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A sustainability assessment system for Chinese iron and steel firms

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ABSTRACT

The environmental impact of the Chinese iron and steel industry is huge due to its high consumption of ore, coal and energy, and water and air pollution. It is important not only for China but also for the rest of the world that the Chinese iron and steel industry becomes more sustainable. A sustainable assessment indicator system is an important tool to support that development. Currently, however, a sustainable assessment system, specifically designed to match the characteristics of Chinese iron and steel firms, is not available. In this paper such a system is proposed and evaluated using data from financial and sustainability reports of four leading Chinese iron and steel firms. The proposed sustainable assessment system is envisaged to help Chinese iron and steel firms to objectively investigate their sustainability performance, provide clear and effective information to decision makers, and support the Chinese iron and steel firms' sustainable development.

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1. Introduction and research background

China is undergoing accelerated industrialization and urbanization, in which the iron and steel (IS) industry plays a fundamental role. IS products are mostly used in the construction and industrial manufacturing sectors, which are the main driving forces of the Chinese economy (Geng and Doberstein, 2008; Xu et al., 2008; Zhang et al., 2013).

China has been the world's largest crude steel producer for 18 continuous years since 1996. The average annual growth rate of crude steel production was over 13% between 1996 and 2013 (Fig. 1). In 2013, the Chinese IS industry produced (WSA, 2014) 779 million tons of crude steel, or 48% of the world's crude steel production. The production of pig iron was nearly as high, 709 million tons, representing 61% of the world's pig iron production. In that year, six Chinese firms were among the world's top ten IS firms (WSA, 2013).

Production of iron and steel is not only important for the development of China, but also unfortunately a source of environmental pollution due to the large consumption of fossil energy and related emissions. In 2010, Chinese IS firms consumed around 461 TWh of electricity and 14,872 PJ of fuel (WSA, 2011; Hasanbeigi et al., 2013; Tian et al., 2013). Coal consumption was 575 million tons, accounting for over 14% of national coal consumption. The corresponding SO_2 and CO_2 emissions were nearly 1.8 million and over 1.2 million tons, which accounted for over 10% and 16% of national SO_2 and CO_2 emissions, respectively (Mao et al., 2013). Even though energy efficiency in the Chinese IS industry has improved greatly in recent years, the energy consumption per ton of steel is still 15—20% higher than the international benchmark (Wang et al., 2007; Zhang et al., 2012). In addition, the Chinese ratio of CO_2 to GDP is one of the highest in the world and the Chinese CO_2 emissions accounted for over 25% (about 8 billion tons) of global CO_2 emissions in 2011 (IEA, 2011). Furthermore, the Chinese IS industry accounts for about 14% of the national total water and gas waste, and for 6% of the total volume of solid waste materials generated (He et al., 2013). Considering all these facts, the Chinese IS industry has great potential for carbon emission reduction and environmental protection. Furthermore, the Chinese IS industry is hard pressed by domestic and overseas stakeholders to think beyond the economic performance of its manufacturing processes and products and also consider environmental and social effects. This creates a need to develop indicators allowing IS companies to assess their sustainability performance, identify "hot spots", support sustainability reporting, increase stakeholder engagement (Azapagic, 2004) and guide firms to formulate a sustainable development strategy.

Interest in sustainability assessment (SA) is also increasing among academics (Labuschagne et al., 2005; Singh et al., 2012; Joung et al., 2013; Samuel et al., 2013; Schrettle et al., 2014).
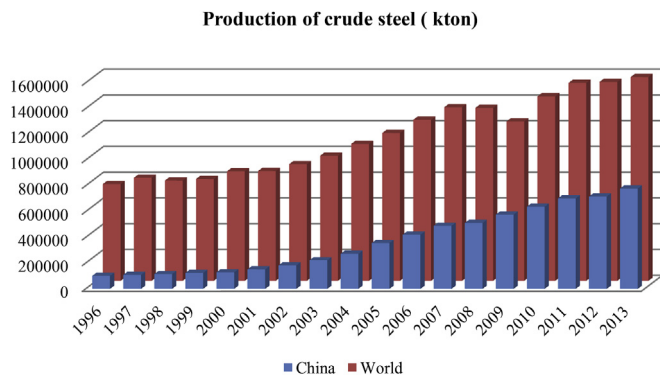

Production of crude steel (kton)

Fig. 1. Comparison of crude steel production between China and the world (based on World Steel Association figures).

However, sustainability research focusing specifically on the IS industry is scarce; only few studies can be found. Strezov et al. (2013), for example, assessed the sustainability indicators of the three major IS technologies, the blast furnace, the electric arc furnace and direct reduced iron. Fruehan (2009) defined sustainable steel-making goals. Zhang et al. (2012) investigated the practices, determinants and effects of CO_2 emission reduction within the Chinese IS industry. Anane et al. (2012) added the social dimension of industrial development and tested a preliminary set of indicators across different molten steel production processes. Zhang et al. (2009) used eMergy synthesis and other methods to evaluate the emission impact of Chinese IS industry between 1998 and 2004.

In summary, there is no hiding from the fact that the Chinese IS industry is a major player in terms of production and energy consumption at national as well as international level. Awareness of sustainability is growing fast, in China just as in the rest of the world. In order to support firms in their attempts to increase the sustainability of their operations, SA indicators are needed. There is limited research on sustainability aspects of the Chinese IS industry and no comprehensive set of SA indicators for Chinese IS firms. The objective of this paper is to explore this gap and develop and evaluate a comprehensive SA system for the Chinese IS industry.

The paper is organized as follows. In Section 2, the concept of sustainability is introduced in terms of the "triple bottom line", followed by a review of existing SA systems. Based on that review, an SA system geared towards the Chinese IS industry is proposed in Section 3. The research method used to evaluate that system is accounted for in Section 4. Results from applying the system in four Chinese IS firms are reported in Section 5. After an evaluation of the system in Section 6, the paper is summarized and concluded in Section 7.

2. Literature review

2.1. The concept of sustainability and the "triple bottom line"

In 1987, the World Commission on Environment and Development (WCED, 1987, p. 43) described sustainability as a "development that meets the needs of the present without compromising the ability of future generations to meet their needs". Since then, many researchers have interpreted and translated this macro-level definition into micro-level definitions from different angles, such as for example business sustainability, which can be defined as "adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining and enhancing the human and natural resources that will be needed in the future" (IISD, 1992, p. 116; see also e.g. Labuschagne et al., 2005).

The most widely recognized and adopted sustainability concept, the "triple bottom line", was developed by Elkington (1994). This concept distinguishes and proposes a balanced approach towards economic, environmental and social aspects of business performance (Gimenez et al., 2012). The concept has been used and applied extensively in research and increasingly so also in practice. Within the concept, economic sustainability is easily understood, and the recent global economic crisis has shown that maintaining economic growth is still an essential and universally accepted objective for firms and the general public (Moldan et al., 2012). Social sustainability requires that the firm's cohesion with society and its ability to work towards common goals be maintained (Gilbert et al., 1996). The World Bank first proposed the concept of environmental sustainability. Initially, the term "environmentally responsible development" was used; later "environmentally sustainable development" became more popular (Moldan et al., 2012). Today, there are plentiful definitions of environmental sustainability developed from many different perspectives, including economic, managerial and ecological viewpoints.

2.2. A review of sustainability assessment systems

Even if the "triple bottom line" is a relatively mature framework, it still remains difficult to express it in concrete, operational terms (Briassoulis, 2001). Yet, many firms have started to find sustainability assessment (SA) solutions and tools to interpret sustainability (Joung et al., 2013). In the last decade, sustainability reports started to emerge as a new trend in corporate reporting, integrating in one report financial, environmental and social indicators (GRI, 2000, 2002), which can be used to assess the sustainability performance of a firm (Krajnc and Glavič, 2005). An SA system helps translate sustainability issues into, preferably quantifiable, measures of economic, environmental and social performance with the ultimate aim of helping firms to address key sustainability concerns and provide information supporting their sustainable development (Azapagic, 2004).

Today, several SA systems are available to analyze sustainability. Different (sets of) indicators and metrics have been developed covering the various levels of decision making for sustainability (Joung et al., 2013), in particular the operational, organizational, regional/national and global levels (OECD, 2006). Since this paper focuses on individual firms, we briefly present existing operational and organizational level SA systems in Table 1.

Table 2, which summarizes the dimensions covered by the six SA systems presented in Table 1, suggests that all but one system address all three "triple bottom line" performance areas.

However, the systems are either industry specific (e.g. Ford PSI for the automotive industry and IChemE for the process industry) or their focus is towards investors and stakeholders (e.g. DJSI). Furthermore, some systems, such as GRI, have more than 70 indicators, which makes it difficult to identify suitable indicators for a particular industry. In short, the universal applicability of the reviewed SA systems is questionable. However, as argued above, the Chinese IS industry, which is not only the world's largest iron and steel producer but also a major consumer of natural resources and ditto source of environmental pollution, urgently needs a suitable SA system supporting full-scale sustainability evaluation. In the remainder of this paper such a system is proposed and evaluated.

3. Proposed SA indicators for Chinese IS industry

This section proposes SA indicators for the Chinese IS industry. Based on these indicators, an SA system will be developed in this section, and illustrated in Sections 4 and 5 using data from four

Table 1
Existing SA systems (operational and organizational level).

SA system	Brief description	Implementation
Lowell Center for Sustainable Production (LCSP) indicator framework	This framework uses a five-tiered approach to achieve a sustainable system at facility level. The five tiers are compliance/conformance indicators (level 1), material use and performance indicators (level 2), effect indicators (level 3), supply chain and product life cycle indicators (level 4), and sustainable systems indicators (level 5).	Operational level
Ford Product Sustainability Index (Ford PSI)	The Ford PSI considers eight sustainability indicators that are specifically relevant to automobile manufacturing and services, namely: mobility capability, life cycle cost, impact on life cycle global warming, life cycle air quality, sustainable materials, restricted substances, safety, and drive-by-exterior noise.	Operational level
International Organization for Standardization (ISO) −Environmental Performance Evaluation (EPE) standard (ISO, 14031)	ISO, 14031 contains two general categories of indicators, namely: (1) environmental performance indicators, including operational performance and management performance indicators, and (2) environmental condition indicators	Operational level
Global Reporting Initiative (GRI)	GRI aim is to provide a standardized and generally accepted sustainability-reporting framework. The GRI framework is generally recognized as the most widely used sustainability reporting tool. The guideline contains more than 70 performance indicators, which are used to measure and report economic, environmental and social performance.	Organizational level
Sustainability Metrics of the Institution of Chemical Engineers (IChemE)	This framework is less complex and impact oriented and includes sustainability metrics covering the environmental, economic and social dimensions to evaluate the sustainability performance of the process industry.	Organizational level
Dow Jones Sustainability Indexes (DJSI)	DJSI tracks the performance of the top 20% of the firms in the Dow Jones Global Total Stock Market Index of 600 firms that lead the field in terms of corporate sustainability. The index evaluates firm performance on 12 criteria, covering mainly the economic dimension, but also including some environmental and social aspects.	Organizational level

Chinese IS firms. First, however, we present the necessary criteria for selecting SA indicators and assessing the resulting SA system. These criteria will be used in Section 6 to evaluate the system.

3.1. SA system − selection and evaluation criteria

"Indicators arise from values (we measure what we care about), and they create values (we care about what we measure)" (Meadows, 1998, p. viii). In the presence of the large number of SA indicators proposed in the literature, many authors have noted that there is lack of guidance on how to choose between indicators (Veleva and Ellenbecker, 2000). Unfortunately, there is little agreement among the authors addressing this problem − a large variety of selection criteria have been proposed in the literature. Based on and choosing from the work of, amongst others, Schomaker (1997) (referred to in Niemeijer and de Groot, 2008), Hughes (2002), Niemeijer and de Groot (2008), Fan and Bai (2010), Liu (2010), Singh et al. (2007), 2012), White and Noble (2013) and Joung et al. (2013), we propose the following criteria for selecting SA indicators, which, taken together, determine the usability of the SA system:

- Relevance − an indicator should be directly related to an aspect of sustainability that is meaningful and purposeful for the firm concerned.

- Accessibility − information on an indicator should be easy to identify, i.e. within a reasonable time frame.
- Measurability − it should be simple to measure an indicator qualitatively or, preferably, quantitatively.
- Reliability − an indicator should be trustworthy.
- Understandability − it should be easy for stakeholders to interpret an indicator.

Furthermore, the total set of indicators should be comprehensive yet parsimonious. That is, the set of SA indicators should be focused, yet support the evaluation of all *key* economic, social and environmental aspects.

Finally, the system should not only be usable but also useful and help firms assess their sustainability performance, identify "hot spots" (Azapagic, 2004, p. 651), guide them to formulate a sustainable development strategy and, thus, support their sustainable development.

In Section 6 we will evaluate the SA indicator developed in this paper against these criteria.

3.2. The economic sub-indicator system

The economic sub-indicator system contains mostly financial indicators, which are related to cost, revenue and, thus, profit − the basis for continued development of the firm. In selecting financial

Table 2
The dimensions covered by six major SA systems.

Dimensions	SA indicators					
	LCSP	Ford PSI	ISO14031-EPE	GRI	IChemE	DJSI
Economic		√	√	√	√	√
Environmental	√	√	√	√	√	√
Social (including health & safety)	√	√	√	√	√	√

indicators, we mainly relied on the Chinese Ministry of Finance's Enterprise performance evaluation operating rules (which is generally accepted by Chinese firms and used in financial evaluation). In addition, other Chinese and Asian based literature (Fan and Bai, 2010; Iwata and Okada, 2011; Liu, 2010, 2011; MoF, 2002; Yang, 2011) was examined. Seven indicators of economic performance emerged, which can be grouped into four categories:

- *Corporate profitability*:
  - Return on equity rate = net profit/net assets.
  - Return on total assets = net profit/average total assets.
- *Corporate capital turnover*:
  - Total assets turnover rate = net revenue/average total assets.
  - Current assets turnover rate = net revenue/average current assets.
- *Corporate debt-paying ability*:
  - Debt to assets ratio = total liabilities/total assets.
  - Quick ratio (acid test) = quick assets/current liabilities = (current assets-inventory)/current liabilities.
- *Corporate development ability*:
  - Operating revenue growth rate = (operating revenue this year − operating revenue last year)/operating revenue last year.

Each of the economic indicators is operationalized as a dimensionless ratio of financial indicators. Furthermore, they are all derived from traditional financial indicators, and therefore not discussed in detail in this paper.

3.3. The social sub-indicator system

Social sustainability concerns the consideration of the human and social performance of a firm. Research of social sustainability is relatively weak compared to the other two (economic and environmental) sustainability aspects. Following Székely and Knirsch (2005) and Xiao (2010), we propose to operationalize social sustainability evaluation using the following relativized criteria:

- *Social contribution rate*, the ability of a firm to use its assets to create or pay value to society, including social welfare spending and other expenditure to society, can be calculated as: social contribution rate = total social contribution/total assets.
- Reflecting the tax a firm creates off its assets, *property tax rate* = taxes paid/total assets. It demonstrates the corporate contribution to the national government.
- *Per capita employee income growth rate* = (per capita employee income this year − per capita employee income last year)/per capita employee income last year.
- The *employee injury rate* reflects corporate safety and security. The primary sector, including the iron and steel, oil, gas and coal industries, faces a higher likelihood of production accidents than companies in the other economic sectors. Injury rate is therefore an important indicator of the social performance of the Chinese IS industry and can be measured as the number of injured employees per year per thousand employees.

All social sub-indicators are also dimensionless ratios.

3.4. The environmental sub-indicator system

The indicators of the environmental sub-system should reflect three aspects, namely investment in pollution control and environmental protection, energy consumption, and waste emissions. There is much literature concerning environmental sustainability indicators. Considering the nature of the Chinese IS industry and based on relevant publications (Olsthoorn et al., 2001; Székely and Knirsch, 2005; Singh et al., 2007; Comoglio and Botta, 2012; Ma et al., 2014; Moldan et al., 2012), the following environmental sub-indicators, all relativized, are proposed:

- *Investment in pollution control* reflects the degree of corporate effort to control aspects such as water, air, light and sound pollution (Olsthoorn et al., 2001). *Investment in environmental protection* reflects the responsibility for protecting and improving the environment in which the firm operates. These two practices represent not only the environmental responsibility a firm must take, but also create a good external environment for enterprise development. The relative investment in pollution control and environmental protection = the investment in pollution control and environmental protection/total operating revenue.
- *COD (chemical oxygen demand) emission*. The COD test is commonly used to measure the amount of organic compounds in wastewater. It is a useful measure of water quality (Comoglio and Botta, 2012). A higher COD level means that there are more organic compounds in the water, i.e. water pollution is more serious. The COD emission per unit of production = the quantity of COD emission/total quantity of production output. It is expressed in kg per ton (kg/t).
- SO_2 *emission*. The majority of iron and steel production requires burning coal, oil and/or gas, which often contain sulfur compounds and therefore generates sulfur dioxide (SO_2). In 2001, the Chinese State Environmental Protection Administration (SEPA) and the Chinese State Administration for Quality Supervision and Inspection and Quarantine (AQSIQ) jointly published the emission standard of air pollutants for coal-burning, oil-burning and gas-fired boilers (Ma et al., 2014; Moldan et al., 2012). Regarded as the most important indicator of the level of waste gas control by Chinese IS firms, the SO_2 emission rate per unit of production = the quantity of SO_2 emission/total quantity of production output. It is expressed in kg per ton (kg/t).

Whereas these three indicators are measures of pollution and pollution prevention, the next three indicators measure the consumption of natural resources. There are a number of production routes through which iron and steel can be manufactured. Therefore, in order to accurately determine the energy and water consumption associated with IS production, IS production system boundaries needs to be clearly defined. In this study, the IS production system is considered to include coke making, pelletizing, sintering, iron making, steel making, steel casting, hot and cold rolling, and processing such as galvanizing or coating.

- *Energy consumption*. As coal is the main energy resource they use, IS firms always convert the total energy consumption into standard coal consumption. The energy consumption rate per unit of production = the quantity of the total energy consumption (converted into standard coal)/total quantity of production output. It is expressed in kgce per ton (kgce/t) ("ce" stands for "coal equivalent").
- *Water consumption*. This indicator shows the level of water consumed for production purposes. Water is one of the most important and cherished resources in the world, and the manufacturing of iron and steel requires vast volumes of water (Jasch, 2000b). The water consumption per unit of production = the quantity of water consumption/total quantity of production output. It is expressed in cubic meters per ton (m^3/t).
- *Utilization of solid waste*. The IS industry produces a lot of solid waste residue, such as spoil, tailings, and blast furnace and steel

slag, which can be used and/or recycled for other purposes (Singh et al., 2007; Székely and Knirsch, 2005). The utilization rate of wasted resources = the quantity of utilization of wasted resources/the quantity of production output of wasted resources.

In contrast to the economic and social indicators, most environmental sub-indicators are *not* dimensionless ratios. The exceptions are investment in pollution control and environmental protection, and utilization of solid waste.

3.5. Summary: SA indicators for the Chinese IS industry

Table 3 summarizes the SA indicators proposed above.

4. Development and industrial evaluation of the SA system

A firm's overall sustainability performance using the indicators developed above can be calculated with the following equation:

$$S = \sum_{i=1}^{j} X_i' w_i \qquad (1)$$

S represents the firm's overall sustainability performance, X_i' is the dimensionless (see below) performance indicator, and w_i is the weight of the indicator, calculated based on expert opinions (see below) and using the analytic hierarchy process (AHP) technique.

Fig. 2. The process of industrial evaluation of the SA system.

Step 1
• Survey providing input for weight calculations based on AHP

Step 2
• Collection and non-dimensionalization of empirical data from four Chinese IS companies' financial and sustainability reports

Step 3
• Calculation of the overall sustainability performance of the four Chinese IS companies, using equation (1)

The SA system was developed and evaluated in three steps, visualized in Fig. 2.

4.1. Step 1: survey for weight calculations based on AHP

In order to calculate the weights for the indicators included in the SA system, we conducted a survey using the following process:

(1) Constructing the SA indicators hierarchy model shown in Table 3.
(2) Collecting data from experts through a questionnaire (see Appendix A for details), using five-point Likert scales, for AHP weight calculation of the SA indicators. The target group

Table 3
An SA system for the Chinese IS industry.

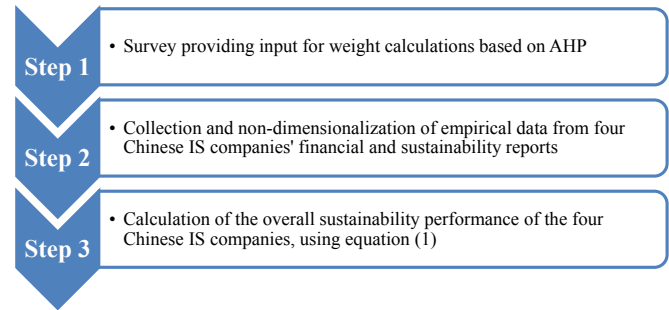| Level 1	Level 2	Level 3	Main references
SA system	Economic sub-indicator system	Return on equity = net profit/net assets Return on assets = net profit/average total assets Total assets turnover rate = net revenues/average total assets Current assets turnover rate = net revenues/average current assets Debt to assets ratio = total liabilities/total assets Quick ratio (acid test) = quick assets/current liabilities = (current assets-inventory)/current liabilities Operating revenue growth rate = (operating revenue this year − operating revenue last year)/operating revenue last year	(Iwata and Okada, 2011; MoF, 2002)
	Social sub-indicator system	Social contribution rate = total social contribution/total assets Property tax rate = taxes paid/total assets Per capita employee income growth rate = (per capita employee income this year − per capita employee income last year)/per capita employee income last year Employee injury rate = number of injured employees per year per thousand employees	(Székely and Knirsch, 2005; Xiao, 2010)
	Environmental sub-indicator system	Investment in pollution control and environmental protection = the investment in pollution control and environmental protection/total operating revenue COD emission = the quantity of COD emission/total quantity of production output SO_2 emission = the quantity of SO_2 emission/total quantity of production output Energy consumption = the quantity of the total energy consumption (converted into standard coal)/total quantity of production output Water consumption = the quantity of water consumption/total quantity of production output Utilization of solid waste = the quantity of utilization of wasted resources/the quantity of production / output of wasted resources	(Comoglio and Botta, 2012; Olsthoorn et al., 2001); (Moldan et al., 2012); (Jasch, 2000a); (Singh et al., 2007)

Table 4
AHP ranking of SA indicators.

Level 1	Level 2	Weight	Level 3	Global weight	Ranking
Integrated SA system	Economic sub-indicator system	0.480	Return on equity	0.116	1
			Return on assets	0.081	3
			Total assets turnover rate	0.078	5
			Current assets turnover rate	0.044	13
			Debt to assets ratio	0.071	6
			Quick ratio	0.025	15
			Operating revenue growth rate	0.067	7
	Social sub-indicator system	0.192	Social contribution rate	0.064	9
			Property tax rate	0.078	4
			Per capita employee income growth rate	0.036	14
			Employee injury rate	0.014	17
	Environmental sub-indicator system	0.328	Investment in pollution control and environmental protection	0.083	2
			COD emission	0.056	10
			SO_2 emission	0.055	11
			Energy consumption	0.064	8
			Water consumption	0.051	12
			Utilization of solid waste	0.018	16

Table 5
The empirical data of 2012.

Indicator	Baosteel	WISCO	TISCO	HBIS
Return on equity (dimensionless ratio)	0.095	0.006	0.047	0.003
Return on assets (dimensionless ratio)	0.047	0.000	0.018	0.009
Total assets turnover rate (dimensionless ratio)	0.860	0.940	1.162	0.755
Current assets turnover rate (dimensionless ratio)	2.572	3.619	3.391	2.191
Debt to assets ratio (dimensionless ratio)	0.453	0.628	0.627	0.712
Quick ratio (dimensionless ratio)	0.494	0.253	0.409	0.355
Operating revenue growth rate (dimensionless ratio)	−0.141	−0.093	−0.063	−0.162
Social contribution rate (dimensionless ratio)	0.000	0.000	0.000	0.001
Property tax rate (dimensionless ratio)	0.021	0.020	0.020	0.013
Per capita employee income growth rate (dimensionless ratio)	−0.058	−0.004	0.035	−0.061
Employee injury rate (dimensionless ratio)	0.360	0.164	0.078	0.038
Investment in pollution control and environmental protection (dimensionless ratio)	0.008	0.001	0.011	0.009
COD emission (kg/t)	0.047	0.110	0.027	0.042
SO_2 emission (kg/t)	0.645	1.430	0.500	1.340
Energy consumption (kgce/t)	607.31	623.00	542.00	579.04
Water consumption (m^3/t)	3.780	4.050	1.460	3.170
Utilization of solid waste (dimensionless ratio)	0.925	0.973	0.949	0.977

of experts included top management, senior financial and technical representatives, all from the iron and steel, chemical and other processing industries, as well as academic experts. The total number of questionnaires distributed was 153; 70 experts responded. Due to missing entries and other problems, 18 responses had to be discarded leading to a final sample of 52 responses. Among these 52 responses, there were 23 experts from industry: 13 general managers, 6 financial managers and 4 technical managers. The rest of the 29 respondents represented academia: 14 economists and management scientists, 10 engineering scientists and 5 social scientists.

(3) Calculating the weights of the SA indicators using the AHP procedure described by Ghodsypour and O'Brien (1998) and Hafeeza et al. (2002).

After the AHP weight calculation, we progressed towards the ranking of SA indicators described in Table 4.

Table 4 shows that return on equity, return on assets and total assets turnover rate are ranked 1st, 3rd and 5th among the 17 SA indicators. These three indicators represent corporate profitability and capital turnover ability. Interestingly, though, investment in pollution control and environmental protection is ranked 2nd, while energy consumption is ranked 8th. This demonstrates that, although the first concern is still with financial indicators, the environment and energy are also considered relatively important.

Except for property tax rate, the highest ranked social indicator, social issues rank relatively low.

4.2. Step 2: non-dimensionalization of actual sustainable performance data from Chinese IS firms

In step 2, performance data from four Chinese IS firms were collected. The firms are Baosteel Corporation (Baosteel), Wuhan Iron and Steel Corporation (WISCO), Taiyuan Iron and Steel Corporation (TISCO), and Hebei Iron and Steel Corporation (HBIS). HBIS, Baosteel and WISCO rank 3rd, 4th and 6th of the World Steel Association (WSA) member firms in 2012 (WSA, 2013). TISCO is the world's largest stainless steel producer. The social and environmental sub-indicators were collected from these firms' 2011 and 2012 sustainability reports (Baosteel, 2011b; Baosteel, 2012b; WISCO, 2011b; WISCO, 2012b; TISCO, 2011b; TISCO, 2012b, HBIS, 2011b; HBIS, 2012b), the economic sub-indicators from the 2011 and 2012 financial reports (Baosteel, 2011a; Baosteel, 2012a; WISCO, 2011a; WISCO, 2012a; TISCO, 2011a; TISCO, 2012a, HBIS, 2011a; HBIS, 2012a). See Table 5 for an example.[1]

Before calculating overall sustainability performance, all the indicators need to be non-dimensionalized in order to remove the impact of different units or different orders of magnitude on the

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[1] The 2011 data are available upon request from the authors.

whole SA system. For example, the indicator return on equity rate is a dimensionless ratio, while the indicators COD emission or water consumption are ratios with (essentially different) dimensions, kg/t and m³/t, respectively.

Furthermore, the SA system includes positive type indicators − "more is better" (e.g. return on equity), and negative type indicators − "less is better" (e.g. COD emission). Equations (2) and (3) (Krajnc and Glavič, 2005) serve to non-dimensionalize the indicators.

Positive type indicators:

$$X_i' = \frac{x_i - m_i}{M_i - m_i} = \begin{cases} 1, & x_i = M_i \\ \frac{x_i - m_i}{M_i - m_i}, & m_i < x_i < M_i \\ 0, & x_i = m_i \end{cases} \quad (2)$$

Negative type indicators:

$$X_i' = \frac{M_i - x_i}{M_i - m_i} = \begin{cases} 1, & x_i = m_i \\ \frac{M_i - x_i}{M_i - m_i}, & m_i < x_i < M_i \\ 0, & x_i = M_i \end{cases} \quad (3)$$

Terminology:

X_i' The dimensionless value of an indicator
M_i Indicator with the highest value in a set that needs to be non-dimensionalized
m_i Indicator with the lowest value in a set that needs to be non-dimensionalized
x_i Any other indicator in a set that needs to be non-dimensionalized

We use the positive type indicator "return on equity rate (ROE)" and the negative type indicator "COD emission (COD)" in 2012 as examples to explain the non-dimensionalization process:

(1) The ROE values of the four firms in 2012 are (see Table 5):

x_{ROE} = [0.095, 0.006, 0.047, 0.003]; M_i = 0.095; m_i = 0.003.
$X_{0.003}'$ = 0; $X_{0.095}'$ = 1

$$X_{0.047}' = \frac{0.047 - 0.003}{0.095 - 0.003} = 0.478; X_{0.006}' = \frac{0.006 - 0.003}{0.095 - 0.003} = 0.033$$

(2) The COD values of the four firms in 2012 are:

x_{COD} = [0.047, 0.110, 0.027, 0.042]; M_i = 0.110; m_i = 0.027.
$X_{0.110}'$ = 0; $X_{0.027}'$ = 1

$$X_{0.047}' = \frac{0.110 - 0.047}{0.110 - 0.027} = 0.759; X_{0.042}' = \frac{0.110 - 0.042}{0.110 - 0.027} = 0.819$$

Thus, using equations (2) and (3), the dimensionless indicators of the four firms for the year 2012 are (Table 6):

4.3. Step 3: overall SA calculation

After having non-dimensionalized the SA indicators, we used equation (1) to calculate the firms' sustainability performance. The results for 2011 and 2012 are shown in Table 7. The next example, based on Baosteel 2012 data, shows how these performances were calculated:

(1) Economic performance = Σ(the global weights of economic sub-indicators*dimensionless indicators of 2012) = (0.116*1 + 0.081*1 + 0.078*0.258 + 0.044*0.267 + 0.071*1 + 0.025*1 + 0.067*0.212) = 0.339

(2) Social performance = Σ(the global weights of social sub-indicators * dimensionless indicators of 2012) = (0.064*0.220 + 0.078*1 + 0.036*0.031 + 0.014*0) = 0.093

(3) Environmental performance = Σ(the global weights of environmental sub-indicators*dimensionless indicators of 2012) = (0.083*0 + 0.056*0.759 + 0.055*0.844 + 0.064*0.806 + 0.051*0.896 + 0.018*0) = 0.186

(4) Overall comprehensive sustainability performance = economic performance + social performance + environmental performance = 0.339 + 0.093 + 0.186 = 0.618

5. Sustainability performance evaluation of Chinese IS firms using the SA system

5.1. Economic performance

The economic performance values for the years 2011 and 2012 are shown in Fig. 3.

The IS industry is the foundation of industrial growth of several countries, in particular China, and it is vulnerable to macroeconomic fluctuations. In 2011 and 2012, the impact of the global economic crisis was still felt. Demand for and prices of steel had decreased sharply in international and domestic market, fuel prices continued to go up and down, and IS enterprises encountered low economic performance. The year 2012 has been called the most difficult year for the IS industry in the new century.

The values of the economic sub-indicators for 2011 and 2012 in Fig. 3 show that Baosteel is the leading Chinese ISI enterprise, relying on advantages such as cost control, equilibrium production and sales (Baosteel, 2012a,b). In 2012, WISCO improved its economic performance compared to HBIS through cost control and improving its production capability. Overall, in 2012 the economic performance of TISCO and HBIS deteriorated. One of the reasons for the dramatic economic drop of HBIS is mainly attributed to the return on equity decrease from 3.7% (2011) to 0.26% (2012) (HBIS, 2012a,b). In TISCO's case the economic decline is minor due to its strong position in stainless steel (TISCO, 2012a,b).

5.2. Social performance

Fig. 4 shows the four companies' social performance values, and demonstrates that their ranking changed from 2011 to 2012. In 2011, Baosteel's social responsibility performance was highest, HBIS′ performance lowest. In 2012, TISCO performed best and WISCO worst.

TISCO has paid more attention to the social responsibility and kept on reinforcing social responsibility, including establishing a good social responsibilies management system, and integrating social responsibility concepts into its enterprise development strategy and business and operation management processes (TISCO, 2012a,b).

HBIS's social responsibility performance improved even though its economic performance is poor (Fig. 3). This is mainly due to the company's huge financial donation to sudden flooding causing natural disasters in Lai Yuan county, Hebei province (HBIS, 2012a,b).

In 2012, Baosteel's social performance is still better than HBIS′ performance, even though its ranking decreased. Baosteel leads in factors such as tax paying and safety in production (absolute value) (Baosteel, 2012a,b), but compared to its economic power, the

Table 6
Dimensionless indicators of 2012.

Indicator	Baosteel	WISCO	TISCO	HBIS
Return on equity (positive type)	1	0.033	0.478	0
Return on assets (positive type)	1	0	0.378	0.185
Total assets turnover rate (positive type)	0.258	0.455	1	0
Current assets turnover rate (positive type)	0.267	1	0.840	0
Debt to assets ratio (negative type)	1	0.324	0.328	0
Quick ratio (positive type)	1	0	0.647	0.423
Operating revenue growth rate (positive type)	0.212	0.697	1	0
Social contribution rate (positive type)	0.220	0.075	0	1
Property tax rate (positive type)	1	0.020	0.909	0
Per capita employee income rate (positive type)	0.031	0.595	1	0
Employee injury rate (negative type)	0	0.609	0.876	1
Investment in pollution control and environmental protection (positive type)	0	0.574	1	0.443
COD emission (negative type)	0.759	0	1	0.824
SO_2 emission (negative type)	0.844	0	1	0.097
Energy consumption (negative type)	0.806	0	1	0.543
Water consumption (negative type)	0.896	0	1	0.340
Utilization of solid waste (positive type)	0	0.731	0.375	1

Table 7
The overall performance of the four firms in 2011 and 2012.

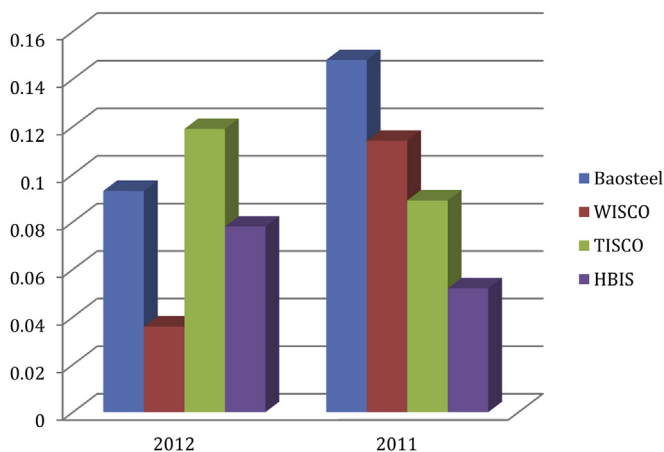| Firms	Baosteel		WISCO		TISCO		HBIS	
Year	2012	2011	2012	2011	2012	2011	2012	2011
Item								
Economic performance	0.339	0.302	0.153	0.083	0.307	0.334	0.025	0.098
Social performance	0.093	0.148	0.036	0.114	0.119	0.089	0.078	0.052
Environmental performance	0.186	0.182	0.060	0.099	0.317	0.296	0.158	0.167
Sustainability performance	0.618	0.632	0.249	0.296	0.743	0.719	0.261	0.317
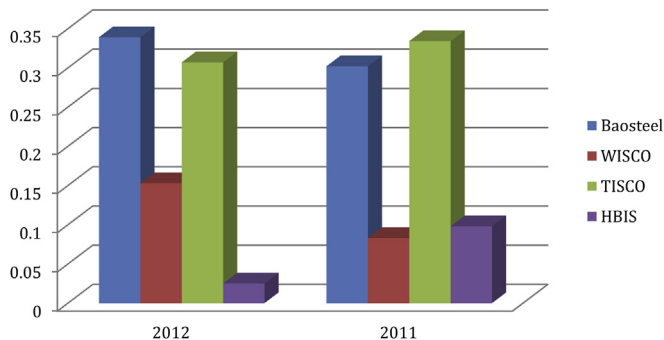
Fig. 3. The four firms' economic performance in 2011 and 2012

company will need to strengthen its participation in social activities.

Except for employee injury rate, all WISCO's social responsibility indicators decreased from 2011 to 2012. Especially the per capita employee income growth rate decreased seriously (from 0.265 to −0.004). In effect, WISCO's social responsibility performance dropped dramatically from 2011 to 2012 (WISCO, 2012a,b).

5.3. Environmental performance

The environmental performance values in 2011 and 2012 are shown in Fig. 5.

Fig. 5 shows that the environmental performance ranking of the four Chinese IS companies' remained unchanged from 2011 to 2012.
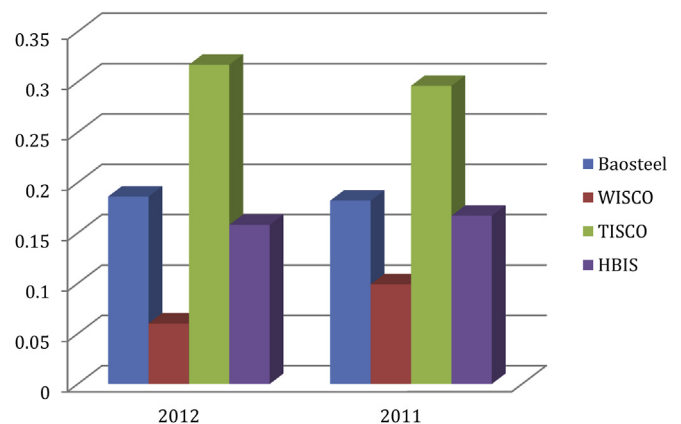

Fig. 4. The four firms' social performance in 2011 and 2012

Fig. 5. The four firms' environmental performance in 2011 and 2012

In both 2011 and 2012, TISCO had the highest environmental performance of the four companies considered here, which reflects the company's efforts to implement green-technological innovations that support energy saving and high efficient manufacturing. TISCO has successfully reduced waste of water, gas and residue. In 2012, TISCO was the leading firm in terms of investments in environmental protection and pollution control, had the lowest COD and SO_2 emission rates, and the lowest energy and water consumption rates of the four firms.

Baosteel ranked second. In 2012, this firm completed a number of important energy renovation projects and explored and used clean production, green manufacturing and new energy technologies in the manufacturing process. Its investments in environmental protection and pollution control ranked second, and the other indicators also have relatively high values (Baosteel, 2012a,b).

HBIS is relatively good in all the environmental indicators and the total environmental performance value is close to that of Baosteel. The sustainability report suggests that HBIS has put considerable effort into energy conservation, emission reduction and reforming plant surroundings.

WISCO ranked last in both years and its environmental performance needs serious attention. Table 6 shows that WISCO's environmental indicator ranked lowest on four of the six environmental performance indicators. That situation was the same in 2011 (WISCO, 2011a,b).

5.4. Overall sustainability performance

The four firms' sustainability performance, which consolidates economic, social and environmental performance in one value, for the 2011–2012 period is shown in Fig. 6.

According to Fig. 6, the overall sustainability ranking of the four Chinese IS companies remains unchanged from 2011 to 2012. TISCO had the best sustainability performance of the four firms, followed by Baosteel. TISCO had a strong competitive position in stainless steel, paid more attention to social responsibility, invested more in environmental technology and management areas, but only achieved a slight increase in overall performance due to the decline in economic performance from 2011 to 2012.

Baosteel performed well economically and did not do badly in environmental performance either. The small drop in overall performance is entirely due to a deterioration of social performance.

WISCO and HBIS had similar levels of sustainability performance both in 2011 and 2012, and both companies' performance deteriorated in that period. HBIS' low sustainability performance can largely be attributed to a severe drop in economic performance while also its environmental performance decreased

slightly from 2011 to 2012. Worldwide, the IS industry faces severe market conditions and HBIS needs to keep cutting cost, improve efficiency and innovation ability to enhance its sustainability performance.

WISCO's economic performance improved a bit from 2011 to 2012. Its main problem was relatively weak and decreasing performance in social responsibility and environmental aspects. WISCO's future development direction requires taking social responsibility more seriously and doing more for environment protection, energy conservation and emission reduction.

6. Evaluation

In order to select among many possible sub-indicators for the proposed SA, the following criteria were adopted (Hughes, 2002; Niemeijer and de Groot, 2008; Fan and Bai, 2010; Liu, 2010; Singh et al., 2007, 2012; White and Noble, 2013; Joung et al., 2013):

- Relevance – All the data are related to one of the three "triple bottom line" areas, and either generally used by Chinese firms (e.g. the financial sub-indicators, following the Chinese Ministry of Finance's Enterprise performance evaluation operating rules), relatively important for the IS industry (e.g. employee injury rate), process industry specific (e.g. COD and SO_2 emissions) or IS industry specific (e.g. energy and water consumption).
- Accessibility and measurability – All the raw data used are quantifiable and, based on the four companies' financial and sustainability reports, publicly available and, thus, easy to collect.
- Reliability – Most criteria are objective and, considering that they are published in official company reports, they should also be reliable.
- Understandability – All the data are easy to interpret by stakeholders.

In this paper 17 sub-indicators were identified for the proposed SA system. We cannot be sure about the comprehensiveness and parsimony of the set of indicators. Some SA systems contain fewer indicators (e.g. Ford Product Sustainability Index), some systems include many more indicators (e.g. Global Report Initiative (GRI). Further research is needed to shed light on this important aspect. Likely candidates for inclusion in a future version of the SA system are indicators of particle and NO_x emissions, well-known forms of emission from iron and steel production (e.g. Dragović et al., 2014) but not currently reported by all Chinese IS companies and, therefore, excluded from the present study.

The application of the SA system using data from four companies suggests that the system should not only be usable for researchers but for companies as well. We did not evaluate the usefulness of the study. Further field research in close collaboration with the four IS firms involved in this study and ideally other IS firms as well is needed for this purpose.

7. Conclusion

7.1. Contribution

The purpose of the SA system proposed, illustrated and evaluated in this paper is to convert the abstract concept of sustainability into simplified and quantified expressions of economic, social, environmental and overall sustainability performance, which provides clear and effective decision-support information to the management, investors and other stakeholders. Currently, no SA system exists, which is specifically targeted at the Chinese IS industry. The SA system proposed in this paper aims to help Chinese
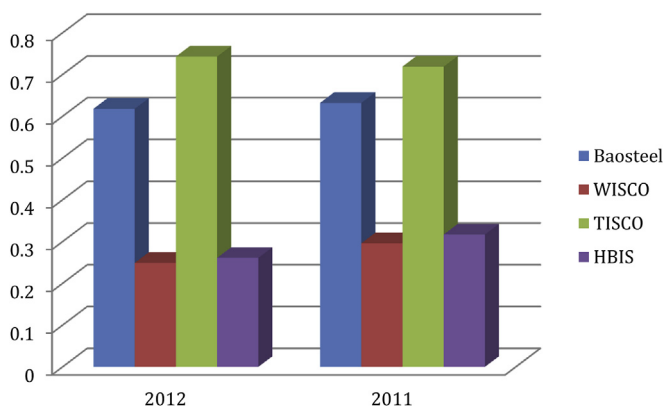
Fig. 6. The four firms' overall sustainability performance in 2011 and 2012

IS firms assess their sustainability performance, identify "hot spots" (Azapagic, 2004, p. 651), guide them to formulate a sustainable development strategy and, thus, support their sustainable development. The system is based on the "triple-bottom line", developed by Elkington (1994), which is the most widely recognized and adopted sustainability concept.

The SA system proposed meets the key criteria for the selection of indicators. Its structure is close to that of the GRI system, which is generally recognized as the most widely used sustainability reporting tool. In order to meet the parsimony requirement and enhance its practical usability and understandability, we only included 17 indicators, which is relatively low compared to the more than 70 in the GRI system. Furthermore, the environmental indicators are relatively specific for the iron and steel industry.

Although further research is needed to validate and generalize the system (see below), it is expected that it can also be used as a benchmarking tool for other Chinese and foreign IS firms for cross-sectional and longitudinal comparison. Additionally, the system should also be easily adaptable to other process industries, especially the coal, gas, petrol and chemical processing industries.

7.2. Limitations and further research

We used public reports from four companies for the years 2011 and 2012, which may present two limitations. First, in the aftermath of the global economic crisis, all industries worldwide were still recovering from the crisis and the Chinese IS industry was no exception. Second, a period of two years is too short to identify a valid sustainability trend for the four companies, let alone the Chinese IS industry as a whole. We cannot know, based on the data available, if the changes in economic, environmental, social and overall sustainability performance are indicative of a longer-term trend. Longitudinal field research, possibly combined with other assessment methods, such as the Balance Scored Card (Kaplan and Norton, 1992) or Data Envelopment Analysis (Charnes et al., 1978), should be used to generalize the study to a longer time horizon for the Chinese as well as international IS industry. Such a study will also provide further insight in the perceived usefulness of the SA system proposed in this paper.

Finally, further research is needed to test the comprehensiveness and parsimony of the set of indicators included in the system. Indicators of particle and NO_x emissions are among the likely candidates for inclusion in a future version of the SA system.

Acknowledgments

Appendix A. Questionnaire

Section A. The basic characteristics of the firm

1. The name of the firm
2. In what year was the firm established
3. The size of the business unit (employees in 2012)
4. The sales volume of the firm
5. The total assets of the firm
6. What is your job title?
7. How long have you been working in this firm?
8. Your email address
9. Your phone number

Section B. The importance of sustainable development of Chinese iron and steel firms

1. Economic sub-indicator system:

The economic sub-indicator system refers to financial indicators. In the selection of financial indicators, this survey enquires about four traditional financial aspects to evaluate the economic performance of a firm: corporate profitability, capital turnover ability, debt-paying ability, and development ability. These four aspects are divided into seven financial indicators as follow: (1) return on equity; (2) return on assets; (3) total assets turnover rate; (4) current assets turnover rate; (5) debt to assets ratio; (6) quick ratio; (7) operating revenue growth rate.

How important are these seven indicators for you on the scale 5-Very important; 4-important; 3-Indifferent; 2-Less important; 1-Not important?

1. Return on equity
2. Return on assets
3. Total assets turnover rate
4. Current assets turnover rate
5. Debt to assets ratio
6. Quick ratio
7. Operating revenue growth rate

2. Social sub-indicator system:

Social responsibility requires the firm to go beyond the traditional idea that profit is the only goal to pursue, and emphasizes the consideration of people and the social contribution of the firm. The scope of social responsibility is wide. In this survey, four aspects are considered: society, nation, employee and security. These four aspects could be divided into four indicators as follow: (1) social contribution rate; (2) property tax rate; (3) per capita employee income growth rate; (4) employee injury rate.

How important are these four indicators for you on the scale 5-Very important; 4-important; 3-Indifferent; 2-Less important; 1-Not important?

1. Social contribution rate
2. Property tax rate
3. Per capita employee income growth rate
4. Employee injury rate

3. Environmental sub-indicator system:

The indicators included in the environmental sub-system cover pollution control, environmental protection, energy consumption, "three wastes" emissions (water, gas, residue) and energy and water consumption. After consideration of the characteristics of the IS industry and the data from the sustainability reports of Chinese firms, this survey has selected six indicators: (1) investment in pollution control and environmental protection; (2) COD emission; (3) SO_2 emission; (4) energy consumption; (5) water consumption; (6) utilization of solid waste.

How important are these six indicators for you on the scale 5-Very important; 4-important; 3-Indifferent; 2-Less important; 1-Not important?

1. Investment in pollution control and environmental protection
2. COD emission
3. SO_2 emission
4. Energy consumption
5. Water consumption
6. Utilization of solid waste

4. The general (aspect) indicator system:

When comprehensively considering the general performance of sustainable development and operation of IS firms, how important are the following systems for you on the scale 5-Very important; 4-important; 3-Indifferent; 2-Less important; 1-Not important?

1. Economic sub-indicator system
2. Social sub-indicator system
3. Environmental sub-indicator system

5. Additional aspects:

Which other factors for sustainability assessment of the Chinese iron and steel industry do you find important (open question)?

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