of carbon dioxide emission permits with the minimum cost for Chinese provinces. *J. Clean. Prod.* 142 (Part 2), 886e893.
- Cao, B., Wang, S., 2017. Opening up, international trade, and green technology progress. *J. Clean. Prod.* 142 (Part 2), 1002e1012.
- Chen, L., Jia, G., 2017. Environmental efficiency analysis of China's regional industry: a DEA based approach. *J. Clean. Prod.* 142 (Part 2), 846e853.
- Chen, J., Wu, Y., Wen, J., Cheng, S., Wang, J., 2017a. Regional differences in China's fossil energy consumption: an analysis for the period 1997-2013. *J. Clean. Prod.* 142 (Part 2), 578e588.
- Chen, X., Shao, S., Tian, Z., Xie, Z., Yin, P., 2017b. Impacts of air pollution and its spatial spillover effect on public health based on China's big data sample. *J. Clean. Prod.* 142 (Part 2), 915e925.
- Cherniwchan, J., 2012. Economic growth, industrialization, and the environment. *Resour. Energy Econ.* 34, 442e467.
- Deng, X., Gibson, J., Wang, P., 2017a. Quantitative measurements of the interaction between net primary productivity and livestock production in Qinghai Province based on data fusion technique. *J. Clean. Prod.* 142 (Part 2), 758e766.
- Deng, X., Gibson, J., Wang, P., 2017b. Management of trade-offs between cultivated land conversions and land productivity in Shandong Province. *J. Clean. Prod.* 142 (Part 2), 767e774.
- Deng, X., Gibson, J., Wang, P., 2017c. Relationship between landscape diversity and crop production: a case study in the Hebei Province of China based on multi- source data integration. *J. Clean. Prod.* 142 (Part 2), 985e992.
- Dubey, R., Gunasekaran, A., Papadopoulos, T., Childe, S., Shibin, K., Wamba, S., 2017. Sustainable supply chain management: framework and further research directions. *J. Clean. Prod.* 142 (Part 2), 1119e1130.
- Gong, B., Guo, D., Zhang, X., Cheng, J., 2017. An approach for evaluating cleaner production performance in iron and steel enterprises involving competitive relationships. *J. Clean. Prod.* 142 (Part 2), 739e748.
- Hazen, B., Boone, C., Wang, Y., Khor, K., 2017. Perceived quality of remanufactured products: construct and measure development. *J. Clean. Prod.* 142 (Part 2), 716e726.
- He, F., Gu, L., Wang, T., Zhang, Z., 2017. The synthetic geo-ecological environmental evaluation of a coastal coal-mining city using spatiotemporal big data: a case study in Longkou, China. *J. Clean. Prod.* 142 (Part 2), 854e866.
- Hou, B., Tang, X., Ma, C., Liu, L., Wei, Y., Liao, H., 2017. Cooking fuel choice in rural China: results from microdata. *J. Clean. Prod.* 142 (Part 2), 538e547.
- Huang, H., Fu, D., Qi, W., 2017a. Effect of driving restrictions on air quality in Lanzhou, China: analysis integrated with Internet data source. *J. Clean. Prod.* 142 (Part 2), 1013e1020.
- Huang, Z., Cao, F., Jin, C., Yu, Z., Huang, R., 2017b. Carbon emission flow from self-driving tours and its spatial relationship with scenic spots e a traffic-related big data method. *J. Clean. Prod.* 142 (Part 2), 946e955.
- Ji, X., Sun, J., Wang, Y., Yuan, Q., 2017. Allocation of emission permits in large data sets: a robust multi-criteria

- approach. *J. Clean. Prod.* 142 (Part 2), 894e906.
- Jiang, W., Jia, K., Chen, Z., Deng, Rao, P., 2017. Using spatiotemporal remote sensing data to assess the status and effectiveness of the underground coal fire suppression efforts during 2000-2015 in Wuda, China. *J. Clean. Prod.* 142 (Part 2), 565e577.
- Kung, C., Zhang, L., Chang, M., 2017. Promotion policies for renewable energy and its effects in Taiwan. *J. Clean. Prod.* 142 (Part 2), 965e975.
- Li, T., Liu, A., 2017. Spatiotemporal dynamic analysis of forest ecosystem services using “big data”: a case study of Anhui province, central-eastern China. *J. Clean. Prod.* 142 (Part 2), 589e599.
- Li, L., Hao, T., Chi, T., 2017a. Evaluation on China's forestry resources efficiency based on big Data. *J. Clean. Prod.* 142 (Part 2), 513e523.
- Li, Z., Meng, N., Yao, X., 2017b. Sustainability performance for China's transportation industry under the environmental regulation. *J. Clean. Prod.* 142 (Part 2), 688e696.
- Li, Y., Cao, Z., Long, H., 2017c. Dynamic analysis of ecological environment combined with land cover and NDVI changes and implications for sustainable urban-rural. *J. Clean. Prod.* 142 (Part 2), 697e715.
- Li, X., Qiao, Y., Shi, L., 2017d. The aggregate effect of air pollution regulation on CO₂ mitigation in China's manufacturing industry: an econometric analysis. *J. Clean. Prod.* 142 (Part 2), 976e984.
- Lin, B., Lin, J., 2017. Evaluating energy conservation in China's heating industry. *J. Clean. Prod.* 142 (Part 2), 501e512.
- Liu, L., Wu, G., 2017. The effects of carbon dioxide, methane and nitrous oxide emission taxes: an empirical study in China. *J. Clean. Prod.* 142 (Part 2), 1044e1054.
- Liu, X., Zhang, C., 2017. Corporate governance, social responsibility information disclosure, and enterprise value in China. *J. Clean. Prod.* 142 (Part 2), 1075e1084.
- Liu, H., Zhang, Y., Zhu, Q., Chu, J., 2017a. Environmental efficiency of land transportation in China: a parallel Slack-Based Measure for regional and temporal analysis. *J. Clean. Prod.* 142 (Part 2), 867e876.
- Liu, X., Chu, J., Yin, P., Sun, J., 2017b. DEA cross-efficiency evaluation considering undesirable output and ranking priority: a case study of eco-efficiency analysis of coal-fired power plants. *J. Clean. Prod.* 142 (Part 2), 867e876.
- Liu, Y., Guo, J., Fan, Y., 2017c. A big data study on emitting companies' performance in the first two phases of the European Union Emission Trading Scheme. *J. Clean. Prod.* 142 (Part 2), 1028e1043.
- Louhghalam, A., Akbarian, M., Ulm, F., 2017. Carbon management of infrastructure performance: integrated big data analytics and pavement-vehicle-interactions. *J. Clean. Prod.* 142 (Part 2), 956e964.
- Lu, J., Liu, Z., Zhang, Y., Li, B., Lu, Q., Ma, Y., Shen, R., Zhu, Z., 2017. Improved production and quality of biocrude oil from low-lipid high-ash macroalgae *Enteromorpha prolifera* via addition of crude glycerol. *J. Clean. Prod.* 142 (Part 2), 749e757.
- Luo, X., Dong, L., Dou, Y., Zhang, N., Ren, J., Li, Y., Sun, L., Yao, S., 2017. Analysis on spatial-temporal features of taxis' emissions from big data informed travel patterns: a case of Shanghai, China. *J. Clean. Prod.* 142 (Part 2), 926e935.

- Papadopoulos, T., Gunasekaran, A., Dubey, R., Altay, Z., Childe, S., Fosso-Wamba, S., 2017. The role of Big Data in explaining disaster resilience in supply chains for sustainability. *J. Clean. Prod.* 142 (Part 2), 1108e1118.
- Schilling, M., Chiang, L., 2011. The effect of natural resources on sustainable development policy: the approach of non-sustainable externalities. *Energy Policy* 39, 990e998.
- Shabanpour, H., Yousefi, S., Saen, R., 2017. Forecasting efficiency of green suppliers by dynamic data envelopment analysis and artificial neural networks. *J. Clean. Prod.* 142 (Part 2), 1098e1107.
- Sparling, D.W., 2014. *Natural Resource Administration Wildlife, Fisheries, Forests and Parks* (San Diego, USA).
- Sterner, T., Coria, J., 2011. *Policy Instruments for Environmental and Natural Resource Management*. Resources for the Future Press, New York.
- Sun, Y., Liu, N., Shang, J., Zhang, J., 2017. Sustainable utilization of water resources in China: a system dynamics model. *J. Clean. Prod.* 142 (Part 2), 613e625.
- Tseng, M., 2017. Using social media and qualitative and quantitative information scales to benchmark corporate sustainability. *J. Clean. Prod.* 142 (Part 2), 727e738.
- Wan, L., Zhang, Y., Qi, S., Li, H., Chen, X., Zang, S., 2017. A study of regional sustainable development based on GIS/RS and SD model: a case of Hadaqi Industrial Corridor. *J. Clean. Prod.* 142 (Part 2), 654e662.
- Wang, T., Lin, B., 2017. China's natural gas consumption peak and factors analysis: a regional perspective. *J. Clean. Prod.* 142 (Part 2), 548e564.
- Wang, Z., Ye, D., 2017. Forecasting Chinese carbon emissions from fossil energy consumption using nonlinear grey multivariable models. *J. Clean. Prod.* 142 (Part 2), 600e612.
- Wang, H., Xu, J., Zhang, M., Yang, Y., Shen, X., Wang, Y., Chen, D., Guo, J., 2014. A study of the meteorological causes of a prolonged and severe haze episode in January 2013 over central-eastern China. *Atmos. Environ.* 98, 146e157.
- Wang, Y., Xie, T., Yang, S., 2017a. Carbon emission and its decoupling research of transportation in Jiangsu Province. *J. Clean. Prod.* 142 (Part 2), 907e914.
- Wang, H., Deng, J., Wang, C., Zhang, G., 2017b. A novel power market clearing model based on the equilibrium principle in microeconomics. *J. Clean. Prod.* 142 (Part 2), 1021e1027.
- Wei, C., Li, C., 2017. Resource misallocation in Chinese manufacturing enterprises: evidence from firm-level data. *J. Clean. Prod.* 142 (Part 2), 837e845.
- Wong, E., 2013. As Pollution Worsens in China, Solutions Succumb to in Fighting. March 22. *The New York Times*.
- Wu, K., Liao, C., Tseng, M., Lim, M., Hu, J., Tang, K., 2017a. Toward sustainability: using big data to explore the decisive attributes of supply chain risks and uncertainties. *J. Clean. Prod.* 142 (Part 2), 663e676.
- Wu, R., Geng, Y., Liu, W., 2017b. Trends of natural resource footprints in the BRIC countries. *J. Clean. Prod.* 142 (Part 2), 775e782.
- Xiao, Y., Wu, X., Wang, L., Liang, J., 2017. Optimal farmland conversion in China under double restraints of economic growth and resource protection. *J. Clean. Prod.* 142 (Part 2), 524e537.
- Xie, H., He, Y., Xie, X., 2017a. Exploring the factors influencing ecological land change for China's Beijing-

- Tianjin-Hebei Region using big data. *J. Clean. Prod.* 142 (Part 2), 677e687.
- Xie, X., Tou, X., Zhang, L., 2017b. Effect analysis of air pollution control in Beijing based on an odd-and-even license plate model. *J. Clean. Prod.* 142 (Part 2), 936e945.
- Yang, L., Wang, J., Jun, S., 2017a. Can China meet its 2020 economic growth and carbon emissions reduction Targets. *J. Clean. Prod.* 142 (Part 2), 993e1001.
- Yang, T., Long, R., Cui, X., Zhu, D., Chen, H., 2017b. Application of the public-private partnership model to urban sewage treatment. *J. Clean. Prod.* 142 (Part 2), 1065e1074.
- Zhang, N., Chen, Z., 2017. Sustainability characteristics of China's Poyang Lake eco- economics Zone in the big data environment. *J. Clean. Prod.* 142 (Part 2), 642e653.
- Zhang, Z., Huisingh, D., 2017. Carbon dioxide storage schemes: technology, assessment and deployment. *J. Clean. Prod.* 142 (Part 2), 1055e1064.
- Zhang, Y., Ren, S., Liu, Y., Si, S., 2017a. A big data analytics architecture for cleaner manufacturing and maintenance processes of complex products. *J. Clean. Prod.* 142 (Part 2), 626e641.
- Zhang, L., Hao, Y., Chang, Y., Pan, M., Tang, S., 2017b. Energy based resource intensities of industry sectors in China. *J. Clean. Prod.* 142 (Part 2), 829e836.
- Zhang, W., Pan, X., Yan, Y., Pan, X., 2017c. Convergence analysis of regional energy efficiency in China based on large-dimensional panel data model. *J. Clean. Prod.* 142 (Part 2), 801e808.
- Zhao, R., Liu, Y., Zhang, N., Huang, T., 2017. An optimization model for green supply chain management by using a big data analytic approach. *J. Clean. Prod.* 142 (Part 2), 1085e1097.
- Zhou, X., Zhang, M., Zhou, M., Zhou, M., 2017a. A comparative study on decoupling relationship and influence factors between China's regional economic development and industrial energy related carbon emissions. *J. Clean. Prod.* 142 (Part 2), 783e800.
- Zhou, D., Meng, F., Bai, Y., Cai, S., 2017b. Energy efficiency and congestion assessment with energy Mix effect: the case of APEC countries. *J. Clean. Prod.* 142 (Part 2), 819e828.
- Zhu, Q., Wu, J., Li, X., Xiong, B., 2017. China's regional natural resource allocation and utilization: a DEA-based approach in a big data environment. *J. Clean. Prod.* 142 (Part 2), 809e812.

