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SPECIAL FEATURE: ORIGINAL ARTICLE

Sustainability Science and Implementing the Sustainable Development Goals

A methodological approach for the design of sustainability initiatives: in pursuit of sustainable transition in China

Nasrin R. Khalili[1] · **Weiquan Cheng**[2] · **Abagail McWilliams**[3]

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Abstract The foundation of sustainability science is the effort to understand the fundamental interactions between nature and society, and to guide these interactions along sustainable trajectories (Miller et al. Sustain Sci 9(2):240–246, 2014). More importantly, sustainability science aims at creating knowledge needed to improve relevancy and quality of sustainability decision-making processes through broader representation of knowledge and values. This study contributes to the sustainability science literature in the areas of strategic planning and decision-making. Both the values and the role of decision-making science in promoting sustainability are examined through the design of a strategic framework and application of a graphical multi-agent decision-making model (GMADM). This approach allows for analysis, valuation, and ranking of potential sustainability initiatives according to their projected benefits and gains for organizations and for society. The model is structured on three interrelated pillars: (I) stakeholder views and concerns (government, industry, academic institutions); (II) sustainable development trends and requirements (World Bank data); and (III) valuations of the benefits expected from sustainability efforts. The framework is applied to case studies of Shandong and Guangdong provinces in China. Qualitative and quantitative analysis of data obtained from three groups of stakeholders in each province confirmed the utility of the proposed decision-making approach for promoting sustainable transition in China. Results also demonstrated the convenience and effectiveness of the proposed framework for guiding organizations' efforts toward optimizing their sustainability initiatives while supporting regional economic growth and sustainable development policies.

Keywords Decision-making science · Graphical multi-agent decision-making model · Social responsibility · Stakeholders · Sustainability science

Handled by Shunsuke Managi,Tohoku University, Japan.

✉ Nasrin R. Khalili
khalili@iit.edu

Weiquan Cheng
wcheng15@hawk.iit.edu

Abagail McWilliams
abby@uic.edu

[1] Environmental Management and Sustainability Program, Stuart School of Business, Illinois Institute of Technology, 565 W. Adams Street, Chicago, IL 60661, USA

[2] Stuart School of Business, Illinois Institute of Technology, 565 W. Adams Street, Chicago, IL 60661, USA

[3] College of Business Administration, University of Illinois at Chicago, 601 South Morgan Street, Chicago, IL 60607, USA

Introduction

In an effort to contribute to the science-of-sustainability literature in the realms of solution formulation and adaptation, this study (a) develops a decision-making framework that incorporates the values and expectations of multiple stakeholders and (b) tests the framework through a case study in China. While accounting for interactions of global, social, and human systems, this study emphasizes the importance of including shared visions and values of multiple stakeholders in the decision-making phases of sustainability planning.

Since its conception, the sustainability paradigm has attempted to provide fundamental human needs while maintaining global life-support systems. Sustainability transition studies were aimed at understanding how transitions could evolve over time, while generating explicit policies, guidelines, and frameworks to support progressing transitions. In the last quarter-century, research programs in biological, geophysical, social, and technological domains have fostered development of sustainability science under the umbrella of global change science. Many studies suggested that sustainability should be considered as a regional, place-based, and integrated phenomenon that requires understanding of uncertainties associated with globalization of the economies, governance of resources, knowledge of regional trajectories, and emerging criticality through a common journey (Kate 2000).

Among the dominant approaches used to study sustainability transitions are multi-level perspectives that consider inclusion of different stakeholder groups (de Gooyert et al. 2016). Transition to sustainability more specifically requires complex transformations involving key subsystems within economic, technological, political, environmental, and social systems (Lachman 2013) that are connected locally, regionally, and globally.

The complexity of sustainability issues, including the necessity for transition, has directed efforts toward developing the knowledge required to understand types, specifications, dependency, and correlations among variables influencing sustainability decisions, including decision-making or guiding interactions along sustainable trajectories (Rives et al. 2012; Salter et al. 2010). Sustainability rules (i.e., the need for development and the use of environmental sustainability or inclusive wealth indices) have addressed theoretical concerns about depleting nonrenewable resources, which in turn suggested that the rate of depleting such resources should be maintained at a level equal to the development of renewable substitutes (Goodland 2005; Gasparatos and Scolobig 2012; de la Fuente et al. 2017; Siche et al. 2008; Srdjevic and Srdjevic 2017; Shuaib et al. 2014). Inspired by social welfare theory, the inclusive wealth index was proposed to predict stability and resilience of sustainability subsystems (Duraiappah and Muñoz 2012; Managi 2017; Thiry and Roman 2014; Walker et al. 2010).

The difficulty is how to integrate theory, applied science, and policy to make them globally relevant to development (Bettencourt and Kaur 2011). One approach would be to involve local authorities and national governments as champions of the desired changes (Lee et al. 2016). This study designed a framework to create champions at all stakeholder levels by involving local authorities, industry participants, and academicians in a process to support sustainable development. Such a framework (see Fig. 1) requires data for three interrelated pillars: (I) stakeholder views and perceptions of sustainability issues; (II) the requirements of sustainable development trends; and (III) valuations and ranking of the benefits expected from sustainability efforts, through application of graphical multi-agent decision-making modeling.

Using such a framework, this analysis shows how sustainability initiatives can be designed and prioritized according to local conditions and shared visions of multiple stakeholders. This study also demonstrates how transdisciplinary partnerships among stakeholders can be used to develop sustainability solutions within a local context. To be consistent with the goal of sustainability science, the researchers in this study developed a methodology that would apply a decision-making model for customization of sustainability initiatives based on stakeholder views and correlation among sustainability criteria and indicators within two provinces in China.

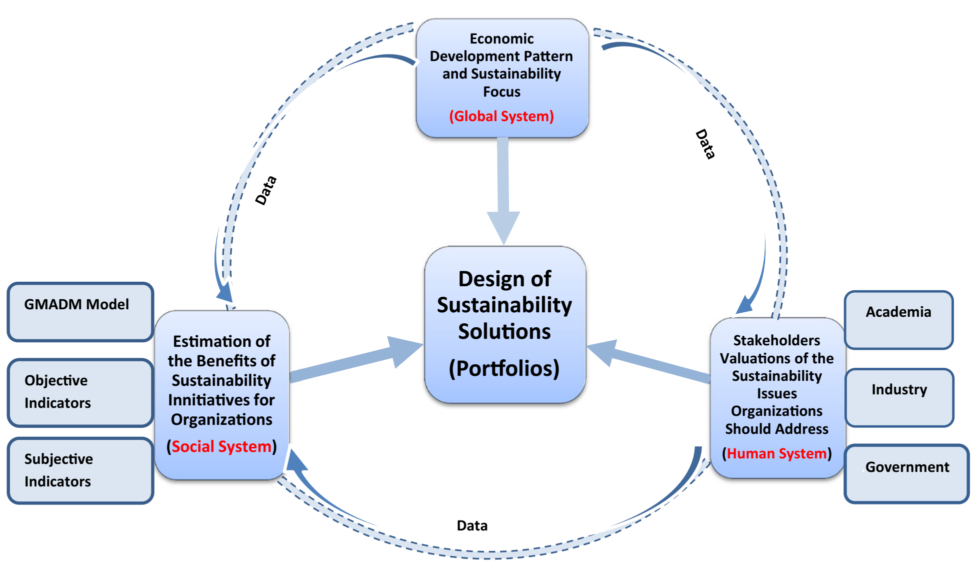


Fig. 1 The proposed framework for the design of sustainability portfolios

Combining diverse knowledge sets and values to develop sustainable solutions by involving stakeholders (including decision-makers and citizens) could result in building the capacity necessary for linking research and planning with sustainability outcomes (Bieluch et al. 2016). In that respect, development of practical sustainability solutions requires integration of stakeholders' views and perceptions, particularly among scientists/researchers, government officials, and industry practitioners (functioning elements of the social system). These three groups of stakeholders must be involved if sustainability objectives are to be responsive to all. This approach is what others have called transformational or transformative engagement. For example, industries that respond at this level of commitment not only embed sustainability into every aspect of their operations and tie it into their strategic objectives, but also give voice to stakeholders and communities with whom they partner (Gray and Stites 2013). Academia provides credibility along with scientific and technical support, and engages public participation. Recent studies concerned with developing sustainability indicators suggest that academia and regional public authorities could cooperate efficiently while involving multiple-stakeholders to obtain desired outcomes (Ramos 2009). Since sustainability problems are complex, it is crucial to integrate knowledge and information from various academic disciplines when possible. In this role, the university utilizes relations with industry and government to contribute to an innovation-driven regional or national economic growth strategy (Yarime et al. 2012). The proposed framework for the design of sustainability initiatives, accordingly, requires data for the three interrelated pillars (see Fig. 1).

Structure of the paper

The following sections detail literature on the importance of understanding complexity and interconnectivity of sustainability issues and the urgency to develop knowledge and specialization of the scholarship needed to address them. In an effort to contribute to the existing knowledge in the field, this study applies the proposed framework for sustainability initiatives in China with examples of how to identify and include the various inputs such as stakeholder opinion and economic context (elements of social systems) when developing a portfolio of sustainability initiatives; it also demonstrates the utility of customizing the design of sustainability initiatives according to regional global and social systems. This is achieved by appropriate statistical techniques detailing the differences in the inputs to the models, and then by showing how those differences result in sustainability portfolios that reflect the region for which they were developed.

Literature

As outlined in the Rio Declaration and Agenda 21, sustainable development has become the overarching goal of the international community, and a guide for development of national sustainability strategies. Despite slow initial responses, higher valued economic activities [activities that create values appropriated by stakeholders of the firm (Lieberman et al. 2016)] address sustainability and contribute to sustainable development. One of the main forces driving this has been legislation, which is increasingly tailored towards promoting sustainable development (Azapagic 2003). The other driving force is the evolution of the sustainability concept in the management literature, where organizational responsibility is linked to business strategy (Freeman 1984; Donaldson 1982; Burke and Logsdon 1996; McWilliams and Siegel 2001). This includes broadening the scope of institutional responsibility toward stakeholders (Jamali 2008), promoting partnerships among public and private actors across global value chains (Welford 1998; Lund-Thomsen and Nadvi 2010; Williams and Schaefer 2013), and taking on initiatives that are above and beyond compliance (Jamali and Mirshak 2007; Jamali et al. 2015).

Strategic planning for sustainability requires both value creation and customization. Value creation refers to how organizations, in general, and business firms, in particular, create economic value for themselves, for their members, and for society. Customization then refers to how organizations modify their product to meet different needs (Moran and Ghoshal 1996) while considering the local economic development concerns, societal concerns, resource constraints, policy requirements, and regulations (Schmidheiny 2006). Value can be also created by examining unrealistic sustainability initiatives that have little connection to the economic contexts within which social systems function (Clarkson 1995; Carbone et al. 2012; Frynas 2005; Sughra and Crowther 2015).

Research has addressed sustainability design problems that are primarily use-inspired, with significant fundamental and applied knowledge components, and with a commitment to transforming such knowledge into societal action (Paraschivescu et al. 2011; Stehr 1994; Thatchenkery et al. 2010; Walker and Becker 2016). Sustainability science as an interdisciplinary and innovative field promoted problem-driven research that could link knowledge to action (Miller 2013), with social learning as a prerequisite (Miller et al. 2014). In the process, some studies have also suggested the need to develop frameworks to help identify critical success factors for sustainability initiatives, while others focused on assisting with the adoption of models proven to be most relevant (Maon et al. 2009; Mazurkiewicz 2004). The literature clearly supports the importance of developing frameworks that assist with the design of sustainability initiatives according to stakeholders' views and valuations of the initiatives relevant to regional and global sustainability issues. The absence of standardized frameworks for the development of sustainability initiatives, however, continues to make it challenging to define, design, or defend initiatives either according to multiple stakeholder expectations or in relation to commonly accepted concepts of sustainable development (Albareda et al. 2007; Van Marrewijk 2003).

Demand for sustainability may come from stakeholders such as governments with explicit regulatory requirements or communities within economic development sectors with expectations of social legitimacy or moral needs (Galbreath 2010; Lin 2010). Consequently, strategic sustainability planning specifically in social domains must include multiple stakeholder views (Harrison and Bosse 2013; Trapp 2014).

As a nonmarket and nonregulatory mechanism, engagement with external stakeholders is a valuable strategy since it can foster innovations, offer access to expertise needed to solve complex problems in social legitimacy (Anderson et al. 2012), and provide learning needed to fundamentally transform the way corporations perceive sustainability (Amaeshi and Crane 2006; Sloan 2009; Tompkins et al. 2008). Since stakeholders reap the financial and nonfinancial benefits of sustainability (Jang et al. 2017), stakeholder relations management needs to be seen as a dynamic capability to harness differences between multiple external stakeholder groups (Watson et al. 2017) and attend to stakeholder claims in economic, social, and environmental domains (Steurer et al. 2005). Moreover, stakeholder engagement strategies as a tenet of sustainability science are tools that need to be included in the decision support systems in order to advance the profile of the benefits expected from effective stakeholder engagement (Cundy et al. 2013).

The use of system approaches as a qualitative tool is also recommended in the literature for addressing complex sustainability issues by providing insights into potential system behavior (Nguyen and Bosch 2013). The guiding principle behind system approaches to sustainability is that the organization and its environment need to be conceived of as a complex and unitary whole (Porter 2008) prior to designing effective strategies and interventions for transition to sustainability. Traditionally, system approaches rely on diagrams to explore the relationships or boundaries between systems of interest, such as sustainability and sustainable development, both representing separate but connected systems (Martin et al. 2005). However, recent studies suggest that application of system thinking in sustainability needs to go beyond quantification and interpretation of the sustainability impacts to a domain where causal relationships between different indicators and sub-systems are revealed (Onat et al. 2017).

In addition to factors such as system approaches and stakeholder engagement, recent studies show that theoretical and practical development of sustainability initiatives involving social systems is a continuous process spreading from the west to the east, assimilating all manner of philosophies, theories, and opinions from different cultures, different countries, and different enterprises (Hou and Li 2014; Xun 2013; Kolk et al. 2010). Clearly, sustainability is increasingly a more important element of strategy for development, particularly in relation to social systems, which have been categorized as open systems composed of multiple sub-systems of communications, operations, and organizations (Moeller 2011).

Methodology

The methodological approach in this study applies multi-stakeholder decision-making models and system theories for the development of a multi-level, nested participatory framework in the dominions of solution formulations and adoption for sustainability. By design, the framework assists with evaluating which local–regional sustainability challenges can be formulated and addressed first while considering socioeconomic systems, resource constraints, and societal views of desired sustainability paths. The framework is also used to formulate adaptive sustainability management systems through integration of planning, monitoring, assessment, and application of a multi-criteria decision-making model capable of accounting for global, social, and human systems.

While embracing contemporary ideas about systems in modeling, the framework provides capabilities to design sustainability initiatives based on local conditions and stakeholders' valuations and perceptions. This leads to involvement of three groups of stakeholders: academicians (who create knowledge), industry (which requires knowledge), and government (which facilitates implementation of knowledge). This methodological approach is used to test application of the framework for the design of sustainability portfolios that can specifically allow for customization according to three pillars designed to serve systems of sustainability (see Fig. 1):

Pillar I: Consideration of the stakeholders' views and valuations of sustainability issues, which need to be addressed by organizations (human system).

Pillar II: Accounting for the context of the economic development within which organizations function (global system).

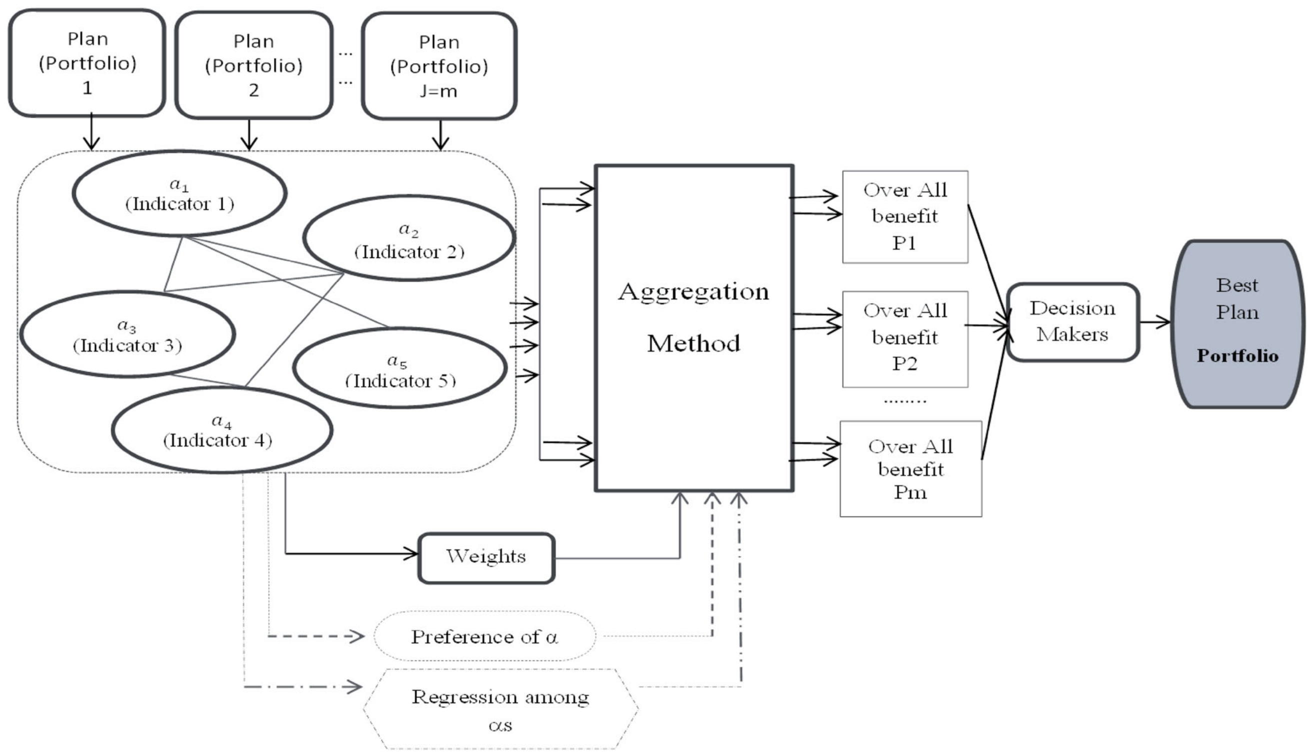


Fig. 2 GMADM model used for ranking of the sustainability indicators (for design of sustainability initiatives) according to their overall benefits

Pillar III: Assessment of the sustainability-focused initiatives according to their correlations and projected total benefit for organizations (social systems sustainability).

The main intent of this proposed framework is to highlight the importance of designing portfolios according to the level of cohesiveness between stakeholder requirements (I), regional sustainable development goals and objectives (II), and organizational strategy (III).

Data

The proposed framework, by design, requires data needed to understand stakeholders' valuations of sustainability issues that organizations might undertake in any geographical location (Pillar I requirements), and assessment of the importance of those issues within the domains of sustainable development goals and objectives at local, national, or regional levels (Pillar II requirements).

Modeling

The framework is designed to assist with the assessment, ranking, and prioritization of sustainability initiatives according to their cumulative benefits (Pillar III) using decision-making models such as the graphical multi-agent decision-making (GMADM) model (Yu and Xu 2012). This model was used due to its capability to take into account both correlations between sustainability indicators and the trends and impacts observed by decision-makers according to the state of local economic development, while allowing for both objective and subjective indicators to be used in design of sustainability portfolios (Pillar III). Similar to most multi-criteria decision-making models, GMADM requires the use of a set of alternative plans (projects designed according to the importance of the indicators) and criteria (see Fig. 2).

The GMADM model also has the capability to solve decision-making problems based on changeable graphic structures that link agents (indicators) according to assumed relationships among them such as prioritization or correlations. A graph is then developed to represent information and relationships between the indicators, utilizing a pair of sets, $G = (V, E)$, satisfying the assumption that $E \subseteq [V]^2$ (elements of E are 2-element subsets of V). The elements of V in this case represent the vertices of the graph G, with elements of E being its edges. The vertices then can be the indicators/agents of multi-agent decision making problems.

The aim of using such a model is to choose an alternative (depending on assumed plans or portfolios) for the design of sustainability initiatives from a set that best satisfies established sustainability criteria and indicators. Such problems can be solved by aggregation techniques, assuming no relationship between the decision factors.

The following sections detail steps involved with designing portfolios of options for sustainability in two cases. Those include data collection and analysis strategies; qualitative and quantitative analyses of the stakeholder data; and the graphical analysis of the economic development patterns and trends in two provinces. Results of the GMADM modeling approach for design of sustainability portfolios for two cases are then presented and compared.

Application of the framework for design of sustainability portfolios: China case studies

Application of the proposed framework is demonstrated for the design of sustainability portfolios in two provinces, Shandong and Guangdong, in North and South China. This case study demonstrates assumptions and steps involved with data collection and analysis, as well as a modeling approach used for the design of portfolios in each province. These two provinces were selected based on their strategic locations, economic development similarities, differences, and accessibility for data collection.

China's growth in industrial production has turned the world's attention to the consequences of rapid industrialization for the external environment in China (Moon and Shen 2010; Luo 2011). Progression in understanding sustainability issues and paradigms in China indicates that concerns include both internal and external environments of organizations, including foreign, multinational, and domestic firms operating in China. Due to the growing importance of meeting sustainable development goals and objectives in fast-growing economies such as China, many studies have attempted to diagnose problems associated with the design of sustainability initiatives (Buhmann 2006; Levinen 2008; Lattemann et al. 2009). These studies, cumulatively, suggested urgency for developing standardized approaches to the design of initiatives according to stakeholders' views and the economies they belong to.

In response to such needs, this study proposed a framework for guiding design of sustainability initiatives (portfolios) according to stakeholders' valuations of sustainability issues (Pillar I requirements), and assessment of the importance of those issues within the domains of sustainable development goals and objectives at either local, national, or regional levels (Pillar II requirements). The framework also guided ranking and prioritization of sustainability initiatives according to their cumulative benefits using decision-making models.

Pillar I: selecting stakeholder groups

The sustainable development goals (SDGs) address issues ranging from poverty eradication and improvements in education and health to protecting global assets such as oceans and a stable climate. Unfortunately, neither the SDGs nor their background documents explain how governments and other stakeholders can judge whether the development programs they undertake meet these goals (Dasgupta et al. 2015). An objective of this study is to develop a strategic framework for the assessment of the developmental programs and sustainability initiatives according to multi-stakeholders' views and valuations.

Data for this pillar were obtained utilizing a comprehensive questionnaire that included both sustainability-specific criteria and defining indicators stakeholders should review and evaluate (see information on method of selecting stakeholders in China, Tables 6, 7, 8 and 9 in the Appendix). The total horizontal and vertical scores obtained for the weighted scores assigned by stakeholders to each indicator were used in the preliminary assessment of the importance of sustainability initiatives that organizations should invest in.

Pillar II: evaluating economic development patterns and trends

The significance of sustainable development trends, their focus, as well as their projected impacts at local, national, and regional (or global) scales, were evaluated through analysis of time-series data obtained from both national and international databases. Subjective indicators data needed for the modeling stage of the study were attained from analysis of the questionnaires completed by the three stakeholder groups who participated in this study. The objective indicators data were selected from lists provided in World Bank reports [World Bank Indicators Group List; WDI Excel File; International Institute for Sustainable Development Data (Statistical Data)].

Pillar III: modeling for design of sustainability portfolios

Design of sustainability portfolios became possible by fitting data obtained for stakeholders' perceptions and economic development trends/focus into the GMADM model that allowed for ranking and prioritization of sustainability initiatives according to their strategic fits and total benefits (analysis of the stakeholders and economic development data were integral components of the design process).

The GMADM decision-making models provide capability to judge several operational plans in order to select the best one(s) according to their projected benefits. This model was preferred in this study due to its capacity to solve decision-making problems while accounting for the relations among decision factors. The GMADM model also has the ability to solve decision-making problems based on changeable graphic structures that links agents (indicators) according to assumed relations among them such as prioritization or correlations. A graph is then developed to represent information and relationships between the indicators.

Case studies

Portfolios were developed for two provinces (Shandong and Guangdong, Fig. 3) in China to demonstrate how the framework incorporates differences in stakeholder perceptions and economic contexts. The data collection methodology was designed with the hypothesis that the portfolios for these provinces, while different, could have some common elements due to similarities owing to their cultural commonalities and anticipated developmental focus. After China's economic revolution in the 1980s, Southern China had a very rapid growth in manufacturing industries. 10 years later Northern China followed this same path, and is still trying hard to catch up with Southern China.

Stakeholders' data

Three groups of stakeholders were selected to participate in this study:

"Academicians," who are well-informed about the creation of knowledge and training (human capital) needed to achieve sustainable economic development,
"Industry leaders," who are in charge of design and implementation of sustainable business strategies, and,
"Government officials," who are critical in developing regulations and policies that can support sustainability.

Participants were associated with industry, government, and academia with background education or work experience in engineering and management domains. Participants were identified through authors' networks and grouped by their interest, background, and level of involvement in the development or assessment of sustainability programs. Factors influencing selection of the participants included accessibility to the experts; experts' willingness to participate; and knowledge of the importance of developing human capital and the socioeconomic systems needed to support sustainable transitions.

Design of the data collection instrument in this study involved development of a comprehensive questionnaire and supporting materials such as videos and instructions to guide participants on how to complete the questionnaire (please see Tables 6, 7, 8 and 9 in the Appendix). The questionnaire and supporting materials were sent to contacts identified for each participating group of stakeholders in China. Contacts were in charge of distributing,

Fig. 3 Case study locations in China. http://en.wikipedia.org/wiki/Northern_and_southern_China

collecting and electronically forwarding completed questionnaires to the research team. The questionnaire was designed to solicit stakeholders' opinions on the importance of sustainability-specific criteria that organizations should adopt and comply with. Questions focused on ten areas of sustainability, four groups of sustainable development criteria, and eighteen indicators covering a broad scope of sustainable economic development, particularly those associated with and important to the design of initiatives. A systems view of sustainable development suggests the importance of creating sustainability sub-systems (such as human, natural, and support systems), sector systems (that could include but not be limited to social and government systems), and a group of indicators for assessing systems importance and interactions. Indicators are specifically important due to their dual functions: (a) representing system variables that could provide information needed to assess the viability of any sustainability sub/sector systems, and (b) their contribution to the performance of other systems with respect to meeting specified sustainability goals and objectives (Bossel 1999). A systems view of sustainability guided data collection and analysis in this study, from selecting sustainability areas to formulating criteria and clusters of indicators. Scores provided by stakeholders assisted in estimating stakeholders' views of the importance and viability of areas of sustainability initiatives (i.e., resource management) in each location. Two developmentally disparate provinces in China were selected to diversify both the systems and indicator groups in order to minimize the possibility of obtaining results that were not distinctive. Analysis specifically targeted human development at different levels of societal organization and social government systems such as infrastructure, economic and resources management, and the environment. Tasks assumed for sustainability initiatives were valued using systems indicators and sector systems drawn from publications provided by the International Institute for Sustainable Development, and world development indicators provided in a World Bank reports (see references provided in Pillar II).

Tables 6, 7 and 8 in the Appendix describe methods of data collection from design of the questionnaire to definitions of the criteria and indicators used to evaluate the importance of sustainability topics we tested in two province. Table 9 summarized the average weighted scores estimated from analysis of the data provided by the questionnaires.

Completing the questionnaire required respondents to both score and assign a weight to indicators associated with each criterion listed for each sustainability area, assuming direction estimates are absolute, while magnitude estimates are relative. Scores ranged from 0 to 3, where 0 = not important, 1 = slightly important, 2 = important, and 3 = very important. Weights assigned to each indicator could take any value between 0 and 1.

There were 34 participants who completed the questionnaires in each region, resulting in a total of 68 fully answered questionnaires. Questionnaires were also designed to gather information on participant demographics (i.e., education level and focus, gender, and expertise or work experience).

Preliminary assessment and data analysis consisted of extraction and summarization of information recorded in the completed questionnaires, followed by qualitative and quantitative analyses of data using tools such as Pearson correlation, Chi-square, ANOVA, and *t* tests. Top-rated sustainability indicators were identified for each province prior to being ranked according to their relative importance in the design of portfolios using the GMADM model.

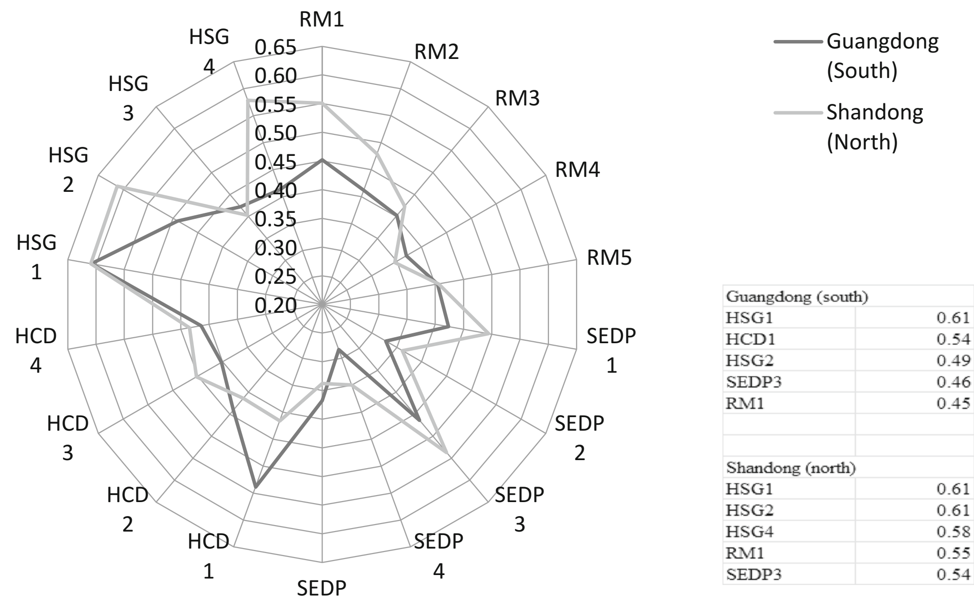
Results

Qualitative analysis concentrated on graphical methods for defining how stakeholder' gender, education, expertise, and location affect valuations of the types and the importance of sustainability initiatives that organizations should pursue.

Analysis suggested five sustainability indicators worthy of mention for each province. These results were further analyzed according to their possible correlations and to their importance to the local/regional economic development patterns prior to being selected.

As shown in Fig. 4, both provinces ranked the indicator HSG1—which calls for design of environmental and financial regulations and policies—to be the most important. Both similarly ranked the importance of sustainability indicators that could address eco-region protection (RM1), management of energy use and intensity (SEDP3), and promotion of green economic development policies (HSG2). However, the scores for these indicators were higher in Shandong. The fifth top-scored indicators were importance of health and risk assessment and management (HCD1) in Guangdong and financial investment in green economy (HSG4) in Shandong. It is important to note that participants were directed to also provide a weight for each indicator they score according to their perceived relative importance of that indicator. Using weight provided a better estimate of the importance of each indicator and assisted with addressing potential bias or possibility that indicator either is under- or over-represented in the study.

Additional data analysis also revealed variations in stakeholder scores based on their demographics, especially gender, education, expertise, and professional backgrounds. Data obtained from the three groups of stakeholders (academic, government, industry) were combined



Guangdong (south)	
HSG1	0.61
HCD1	0.54
HSG2	0.49
SEDP3	0.46
RM1	0.45
Shandong (north)	
HSG1	0.61
HSG2	0.61
HSG4	0.58
RM1	0.55
SEDP3	0.54

Fig. 4 Variations of the weighted average for total scores for sustainability indicators in Guangdong and Shandong

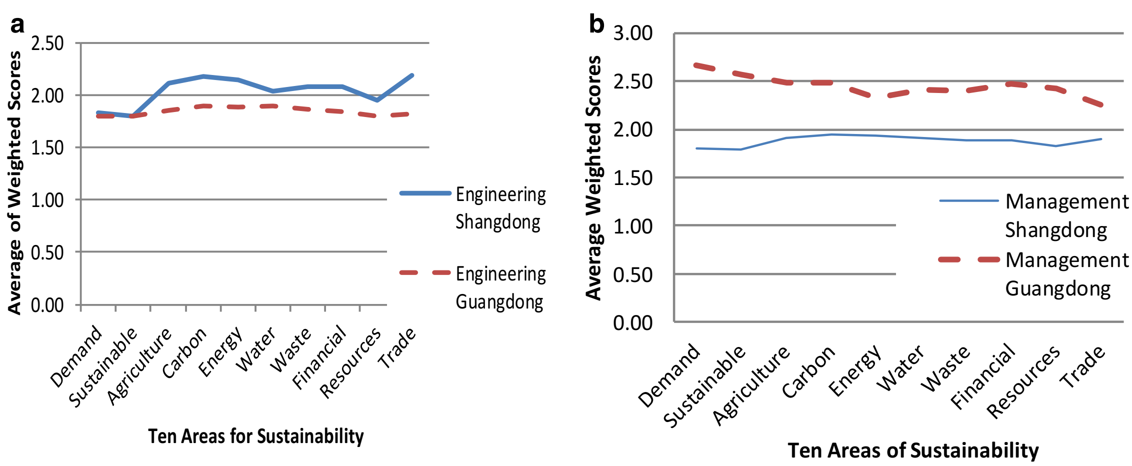


Fig. 5 **a**, **b** Variations in scores obtained for importance of sustainability initiatives tested according to stakeholders' background in each location

in two general categories of "engineering "and "management." The engineering category represented sores provided by stakeholders who educated or worked in technical/engineering fields. The management category, however, represented scores obtained for stakeholders who either work in the business/management areas or had management responsibilities. These observations inspired analysis of the responses according to the reported field of work in each location. As shown in Fig. 5a, b, results of the analysis indicated that Shandong stakeholders who primarily work in engineering fields scored the importance of sustainability areas higher than those working in Guangdong. Strongest emphasis was given to development of financial models in support of sustainability, along with trades and globalization initiatives. These results reversed when analysis considered only data in the management category.

These results suggest that stakeholders field of study and work could be differentiating guiding principles in the design of strategies by organizations.

Comparative analysis of stakeholder data in each location

Statistical analyses examined the extent of similarities, differences, or correlations among scores obtained for each indicator by the three stakeholder groups in Shandong and Guangdong.

The first quantitative analysis of data tested the importance and consistency of the scores obtained for

Table 1 ANOVA test results (ρ values) for equality of the mean responses obtained from three groups of stakeholders (total weighted average data)

	Government	Industry	F value (group)	Sig. ($\alpha = 0.05$) (group)
Faculty	0.436	0.181		
Government		**0.048**	2.053	0.137
Demand management				
Faculty	0.736	**0.008**		
Government		**0.022**	4.163	**0.020**
Transportation				
Faculty	0.831	**0.044**		
Government		0.078	2.376	0.101
Agriculture				
Faculty	0.311	0.483		
Government		0.114	1.325	0.273
Carbon and climate				
Faculty	0.135	0.495		
Government		**0.047**	2.234	0.115
Energy system/demand				
Faculty	0.436	0.502		
Government		0.179	0.934	0.398
Water management				
Faculty	0.559	0.568		
Government		0.282	0.591	0.557
Waste management				
Faculty	0.315	0.477		
Government		0.113	1.324	0.273
Financial models				
Faculty	0.318	0.117		
Government		**0.017**	3.005	0.056
Resources/material				
Faculty	0.595	0.180		
Government		0.078	1.681	0.194
Trade				
Faculty	0.295	0.768		
Government		0.220	0.902	0.411

participants according to gender and level of education using $\chi^2 = \frac{(O_{ij}E_{ij})^2}{E_{ij}}$ homogeneity (χ^2) tests. This test was used to determine the level of consistency observed for the responses. It required organization of the scores from completed questionnaires (observed values (O_{ij})) for listed sustainability topics of interest tested (i), and their importance for scoring intervals of j (j: < 1 = Not Important = NI, $1 \leq x < 2$ = Important = I, ≥ 2 = Very Important = VI) and under assumption of homogeneity (E_{ij}). Since the estimated χ^2 was less than test statistics at 5% levels of significance ($\alpha = 0.05$), the analysis concluded that there is no statistically significant difference among scores reported by stakeholders according to gender or level of education. Accordingly, there was no need to make adjustment to the database for further quantitative analysis. Next, ANOVA and t tests were used to determine equality of the responses obtained by three groups of stakeholders in each province. Results of the first ANOVA test (Table 1) with α at 5% significance indicated that the three stakeholder groups have (more or less) assigned statistically uniform scores to the importance of managing "carbon emissions," "use of energy systems and demand," "management of water/waste treatment," and "importance of trade and globalizations."

The ρ values of 0.022 and 0.017 indicated unequal responses for the importance of sustainability topics among government and industry on "demand management" and "development of sustainability financial models." Such outcomes were also observed for the "demand management" scores for academia and industry ($\rho = 0.008$).

ANOVA tests were used to evaluate equality of the scores obtained for sustainability indicators in the two

Table 2 a, b Impact of location on the importance of sustainability indicators (ρ values) at different levels of significance ($\alpha = 0.1$ (***), 0.05 (**), and 0.01 (*))

(a) One way ANOVA test/*T* test on provinces means	Human capital development (HCD)				Human system and governance (HSG)			
	HCD1	HCD2	HCD3	HCD4	HSG1	HSG2	HSG3	HSG4
Demand management	0.208	0.557	0.174	0.759	0.964	0.194	0.963	0.002***
Sustainable transportation	0.027**	0.732	0.935	0.111	0.390	0.014**	0.352	0.170
Agriculture, food security	0.778	0.907	0.401	0.963	0.829	0.003***	0.428	0.003***
Climate change issues and carbon management	0.464	0.312	0.610	0.821	0.991	0.339	0.668	0.028**
Energy systems, intensity, demand	0.130	0.288	0.091*	0.582	0.777	0.003***	0.165	0.006***
Water management	0.307	0.955	0.568	0.574	0.891	0.631	0.042**	0.077*
Waste management	0.178	0.661	0.478	0.867	0.877	0.368	0.595	0.172
Financial models for sustainable development	0.153	0.833	0.961	0.323	0.319	0.011**	0.708	0.006***
Management of resources and critical material	0.012**	0.542	0.637	0.388	0.526	0.005***	0.598	0.082*
International trade/global issues	0.224	0.759	0.030**	0.015**	0.586	0.053*	0.128	0.025**

(b) One way ANOVA test/*T* test on provinces means	Resource management (RM)					Socio-economic development and prosperity (SEDP)				
	RM1	RM2	RM3	RM4	RM5	SEDP1	SEDP2	SEDP3	SEDP4	SEDP5
Demand management	0.020**	0.001***	0.158	0.951	0.299	0.351	0.763	0.040**	0.810	0.489
Sustainable transportation	0.289	0.276	0.609	0.712	0.956	0.097*	0.309	0.350	0.735	0.359
Agriculture, food security	0.112	0.348	0.287	0.865	0.355	0.154	0.384	0.081*	0.155	0.269
Climate change issues and carbon management	0.010***	0.027**	0.437	0.187	0.925	0.201	0.319	0.586	0.021**	0.530
Energy Systems, Intensity, Demand	0.059*	0.131	0.901	0.600	0.572	0.916	0.784	0.239	0.065*	0.238
Water management	0.002***	0.338	0.464	0.260	0.176	0.729	0.400	0.248	0.555	0.562
Waste management	0.199	0.990	0.799	0.185	0.378	0.199	0.919	0.295	0.681	0.515
Financial models for sustainable development	0.076*	0.122	0.311	0.830	0.568	0.035**	0.103	0.923	0.083*	0.769
Management of resources and critical material	0.043**	0.104	0.741	0.930	0.122	0.344	0.501	0.096*	0.029**	0.598
International trade/global issues	0.865	0.493	0.895	0.295	0.865	0.270	0.429	0.347	0.000***	0.875

*** Means significant level >99%

** Means significant level >95%

* Means significant level >90%

provinces. Comparing test parameter 'ρ' obtained for each indicator, assuming three different values of α (0.01, 0.05, 0.1), suggested that stakeholders in the two provinces do not agree, specifically, on the importance of sustainability indicators RM1 due to the observed ρ value of 0.02, which is smaller than all three values assumed for the α (see Table 2a, b).

Similarly, according to the values reported for the ρ in blank cells, with 85% confidence, the analysis concluded that participants from Shandong and Guangdong generally were in agreement on the importance of the sustainability indicators identified in this study.

The results show that sustainability initiatives and design of portfolios in Shandong could focus on the expansion of government regulations, environmental protection, industrial development, and financial investment, while in Guangdong portfolios and sustainability initiatives should be more concerned with material management, human capital development, and jobs creation. However, quantitative analysis of data suggested dissimilarities for stakeholder opinions according to the estimated scores for the importance of HSG4 (financial investment in green economy) and HCD1 (health risk analysis and management) indicators.

Both provinces, however, equally scored the importance of HSG1 (environmental/financial regulations), HSG2 (green economic development policies), and RM1 (eco-region protection) indicators. Data analysis at this point resulted in identification of the top ranked indicators for the design of sustainability initiatives and portfolios at each province.

Data for indicators were also analyzed to evaluate correlations among them prior to moving forward with the design of portfolios using the GMADM model. The overall results of the regression analysis for all indicators as well as top ranked ones are presented in Table 3. The correlation data in shaded cells are those estimated for the top ranked indicators in each province (see Fig. 4).

The next step in this analysis evaluated economic development patterns for the two provinces. Such information was essential for understanding priorities and preferences of each province (or for comparable countries/regions).

Analysis of economic development patterns

The historical economic development and a review of the current situation within the test provinces of Guangdong and Shandong are important elements in the design and scope of the framework. They help to grasp the overall direction of sustainability initiatives in China.

To be more relevant, data analysis in this section focused on understanding associations between patterns of economic development and energy use and carbon intensity, as those are reported to be the most significant to the success of sustainability initiatives in China (Youguo 2010). In addition, Youguo (2010) study emphasized the importance of creating a number of government policies to accelerate the economic development pattern. Analysis of the economic development patterns and outputs such as gross domestic products (GDP), energy use, and CO_2 emission intensity utilized data provided by the World Bank and National Bureau of Statistics of China.

Analyses were also performed for Shandong, Guangdong, China, and the East Asia and Pacific region. The observed relevance and dependency among carbon emission intensity and economic activities in both provinces, China, and the region are shown in Figs. 6a, b, 7a, b, and 8a, b.

Economic trends and context

As shown in Fig. 6a, b, the CO_2 emission rate per capita increased between 1960 and 2010 in both provinces, in China, and in the East Asia–Pacific Region, with the rate being the highest between 2000 and 2010. The highest rate of emissions is observed for Shandong, followed by China, the East Asia and Pacific region, and Guangdong. Results clearly indicate the importance of reducing CO_2 emission, particularly in Shandong.

Variations for the rate and pattern in CO_2 emission, according to increase in the gross domestic product (GDP) for China, suggested an inverse U-shape curve for CO_2 emission similar to one suggested by Kuznets' theory (Dinda 2004). The pattern suggests slowing down in environmental emissions while economic development continues. A similar pattern may be observed following sustainability initiatives promoted by the creation of new regulations and policies.

Analysis of data presented in Fig. 8a, b indicates that (a) Shandong uses a much larger amount of coal than Guangdong and, therefore, contributes more CO_2 emissions, and that (b) since 2007 Guangdong concentrated on using more natural gas than coal. The lowered level of CO_2 emission and anticipated environmental impact in Guangdong can be associated with the reduction in the use of coal.

Analysis of the GDP contribution from primary, secondary, and tertiary economies presented in Fig. 9a, b shows that agriculture and manufacturing (primary and secondary economies) contribute 60 and 54% of the GDP in Shandong and Guangdong, respectively. The GDP associated with the tertiary economic activities seems to be more pronounced in Guangdong.

Manufacturing profiles also could be different in the two provinces. For example, steel production in Shandong was more active than in Guangdong for over 18 years, while vehicle production is one of the primary manufacturing sectors in Guangdong.

Results of the economic development analysis and suggestions provided by regulatory officers in the two provinces suggest that, to make the design of portfolios relevant, prior to ranking indicators according to their overall benefits projected by the GMADM model, the research should consider including two new indicators—RM2 (Climate Change and Carbon Management) and SEDP1 (Industrial Growth)—to the lists of the top five indicators already identified for the design of the portfolios in Shandong, and Guangdong.

Design of sustainability initiatives (portfolios)

As shown in Fig. 2, GMADM requires assumptions for project plans according to a set of predetermined indicators, indicator weights and correlations, and preferences. An aggregation method is used to choose the best plan(s) with maximal benefit. According to the modeling guideline, indicators $a_{1,}a_2,a_{3,}a_4a_5\ldots a_n$, were partitioned into distinct categories $(a_1,a_2),(a_1,a_3),\ldots(a_1a_n)$with A and E being equal to $\{a_{1,}a_2a_3a_4a_5\ldots a_n\}$ and $(a_1,a_2),(a_1,a_3),(a_1,a_4),\ldots(a_1a_n)\ldots(a_2a_3),(a_2a_4)\ldots$, respectively. The weights of each indicator in the modeling is assessed from the weighted averaging operator estimated by W_i (where $w_i \in [0,1]$ $(i = 1,2,\ldots,n)$, $\sum_{i=1}^{n} W_i$, and WA_w $(a_{1,}a_2a_3a_4a_5\ldots a_n) = \sum_{i=1}^{n} W_i\alpha_i)$).

GMADM modeling also provided a set of plans (P) for the design of portfolios, where $P = \{p_1, p_2,\ldots,p_m\}$. Each plan consisted of a set of indicators shown by A representing a set of vertices in the graph ($G = (A, E)$).

Table 3 Pearson correlation matrix for sustainability indicators in Shandong and Guangdong

Shandong	RM1	RM2	RM3	RM4	RM5	SEDP1	SEDP2	SEDP3	SEDP4	SEDP5	HCD1	HCD2	HCD3	HCD4	HSG1	HSG2	HSG3	HSG4
RM1	1																	
RM2	0.406669	1																
RM3	0.705702	−0.23873	1															
RM4	0.118506	−0.15271	0.192095	1														
RM5	−0.06369	0.309005	−0.44547	0.00434	1													
SEDP1	−0.10715	0.176694	−0.21485	0.379739	−0.17906	1												
SEDP2	−0.35716	−0.54756	0.104338	0.032961	−0.37985	0.476493	1											
SEDP3	0.336045	0.502643	0.055039	0.029395	0.440439	−0.55277	−0.69175	1										
SEDP4	−0.3397	0.308995	−0.54085	−0.48361	−0.22961	0.041397	0.015407	−0.00602	1									
SEDP5	−0.47232	−0.2225	−0.2458	−0.37622	0.070558	0.279177	0.697249	−0.53644	0.079031	1								
HCD1	0.367471	0.039754	0.445156	−0.07251	−0.66568	−0.03503	−0.00832	−0.03728	0.09023	−0.12614	1							
HCD2	−0.34488	−0.63792	0.255897	−0.25756	−0.5512	0.070993	0.774476	−0.49829	−0.01153	0.52488	0.293399	1						
HCD3	−0.52507	−0.3573	−0.08986	−0.35299	−0.04117	−0.50867	0.112061	0.169712	0.065077	0.358209	0.170946	0.513539	1					
HCD4	−0.5599	−0.34577	−0.29811	−0.59035	0.102601	−0.15332	0.526863	−0.29494	0.236426	0.846233	−0.03848	0.59317	0.650602	1				
HSG1	0.145541	0.348674	−0.10222	−0.63596	−0.21241	0.266715	0.278459	−0.28221	0.498795	0.450911	0.401604	0.268537	−0.09936	0.427531	1			
HSG2	−0.09309	0.33422	−0.49922	0.37487	0.337248	0.479606	−0.13877	0.133747	0.082288	−0.232	−0.10255	−0.29256	−0.3416	−0.24281	0.051682	1		
HSG3	−0.61758	−0.07446	−0.55476	−0.35106	−0.29126	0.017799	0.189731	−0.21712	0.75667	0.335127	0.325035	0.268517	0.466988	0.535115	0.383497	0.065127	1	
HSG4	0.146468	0.377122	−0.02917	0.027931	−0.26081	0.112009	0.02531	0.393341	0.584831	−0.29254	0.31337	0.019017	−0.07702	−0.14775	0.314684	0.380209	0.303196	1

Guangdong	RM1	RM2	RM3	RM4	RM5	SEDP1	SEDP2	SEDP3	SEDP4	SEDP5	HCD1	HCD2	HCD3	HCD4	HSG1	HSG2	HSG3	HSG4
RM1	1																	
RM2	0.694865	1																
RM3	0.609471	0.469927	1															
RM4	0.513642	0.126733	0.377222	1														
RM5	0.78444	0.490858	0.537626	0.369865	1													
SEDP1	−0.22559	0.226912	0.127845	−0.09139	−0.16059	1												
SEDP2	−0.42134	−0.38337	−0.18773	−0.05473	−0.45031	−0.40716	1											
SEDP3	0.148347	0.7475	0.255628	−0.27268	0.19141	0.709296	−0.45081	1										
SEDP4	0.10195	0.369236	0.287372	0.047589	−0.39144	0.093081	0.218388	0.20618	1									
SEDP5	0.032719	0.212161	−0.30805	−0.26706	−0.20848	−0.20165	−0.18078	0.118303	0.143705	1								
HCD1	0.460956	−0.00654	0.246947	0.13746	0.304133	−0.1439	−0.25043	−0.27068	−0.16289	−0.36884	1							
HCD2	−0.31651	−0.16669	−0.29128	−0.50832	−0.28015	0.18769	0.015073	0.132563	0.195946	−0.12625	−0.05132	1						
HCD3	−0.20122	−0.53541	−0.03364	0.160011	−0.31068	−0.11701	0.169432	−0.58253	−0.15264	−0.27168	0.54147	−0.42187	1					
HCD4	0.018795	−0.16097	−0.20839	0.329287	0.008517	0.328441	−0.26707	−0.10272	−0.15482	−0.57299	0.479097	0.246252	0.275186	1				
HSG1	0.261043	0.558356	0.433554	0.201927	0.506359	0.408083	−0.23332	0.610348	−0.1431	−0.32278	−0.11677	−0.46965	−0.15635	0.002518	1			
HSG2	0.516777	0.487109	0.712051	0.205321	0.379221	−0.06723	0.193162	0.176631	0.423673	−0.52861	0.393157	−0.09436	0.014271	0.011336	0.418805	1		
HSG3	0.179444	0.436296	0.325924	−0.43498	−0.06429	0.338362	−0.4521	0.540515	0.5607	0.231975	0.100317	0.472612	−0.31136	−0.13555	−0.10042	0.220837	1	
HSG4	0.582653	0.424364	0.452049	0.244305	0.519202	−0.19899	−0.51332	0.114978	−0.09618	0.365366	0.147408	−0.71743	0.106883	−0.36332	0.382131	0.105073	0.118213	1

The formulation of the portfolios (identified as plans in the modeling process described in Fig. 2) required the data obtained in Phase I for stakeholders' views of the importance of indicators (shown as α) and the data obtained in Phase II on those indicators' relevance and anticipated impacts on either local, national, or regional developmental goals and trends. Such trends were identified and added to the list of top indicators (RM2 and SEDP1) selected from analysis of the stakeholder data. They were also used while assessing the magnitude of the influence coefficient between the relevant indicators (shown by (ξ_{ij})) and prioritization relations.

By design, the modeling processes also required integration of indicators for mainstreaming information into investment decision-making. Accordingly, the first step in modeling portfolios is to identify agents (indicators) (α_i) and their graphical relationships to properly estimate values of $\bar{d}(a_i) = \frac{d(a_i)}{\max_j d(a_j)}$, preferences, and magnitude of the correlations ξ_{ij}, followed by estimating correlation coefficients among sustainability indicators, and design of graphics showing relationships and level of correlations between all selected indicators.

The strength of the relationships and values of the correlation coefficients estimated for the top six indicators in

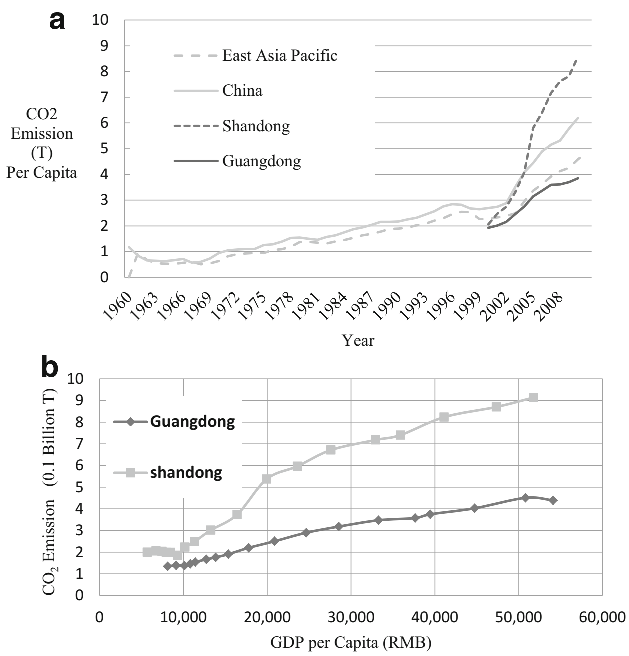


Fig. 6 **a** Pattern of CO_2 emission per capita between 1960 and 2010 in Shandong, Guangdong, China, and East Asia Pacific Region. **b** Pattern of CO_2 emission according to the GDP growth in Shandong and Guangdong

Shandong and Guangdong are shown in Fig. 10a, a′. These figures depict the types and levels of correlation estimated among top indicators. For example, Shandong data depicted in Fig. 10a indicates that indicator α_6 can be correlated to five other indicators, with the strongest correlation associated with $\alpha_6-\alpha_3$ (0.5). Estimated correlation coefficients for data from Guangdong (Fig. 10a′), however, suggest that the strongest correlations are between indicators $\alpha'6$ and $\alpha'4$ (0.71). The correlations were also used in the modeling steps carried out to estimate the total overall benefits associated with investing in any single top indicator.

Table 4 summarizes the steps involved with estimation of the overall total benefits associated with investing in any plan/initiative that is specific to indicator "α". For example, Table 4 presents the total benefits of investing in initiatives to promote "environmental and financial regulations and policies" (identified as $\alpha1$ and $\alpha'1$) for Shandong and Guangdong provinces to be 1.11 and 1.87, respectively. It is logical to expect different output from the framework for Guangdong and Shandong due to differences in the stakeholder data and economic development pattern in these provinces.

Table 5 presents the total overall benefits when investing in any indicator for each province. Also provided in this table are the rankings of the total estimated benefits for investing in each indicator. The highest overall total benefits were identified as investing in development of "Environmental and Financial Regulations and Policies" in Guangdong and "Carbon and Climate Change Management" in Shandong. The second most beneficial projects to invest in were initiatives for promoting "Eco-Region Protection" and "Green Economic Development" in Shandong and Guangdong, respectively.

Discussion of case studies

The purpose of the case studies was to determine if our framework could provide useful information to aid policy makers and organizational strategists in the development of optimal sustainability portfolios. To demonstrate that optimal portfolios are not one-size-fits-all, we conducted two case studies in Chinese provinces that varied in their economic development (Guangdong and Shandong). Our results demonstrate the significance of considering economic development patterns as an input for the design of sustainability portfolios as well as the importance of taking into account both the economic data and estimated total benefits for sustainability initiatives, according to the stakeholders' views.

Analysis and modeling of the data obtained for stakeholders' views and analysis of the economic development context in Shandong and Guangdong were instrumental for finding the most important sustainability issues that organizations should address while operating in each province. As shown in Fig. 11a, b, due to the similarities of the provinces with respect to their socioeconomic dimensions, their portfolios included similar groups of sustainability indicators. The ranking of indicators according to their degree of importance, however, was different for each province, as shown in Fig. 11a, b, where the level of importance of each indicator is identified according to the thickness of the lines.

In these cases, our findings suggested the importance of promoting green economies (HSG4) in Shandong, in contrast to addressing human health risk issues (HCD1) in Guangdong. Specifically, the findings suggested the inclusion of resource management strategies that address carbon emission and energy use (RM2) in Shandong province, and financial initiatives that could support sustainable development and prosperity (SEDP1) in Guangdong province (see indicators 6 and 6′ in Fig. 11a, b).

These results were consistent with the economic development patterns and sustainability issues reported for the provinces. As noted earlier, after China's economic revolution in the 1980s, Southern China (Guangdong) had a very rapid growth in manufacturing industries, while Northern China (Shandong) followed a similar path 10 years later.

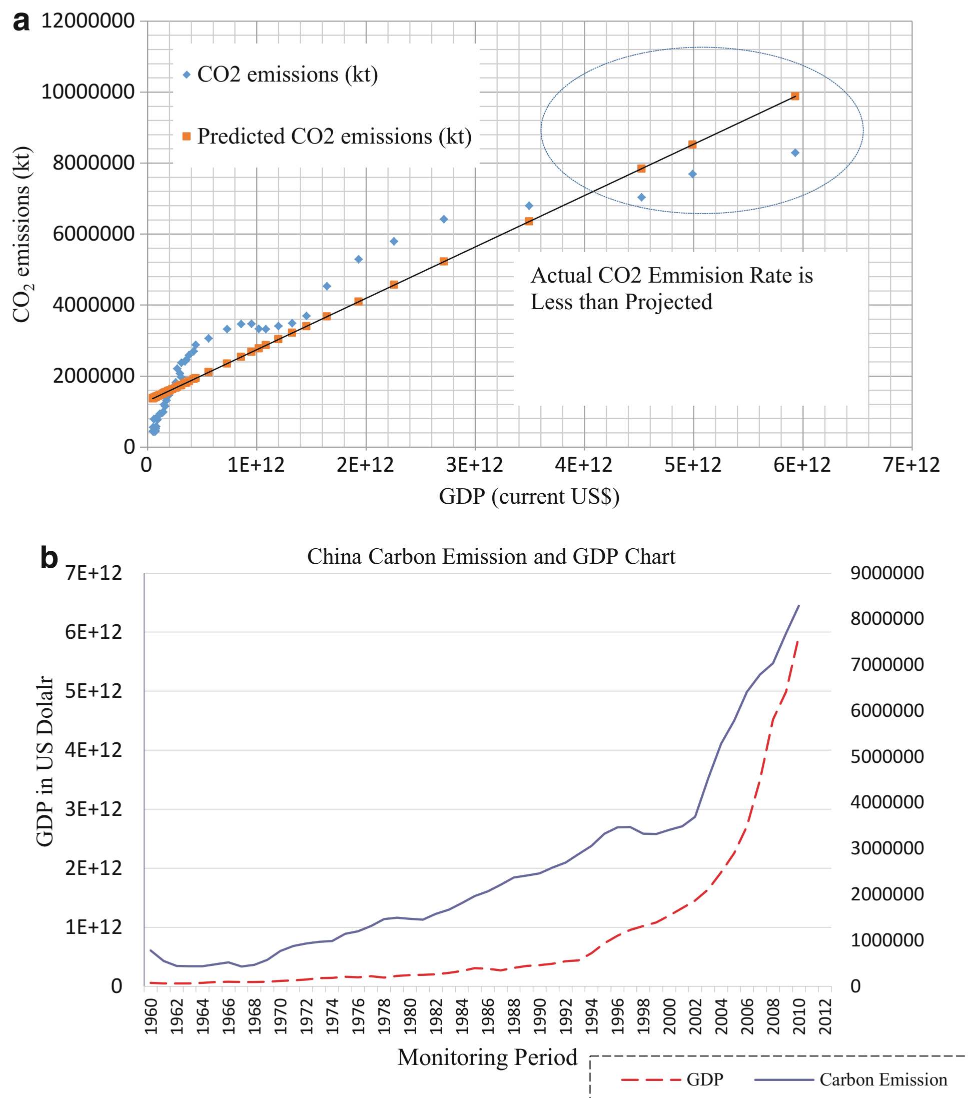


Fig. 7 **a** The predicted and observed variations of the CO_2 emission rate with increase in GDP in China. **b** CO_2 and GDP data for China between 1960 and 2012

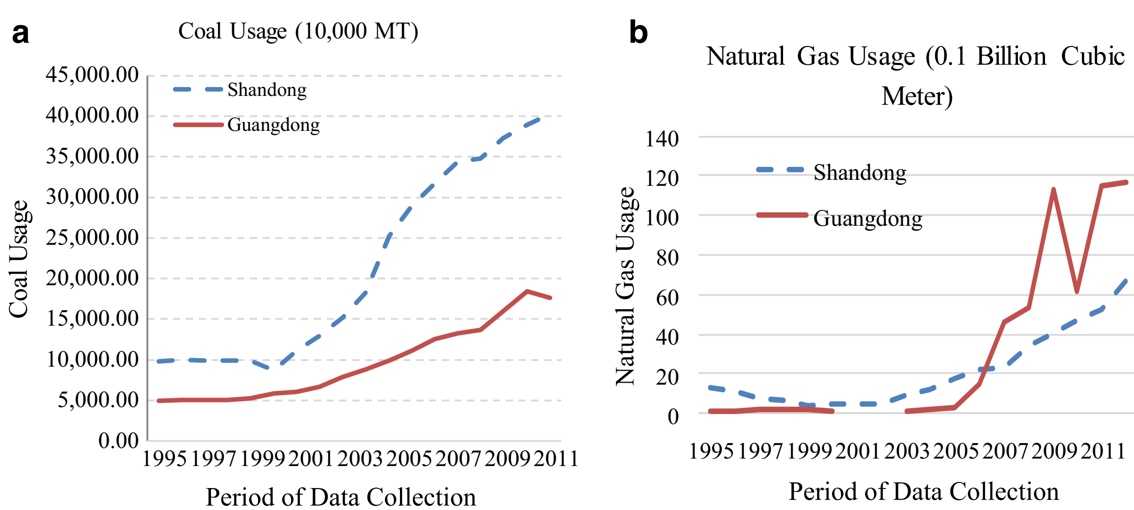


Fig. 8 **a**, **b** Pattern of coal and natural gas use from 1995 to 2011 in Shandong and Guangdong

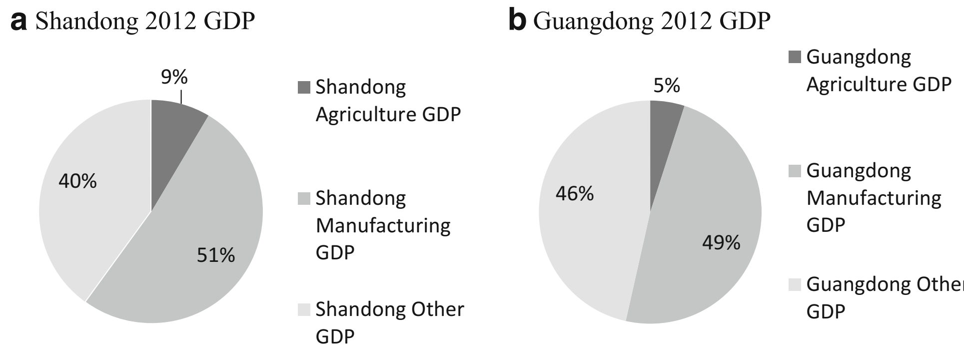


Fig. 9 **a**, **b** GDP contribution from primary, secondary, and tertiary economies in Shandong and Guangdong

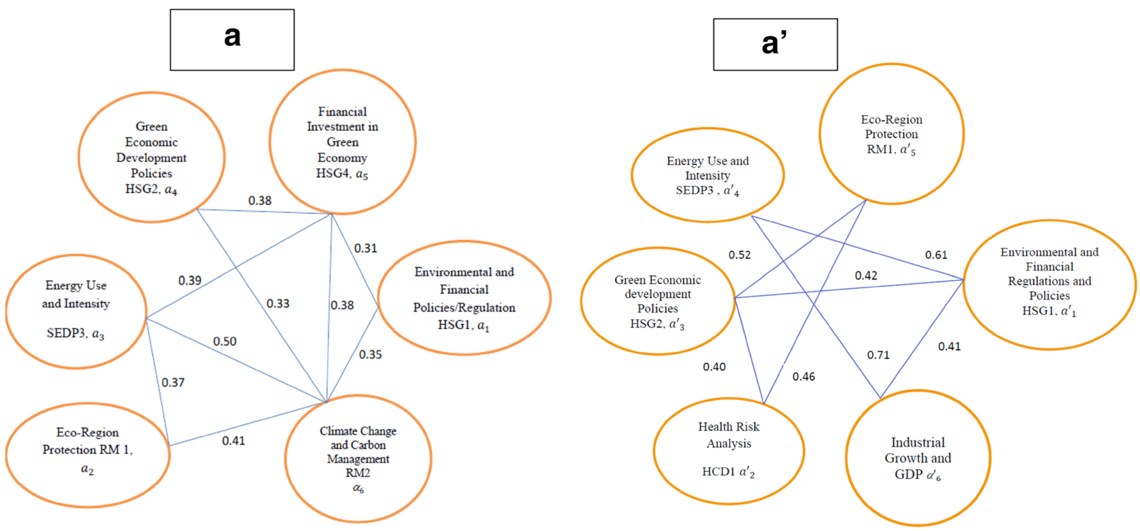


Fig. 10 Graphical structure for indicators correlation in Shandong (**a**) and Guangdong (**a′**)

Therefore, Shandong stakeholders favored investing in sustainability projects that could promote green economies in the province, as indicated in the results by including HSG4 indicator in the portfolio of initiatives. Meanwhile, Guangdong stakeholders favored investing in the management of human health and prosperity in this fast-growing province.

These two cases show that the capability of the proposed modeling approach for ranking sustainability indicators according to their total benefit is a valuable aspect of the proposed framework. Being able to rank sustainability indicators in their decision-making process may be particularly important for organizations that struggle to make economic sense of sustainability initiatives (Beloff and Tanzil 2013).

Summary and conclusions

Much of sustainability science research has been about determining technical solutions, while acknowledging that sustainability is a regional, place-based, and integrated phenomenon. Much of management sustainability research has been about determining the private costs of technical solutions, while acknowledging that there may be intangible benefits. Much of public policy research has been about the costs of not solving sustainability problems, while acknowledging that there may be trade-offs between sustainability and economic development. What has not been addressed as much is the integration of the different viewpoints into a framework that facilitates place-based decision-making in support of sustainability. We contribute to and integrate the three literatures by developing a framework that incorporates different elements of sustainability research to generate a list of sustainability initiatives ranked by the total expected societal benefits they will provide. Since our framework can be used by any organization in any location, it has both practical and theoretical value.

According to Lang et al. (2012), “There is emerging agreement that sustainability challenges require new ways of knowledge production and decision-making” that include multiple stakeholders. Therefore, we propose a new way to produce knowledge (rankings of sustainability

Table 4 Example modeling steps involved with estimating total benefits for each province assuming investment in HSG1 environmental and financial regulation indicator in Shandong and Guangdong, respectively (α1, and α′1)

Shandong	Guangdong (′)
$d(a_1) = 2,\ d((a_2) = 2,\ d((a_3) = 3,\ d((a_4) = 2,\ d((a_5) = 4,\ d((a_6) = 5$	$d(a'_1) = 3, d((a'_3)) = 2, d((a'_2)) = 3, d((a'_4)) = 2, d((a'_5)) = 2, d((a'_6)) = 2$
$\bar{d}(a_i) = \frac{d(a_i)}{\max jd(a_j)}$	$\bar{d}(a_1) = \frac{d(a_1)}{\max_j d(a_j)}$
In our case, $\max_j d(a_j) = 5$. $\bar{d}(a_1) = 0.4\left(\frac{2}{5}\right)$, $\bar{d}(a_2) = 0.4\left(\frac{2}{5}\right)$, $(a_3) = 0.6\left(\frac{3}{5}\right)$, $\bar{d}(a_4) = 0.4\left(\frac{2}{5}\right)$, $\bar{d}(a_5) = 0.8\left(\frac{4}{5}\right)$, $\bar{d}(a_6) = 1\left(\frac{5}{5}\right)$	In our case, $\max_j d(a_j) = 3, \bar{d}(a'_1) = 1\left(\frac{3}{3}\right), \bar{d}(a'_2) = 0.67\left(\frac{2}{2}\right), \bar{d}(a'_3) = 1\left(\frac{3}{3}\right), \bar{d}(a'_4) = 0.67\left(\frac{2}{3}\right), \bar{d}(a'_5) = 0.67\left(\frac{2}{3}\right), \bar{d}(a'_6) = 0.67\left(\frac{2}{3}\right)$
$s_i = \begin{cases} 1 & \text{if } i = 0 \\ \min_j(\bar{d}(a_{ij})), & \text{otherwise} \end{cases}$	$s_i = \begin{cases} 1 & \text{if } i = 0 \\ \min_j\left(\bar{d}\left(a'_{ij}\right)\right), & \text{otherwise} \end{cases}$
Assume $\{a_1, a_2\} > \{a_3, a_4\} > \{a_5, a_6\}$	Assume $\{a'_1, a'_2\} > \{a'_3, a'_4\} > \{a'_5, a'_6\}$
$s_0 = 1,\ s_1 =$ 0.4 because $\min\{\bar{d}(a_1), \bar{d}(a_2)\} = 0.4, s_2 =$ 0.4 because $\min\{\bar{d}(a_3), \bar{d}(a_4)\} = 0.4, s_3 =$ 0.8 because $\min\{\bar{d}(a_5), \bar{d}(a_6)\} = 0.8$	$S_0 = 1, S_1 =$ 0.67 because $\min\{\bar{d}(a'_1), \bar{d}(a'_2)\} = 0.67, S_2$ 0.67 because $\min\{\bar{d}(a'_3), \bar{d}(a'_4)\} = 0.4, S_3 =$ 0.67 because $\min\{\bar{d}(a'_5), \bar{d}(a'_6)\} = 0.8$
$\omega_i = \prod_{k=1}^{i} S_{k-1}$for $i = 1\ldots q$	$\omega_i = \prod_{k=1}^{i} S_{k-1}$ for $i = 1\ldots q$
$\omega_1 = S_0, = 1,\ \omega_2 = S_0 \times S_1 = 0.4,\ \omega_3 = S_0 \times S_1 \times S_2 = 0.016$	$\omega_1 = S_0 = 1,\ \omega_2 = S_0 \times S_1 = 0.67,\ \omega_3 = S_0 \times S_1 \times S_2 = 0.45$
$b = \sum_{ij} w_i b_{ij} = \sum_{i=1}^{q} w_i \sum_{j=1}^{ni} b_{ij}$	$b = \sum_{ij} w_i b_{ij} = \sum_{i=1}^{q} w_i$
If we only invest in a_1 HSG1 (environmental and financial regulations):	If we only invest in a_1 HSG1(environmental and financial regulations):
$b_1^p = t_1 + \bar{t}_{n1} + 0 + 1 = 1,\ b_2^p = 0,\ b_3^p = 0,\ b_4^p = 0, b_5^p = 0.31,\ b_6^p = 0.35$	$b_1'^p = t_1 + \bar{t}_{n1} = 1 + 0 = 1,\ b_2'^p = 0,\ b_3'^p = 0.42,\ b_4'^p = 0.61,\ b_5'^p = 0,$ and $b_6'^p = 0.41$
Overall benefit: $b^{(p)} = \omega_1\left(b_1^p + b_2^p\right) + \omega_2\left(b_3^p + b_4^p\right) + \omega_3\left(b_5^p + b_6^p\right) = 1 \times (1 + 0) + 0.4 \times (0 + 0) + 0.16 \times (0.31 + 0.35) = 1.11$	Overall benefit: $b'^p = \omega_1\left(b_1'^p + b_2'^p\right) + \omega_2\left(b_3'^p + b_4'^p\right) + \omega_3\left(b_5'^p + b_6'^p\right) = 1 \times (1 + 0) + 0.67 \times (0.42 + 0.61) + 0.45 \times (0 + 0.41) = 1.87$

Table 5 Overall total benefits associated with investing in indicators listed for the design of sustainability portfolios in each province

Shandong[a]		Guangdong[b]	
$b^p_{\alpha 1}$	1.11	$b^p_{\alpha' 1}$	1.87
$b^p_{\alpha 2}$	1.21	$b^p_{\alpha' 2}$	1.46
$b^p_{\alpha 3}$	0.91	$b^p_{\alpha' 3}$	1.71
$b^p_{\alpha 4}$	0.51	$b^p_{\alpha' 4}$	1.59
$b^p_{\alpha 5}$	0.84	$b^p_{\alpha' 5}$	1.25
$b^p_{\alpha 6}$	1.31	$b^p_{\alpha' 6}$	1.33
$b^p_{\alpha 6} > b^p_{\alpha 2} > b^p_{\alpha 1} > b^p_{\alpha 3} > b^p_{\alpha 5} > b^p_{\alpha 4}$		$b^p_{\alpha' 1} > b^p_{\alpha' 3} > b^p_{\alpha' 4} > b^p_{\alpha' 2} > b^p_{\alpha' 6} > b^p_{\alpha' 5}$	

[a] Shandong: α_1 = environmental and financial regulations and policies, α_2 = eco-region protection, α_3 - = energy use and intensity, α_4 = green economic development policies, α_5 = Financial investment in green economy, α_6 = climate change and carbon management

[b] Guangdong: α'_1 = environmental and financial regulations and policies, α'_2 = health risk analysis and management, α'_3 = green economic development policies, α'_4 = energy use and intensity, α'_5 = eco-region protection, and α'_6 = industrial growth and GDP

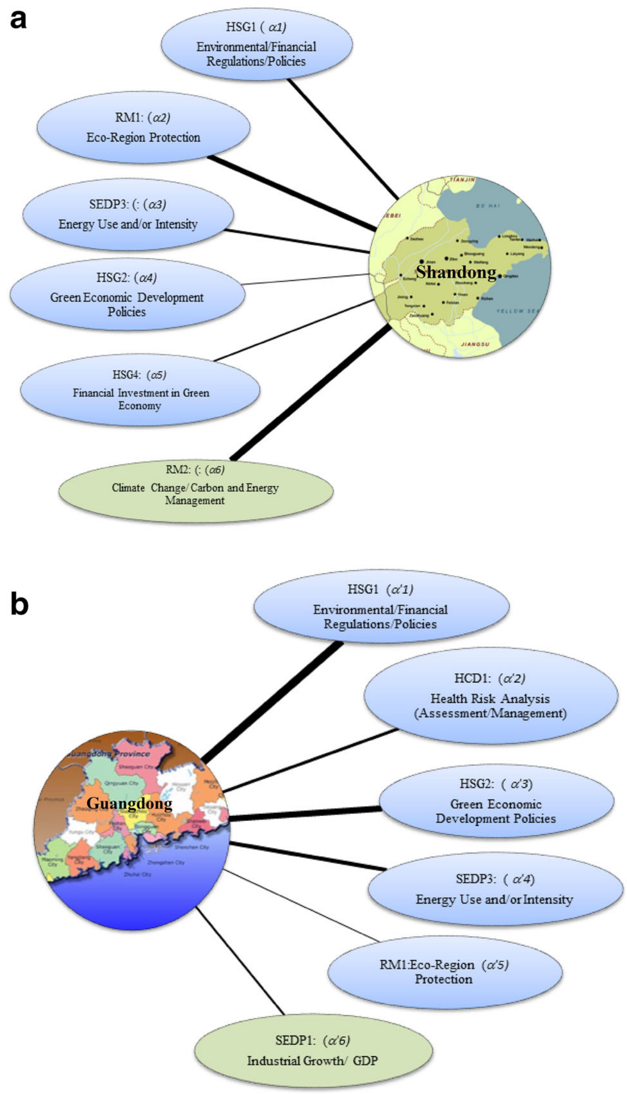


Fig. 11 **a** Top ranked sustainability initiatives in Shandong (*thickness of the lines* are indicatives of the benefits). **b** Top ranked sustainability initiatives in Guangdong (*thickness of the lines* are indicatives of the benefits)

initiatives) that can be invaluable in decision-making about sustainability. We do this through a framework that includes multiple stakeholders, multiple data sources, and a multi-stage process for identifying and ranking sustainability initiatives.

We identified three primary stakeholder groups whose input was necessary for our study. These included (1) policy makers, who develop sustainability regulation and audit industry, (2) academia which develops the intellectual capital necessary for developing sustainability measures, and (3) industry leaders who implement sustainability measures. We used an on-line survey to gather information about preferences and expected benefits from the stakeholders, supplemented with regional economic development data. Employing a graphical multi-agent decision making model we determined the total benefits that could be derived from different sustainability programs.

The final output is a portfolio of possible sustainability initiatives. Within a portfolio, the initiatives are ranked by their potential net benefit to aid decision-makers in choosing how to allocate resources. The rankings support sustainability by demonstrating which initiatives will generate the most benefit and, consequently, the most support from stakeholders such as policy makers and environmentalists. The framework requires identifying stakeholder preferences and concerns, the requirements of sustainable development trends, and the valuation of benefits expected from the organization's sustainability efforts. Inclusion of the development pattern and the context within which organizations function was found to be an important factor in the design of optimal portfolios, resulting in portfolio elements and rankings that are customized to a location.

Both the convenience and effectiveness of the proposed framework were evaluated through two case studies in China. Results of those studies demonstrate that:

(a) The framework is capable of guiding an organization's efforts toward optimizing its sustainability initiatives, according to the sustainability projects' overall benefits.
(b) Including stakeholder data collection and analysis will result in portfolios that create and maintain a balance between the values and expectations of organizations' internal and external stakeholders.
(c) The relevance and practicality of the proposed framework depends on the depth of information provided on organizations' location, socioeconomic conditions, and sustainability focus.

The case studies were intended to highlight how the proposed framework can assist with developing optimized sustainability portfolios of options. The portfolios developed in the case studies, accordingly, show how sustainability initiatives must be customized to reflect both specifications of the socioeconomic dimensions and patterns of economic development within which organizations function.

Future work could appeal to a broader audience by focusing on the design of portfolios for organizations operating in diverse regions, and differing political systems, as well as developed and developing economies, and might include:

- Studying specific economic sectors.
- Identifying different important stakeholders, if and where these are important.
- Examining whether the framework should include resource availability.

- Estimating the effect of educating stakeholders on existing sustainability programs and resources, and determining if such data should be included.

Finally, to advance the utility of the framework, there could be further development of the valuation methods and/or novel applications of new techniques to new data sets.

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Appendix

See Tables 6, 7, 8 and 9.

Table 6 List and definition of the criteria and group indicators

Fundamentals of resource management	Human capital development
RM1 = eco-region protection (e.g., deserts, forests, grasslands	HCD1 = health risk analysis (assessment/management)
RM2 = climate change/carbon and energy management	HCD2 = employment development/equality (gender–age–race)
RM3 = Water management/conservation programs	HCD3 = access to education
RM4 = earth-land use management/critical material	HDC4 = access to labor market
RM5 = use of critical/non renewable material	
Socio-economic development/prosperity	Human system development and governance
SEDP1 = industrial growth/GDP per capita	HSG1 = environmental/financial regulations/policies
SEDP2 = household earning and saving	HSG2 = green economic development policies
SEDP3 = energy use and/or intensity	HSG3 = global cooperation/partnership initiatives
SEDP4 = global partnership	HSG4 = financial investment in green economy
SEDP5 = rate and dispersity of job creation	

Table 7 Stakeholders' background data collection form

1-Discipline (Business, Engineering, Science, Economics,… etc.):					
2-Age					
3-Nationality					
4-Gender					
5-Academic Degree					
6-Are you directly involved with sustainability education/practice? (Circle Yes or No)	Yes		No		If Yes, please describe:
7-What best describes you? (Circle best answer)	Faculty	Researcher	Consultant	Other*	*If Other, please describe:
8-Were you involved with Sustainability Education/Practice in your previous professional activity? (Circle Yes or No)	Yes		No		If Yes, please describe:
9-Do you have any experience in developing curricula for academic education? (Circle Yes or No)	Yes		No		If Yes, please describe:
10-Membership/affiliation with any organizations dealing with sustainability issues?	Yes		No		If Yes, please describe:

Table 8 Questionnaire for collecting data on importance of sustainability areas

Sustainability-focused areas	Resource management (RM)					Socio-economic development and prosperity (SEDP)					Human capital development (HCD)				Human system and governance (HSG)			
	RM1	RM2	RM3	RM4	RMS	SEDP1	SEDP2	SEDP3	SEDP4	SEDPS	HCD1	HCD2	HCD3	HCD4	HSG1	HSG2	HSG3	HSG4
Example scoring values from 0 to 3	3	1	2	2	3	3	2	1	0	2	1	2	1	2	1	2	3	0
Demand management																		
Sustainable transportation																		
Agriculture, food security																		
Climate change issues and carbon management																		
Energy systems, intensity, demand																		
Water management																		
Waste management																		
Financial models for sustainable development																		
Management of resources and critical material																		
International trade/global issues																		
Others 1 (please propose)																		
Others 2 (please propose)																		
Others 3 (please propose)																		
Example weights (any value between 0 and 1)	1	0.5	0.5	1	1	1	1	0	1	0.7	0	0.5	0.3	0.8	0.4	1	0	0.5

Scores: Scores: 0 = not important, 1 = slightly important, 2 = important, 3 = very important

Weights: Weight needs to be a value between 0 and 1 (i.e. 0.2, 0.4, 0.55, … 1) and assigned to each indicator defined for each category (default value = 1). Weight indicates relative importance of the indicators in each criterion/country-region

Table 9 Estimated averaged total scores for each sustainability topic (area)

Descriptive statistic summary	Resource management (RM)					Socio-economic development and prosperity (SEDP)					Human capital development (HCD)				Human system and governance (HSG)			
Sustainability topics	RM1	RM2	RM3	RM4	RM5	SEDP1	SEDP2	SEDP3	SEDP4	SEDP5	HCD1	HCD2	HCD3	HCD4	HSG1	HSG2	HSG3	HSG4
Demand management																		
Southern	0.41	0.34	0.37	0.37	0.38	0.43	0.36	0.42	0.27	0.34	0.54	0.47	0.41	0.46	0.60	0.49	0.39	0.33
Northern	0.54	0.47	0.44	0.36	0.44	0.49	0.38	0.55	0.26	0.39	0.44	0.43	0.50	0.48	0.59	0.59	0.39	0.54
Total	0.47	0.41	0.41	0.37	0.41	0.46	0.37	0.48	0.26	0.36	0.49	0.45	0.46	0.47	0.59	0.54	0.39	0.44
Sustainable transportation																		
Southern	0.45	0.40	0.38	0.40	0.39	0.43	0.30	0.44	0.29	0.37	0.55	0.42	0.43	0.46	0.61	0.46	0.42	0.45
Northern	0.51	0.45	0.41	0.42	0.39	0.53	0.36	0.50	0.30	0.31	0.36	0.40	0.43	0.36	0.52	0.62	0.36	0.55
Total	0.48	0.42	0.39	0.41	0.39	0.48	0.33	0.47	0.30	0.34	0.45	0.41	0.43	0.41	0.57	0.54	0.39	0.50
Agriculture, food security																		
Southern	0.47	0.41	0.41	0.43	0.40	0.42	0.34	0.43	0.29	0.38	0.53	0.43	0.39	0.41	0.58	0.46	0.39	0.40
Northern	0.57	0.46	0.45	0.42	0.35	0.51	0.39	0.54	0.36	0.31	0.50	0.43	0.45	0.41	0.60	0.66	0.45	0.63
Total	0.52	0.43	0.43	0.42	0.37	0.47	0.37	0.49	0.33	0.34	0.51	0.43	0.42	0.41	0.59	0.56	0.42	0.52
Climate change issues and carbon management																		
Southern	0.47	0.48	0.43	0.39	0.42	0.43	0.35	0.52	0.31	0.36	0.52	0.43	0.38	0.41	0.66	0.56	0.41	0.42
Northern	0.61	0.58	0.39	0.33	0.41	0.51	0.29	0.56	0.42	0.32	0.46	0.36	0.41	0.39	0.66	0.62	0.44	0.59
Total	0.54	0.53	0.41	0.36	0.41	0.47	0.32	0.54	0.37	0.34	0.49	0.39	0.40	0.40	0.66	0.59	0.43	0.51
Energy systems, intensity, demand																		
Southern	0.46	0.46	0.41	0.35	0.42	0.47	0.28	0.55	0.28	0.37	0.54	0.47	0.37	0.44	0.62	0.47	0.48	0.40
Northern	0.56	0.53	0.40	0.32	0.45	0.47	0.29	0.63	0.36	0.30	0.40	0.40	0.47	0.41	0.60	0.66	0.37	0.61
Total	0.51	0.50	0.40	0.33	0.43	0.47	0.28	0.59	0.32	0.33	0.47	0.44	0.42	0.42	0.61	0.56	0.42	0.51
Water management																		
Southern	0.46	0.41	0.51	0.37	0.41	0.43	0.33	0.47	0.30	0.36	0.54	0.43	0.42	0.38	0.62	0.55	0.46	0.45
Northern	0.63	0.46	0.54	0.32	0.34	0.45	0.37	0.55	0.33	0.32	0.45	0.43	0.45	0.42	0.61	0.52	0.33	0.58
Total	0.55	0.44	0.52	0.35	0.37	0.44	0.35	0.51	0.32	0.34	0.50	0.43	0.43	0.40	0.61	0.53	0.40	0.52
Waste management																		
Southern	0.51	0.44	0.43	0.38	0.46	0.38	0.32	0.43	0.27	0.36	0.58	0.44	0.40	0.43	0.60	0.55	0.43	0.44
Northern	0.58	0.44	0.44	0.32	0.41	0.46	0.32	0.51	0.29	0.32	0.45	0.42	0.45	0.44	0.61	0.61	0.39	0.53
Total	0.54	0.44	0.44	0.35	0.43	0.42	0.32	0.47	0.28	0.34	0.52	0.43	0.43	0.43	0.61	0.58	0.41	0.48
Financial models for sustainable development																		
Southern	0.42	0.40	0.36	0.33	0.36	0.43	0.35	0.47	0.29	0.37	0.55	0.44	0.43	0.41	0.59	0.48	0.42	0.39
Northern	0.54	0.48	0.41	0.32	0.39	0.57	0.45	0.46	0.36	0.39	0.40	0.45	0.43	0.48	0.69	0.64	0.40	0.59
Total	0.48	0.44	0.38	0.32	0.37	0.50	0.40	0.46	0.32	0.38	0.48	0.45	0.43	0.44	0.64	0.56	0.41	0.49

Table 9 continued

Descriptive statistic summary	Resource management (RM)					Socio-economic development and prosperity (SEDP)					Human capital development (HCD)				Human system and governance (HSG)			
Sustainability topics	RM1	RM2	RM3	RM4	RM5	SEDP1	SEDP2	SEDP3	SEDP4	SEDP5	HCD1	HCD2	HCD3	HCD4	HSG1	HSG2	HSG3	HSG4
Management of resources and critical material																		
Southern	0.44	0.39	0.38	0.37	0.43	0.41	0.32	0.46	0.23	0.37	0.53	0.42	0.40	0.38	0.63	0.43	0.37	0.45
Northern	0.55	0.48	0.40	0.37	0.51	0.48	0.35	0.57	0.33	0.34	0.29	0.38	0.43	0.44	0.57	0.63	0.34	0.57
Total	0.50	0.43	0.39	0.37	0.47	0.45	0.34	0.51	0.28	0.36	0.41	0.40	0.41	0.41	0.60	0.53	0.35	0.51
International trade/global issues																		
Southern	0.43	0.40	0.35	0.32	0.37	0.40	0.34	0.45	0.31	0.39	0.51	0.46	0.38	0.37	0.57	0.46	0.45	0.40
Northern	0.42	0.44	0.35	0.28	0.38	0.47	0.39	0.51	0.47	0.38	0.40	0.44	0.51	0.52	0.63	0.58	0.56	0.58
Total	0.43	0.42	0.35	0.30	0.38	0.43	0.37	0.48	0.39	0.38	0.46	0.45	0.44	0.44	0.60	0.52	0.51	0.49
Weighted average total																		
Southern	0.45	0.41	0.40	0.37	0.40	0.42	0.33	0.46	0.28	0.37	0.54	0.44	0.40	0.41	0.61	0.49	0.42	0.41
Northern	0.55	0.48	0.42	0.35	0.41	0.49	0.36	0.54	0.35	0.34	0.42	0.41	0.45	0.43	0.61	0.61	0.40	0.58
Total	0.50	0.45	0.41	0.36	0.41	0.46	0.34	0.50	0.32	0.35	0.48	0.43	0.43	0.42	0.61	0.55	0.41	0.50

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