Chen and Yang
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Developing decision model and sustainable mapping to screen the efficiency of brownfield redevelopment based on socioeconomic open data

I-Chun Chen[1*] and Bo-Chieh Yang[2]

Abstract

The Sustainable Development Goals (SDGs), adopted by the United Nations in 2015, comprise 17 goals developed to balance social, economic, and environmental sustainability. Regional sustainable development can be considered an important part of investment to redevelop brownfields. With breakthroughs in information technology, Taiwan has established a number of open databases. This study uses open datasets of regional socioeconomic and environmental geo-information to develop a regional SDG map and screen suitable brownfield locations for redevelopment. In addition, this study has designed a Brownfield Redevelopment Query model that combines socioeconomic geographic information obtained from big data with sustainable potentiality for evaluating benefit-cost ratios (BCRs). Land stakeholders can obtain useful information prior to brownfield investment. The flexible user interface is useful for exploring the outcomes of the BCRs (consolidation, internalities, and externalities) for four land-use scenarios (residential, industrial, commercial, and other and public land with renewable energy facilities) of brownfield redevelopment. The brownfield redevelopment BCR is positively dominated by operating profits in the reuse stage for two sites. In addition, the externalities BCR value of the studied cases is positive, particularly in converting the residential land if the site is located at Level 4 or Level 5 of the SDG map. Consequently, this study uses a large quantity of transparent information and a flexible user interface to develop a useful evaluation tool and reduce the possible pitfalls associated with brownfield redevelopment for land stakeholders.

Keywords: Sustainable potentiality, Brownfield redevelopment query (BRQ), Socioeconomic and environmental geo-information, Open data, Flexible user interface design, SDGs map

1 Introduction

Land use, redevelopment, and transformation are complex issues. The responses of decision-makers to urban development are driven by socioeconomic and political factors that transform overall land use [1, 2]. Land use and regional economic growth are often mutually beneficial to urban development. Brownfield redevelopment is often regarded as part of land sustainability policies because it can benefit the environment, economy, and society in urban areas [3]. On the other hand, the land value of a brownfield is usually high when located in an area with relatively mature development conditions, such as environmental, economic, and social characteristics [4, 5]. The success factors of brownfields are often accompanied by zoning conditions to facilitate land reuse [6]. The motivation for brownfield redevelopment by local governments is regional development. Accordingly,

*Correspondence: cogiitri@gmail.com
[1] Department of Land Resources, Chinese Culture University, Taipei 11114, Taiwan
Full list of author information is available at the end of the article

brownfield research has increasingly focused on the sustainability of the local environment, economy, and social conditions to determine the best approach [7–11].

Brownfields have various environmental, social, and economic impacts before redevelopment. In the environmental dimension, the transmission and diffusion of pollutants may damage natural resources and endanger human health and the environment. Brownfields reduce tax revenue, increase the local unemployment rate, and hinder economic development, which reduces the value of the surrounding land. In the social dimension, brownfields are a concern for public security [12]. Brownfields potentially attract criminals and illegal activities, which are detrimental to urban development, neighborhood relationships, and local living standards, further depleting public resources [13]. Furthermore, the land-use decisions for brownfields during long-term redevelopment cannot usually respond to changes in dynamic environmental, economic, and social conditions. Brownfield redevelopment has not been linked to sustainable development, which has led to the decoupling of brownfield redevelopment from the national land management strategy [14, 15]. To facilitate decision-making for brownfield sustainability, indicators have been developed to assess the effectiveness of this approach using drive-pressure-state-impact-response or quantitative analysis [16–20]. Land governance policies should utilize scientific urban research findings and the benefits of sustainability, particularly in brownfield issues [21–23]. However, many researchers have argued that an abundance of electronic information cannot improve the communication gap between the government and stakeholders [24]. In complex brownfield development, if the information is not transparent, most investors remain uncertain about the reuse vision for land policy planning. In addition, effective quantitative analysis for the scenario evaluation of brownfields requires large datasets, even though data-driven analysis has improved public communication about the implementation of the Sustainable Development Goals (SDGs) in megacities [25, 26]. Therefore, further research is required to reduce the uncertainty resulting from electronic information on land governance strategies. Some experts consider that diverse and complex socio-economic and environmental conditions can improve the effectiveness of land governance, in accordance with the following three themes: (1) land change intention plans driven by visualization analysis, (2) territorial governance process of public participation and communication, and (3) external conditions for planning and implementation [2, 24]. If the decision-making system combines the rich social, economic, and environmental information derived from government open data, stakeholders such as landowners, developers, and regulatory agencies can effectively evaluate land value, environmental benefits, and social impacts, thereby reducing investment uncertainty [27–31]. Government entities can employ the decision-making system as the main platform for public communication and review the benefits of promoting various brownfield plans [32].

Rapid changes in Taiwan have shortened the life cycle of each industry and created a large area of contaminated land. In Taiwan, there have been approximately 120,000 factories abandoned since 1986, equalling one abandoned factory per 2.66 km^2 [20]. The number of remedial sites and controlled sites in Taiwan continues to grow annually under the current land-use scenario. In Taiwan, the five types of remedial sites and controlled sites are factories, gas stations, agricultural land, storage tanks, and others, accounting for 4.66, 2.11, 91.18, 0.14, and 2.00% of land-use types, respectively [33]. Environmental remediation is the main strategy for managing remedial sites and controlled sites to promote their reuse in Taiwan. Polluted agricultural land accounts for most land-use areas eligible for Soil and Groundwater Pollution Remediation Funds. The investigation of potentially highly-polluted agricultural lands began in 2002. Approximately 73.2% of this land was cleared by 2020 and released from government control [33]. The Taiwanese government expects the period of all polluted agricultural land to be delisted is more quickly rather than other remedial sites and controlled sites, which means that the most decontaminated sites will come from the ever polluted agricultural lands. Presently, site management has focused on remediation but has failed to deliver deeper insights into the comprehensive governance of urban planning.

According to information published by the Taiwan Environmental Protection Agency (EPA), 3.5 and 6.6 years are required on average for delisting controlled and remediation sites, respectively. According to Article 24 of the Soil and Groundwater Remediation Act, the objectives of the remediation plan can be flexible and depend on the results of the health risk assessment [34]. However, for contaminated sites declared as remedial sites, land-use types cannot be changed until relevant pollutants are removed to the extent that the contamination level is below the pollution control standards. Many highly remedial sites in Taiwan are not ready for redevelopment because of challenges in removing pollutants. Landowners and developers remain cautious about the uncertainties surrounding land investment [35]; therefore, 85% of the listed remediation sites have not been delisted. Presently, only a large investment in remediation funds can delist a site from the category of contaminated land.

The social, economic, and environmental impacts of brownfield redevelopment in the remediation, redevelopment, and reuse stages provide important information. This study contributes to the improvement of decision-making regarding brownfield management. Large amounts of external information based on government open data must be considered for market analysis before decisions on brownfield investments are made by landowners. Regulators can incorporate environmental and social impacts to improve the supervision benefits for brownfield redevelopment. Considering these elements, this study has combined open data of socioeconomic geographic information about contaminated land and has analyzed the potential for sustainable development in Taiwan's various regions. The four goals of this study are to (1) identify the sustainable development dimensions and factors to be considered for brownfield redevelopment planning; (2) construct a sustainability evaluation system and link database for brownfield redevelopment with social, economic, and environmental dimensions, based on the open data published by the government of Taiwan; (3) establish an evaluation tool for brownfield redevelopment queries; and (4) present a case study of Taiwan's management strategies for brownfield redevelopment.

2 Materials and methods

2.1 Sustainable development factors for brownfield redevelopment

The objective of research on brownfield sustainability, since its beginning in 2009, was identified as transformation of brownfields into green land-based on stakeholders' viewpoints [15]. The sustainable development of brownfields involves several complex aspects. The most studied brownfields have achieved economic, social, ecosystem, and environmental objectives to develop sustainable aspects [19, 36]. Cappai et al. performed a cross-analysis of 20 brownfield studies worldwide and concluded that sustainable brownfield redevelopment requires an approach that combines environmental and social equity, justice, and economic strategies [37]. European Union land experts and scholars have suggested an integrated spatial planning strategy in which they identified SDGs that related to land policies, including food security (SDG2), good health and well-being (SDG3), clean water (SDG6), accessible and reliable energy (SDG7), resilient infrastructure (SDG9), sustainable cities (SDG11), responsible consumption and production (SDG12), life below water (SDG14), and sustainable land use (SDG15) [38]. In 2016, the Taiwanese government announced the National Land Planning Law to ensure homeland security and sustainable development. Furthermore, the Taiwan SDGs were established in 2018, and 143 sub-indicators were formally announced in a report [39]. This study integrated Taiwan's sustainable development-oriented indicators and the most relevant literature. The dataset for evaluating the sustainability of brownfield research redevelopment was available from open data, as shown in Table 1. Consequently, this study adds Goals 1 and 4, eliminates Goal 14, and combines Goal 9 with Goal 10.

Taiwan established an open database project in 2013 called the Advanced Action Program for Open Government Data, which includes data on population, employment, land, education, medical care, social welfare, energy, water resources, and the environment. A total of 150,793 socioeconomic geographic information datasets were planned based on geographical classification [40]. Information is provided in the form of JavaScript object notation, extensible markup language comma-separated values, spatial shapefile data, web map services, and other file formats. Therefore, this study utilized the Taiwan Open Database to present the potential for sustainable development in various regions. In addition, rich data can enhance the credibility of data analysis [41, 42]. Socioeconomic geographic information can effectively provide extensive applications such as urban development, residential land supply and demand planning, pollution prediction, and regional population change adaptation. The same temporal and spatial datasets can improve the quality of the studied results using the largest open data; therefore, all data sources used the same geographic classification (township level) and the extracted dataset from 2018 to 2019 in this study. To consider the SDG-related information from open data [43–45], study overlays specific to poverty (SDG1), food security (SDG2), health (SDG3), education (SDG4), environmental quality (SDG6), affordable energy (SDG7), infrastructure (SDG8), sustainable cities (SDG11), and land degradation (SDG15) as shown in Table 2.

Improved natural, social, economic, and environmental conditions can induce regional development towards becoming a sustainable and mature city. As a result, the indicators were organized into five potentialities according to stakeholder questionnaires addressing key factors. These potentialities were applied to screen the priority remedial sites for Taiwan EPA [46]. The weighted values in terms of "public service potentiality," "land potentiality," "developing potentiality," "environment potentiality," and "big data and Internet of Things (IoT) potentiality" are 15.96, 23.76, 34.00, 14.17, and 12.12%, respectively, in Taiwan [46, 47]. Public service potentiality includes livelihood service facilities, public infrastructure service facilities, and cultural service facilities, among others. Livelihood service facilities (hospitals and schools) are the main monitoring factors for regional governance; therefore, it is easy to obtain township-level open data. Land potentiality includes land price, regional land-use

Table 1 Literature reviews of developing sustainable indicators of brownfields redevelopment

Aspects	UNSDGs	Dimensions	References
Social	SDG1 No poverty	• Provide adequate local service.	[15, 36, 37]
	SDG2 Zero huger	• Provide enough land from food production to ecosystem services.	[38]
	SDG4 Quality education	• Facilitate education.	[15, 19, 36]
Economic	SDG8 Decent work and economic growth	• Provide employment opportunities. ˙Promote local and regional economic. • Improve site marketing.	[15, 19, 36]
	SDG9* Industry, innovation and infrastructure	• Reduce infrastructure time cost.	[36–38]
	SDG11 Sustainable cities and communities	• Promote local affluence and community prosperity.	[15, 19, 36–38]
Environmental	SDG3 Good health and well-being	• Promote health of worker and residence. ˙Reduce and management of contamination risk.	[15, 36–38]
	SDG6** Clean water and sanitation	• Promote land, water, soil, and air quality.	[15, 19, 36–38]
	SDG7 Affordable and clean energy	• Minimise and management the use of resources.	[15, 36, 37]
Ecosystem	SDG14 Life below water	• Protect biodiversity and natural environment.	[36–38]
	SDG15 Life below land	• Protect biodiversity and natural environment	[36–38]

Note:

* SDG9 indicates the affordable, safe, environmentally friendly, resilient and sustainable transportation in Taiwan, in which meaning is different with an asterisk of UNSGD

** SDG6 indicates the environmental quality and sustainable management of environmental resources in Taiwan, in which meaning is different with an asterisk of UNSGD

type, and polluted site area. In particular, the different patterns of regional land-use types affect people's needs, such as food supply, living comfort, and environmental conditions (terrestrial ecosystem). Developing potentiality includes the degree of the surrounding population and enterprise clustering, regional economic trends, and traffic convenience, among others. Environment potentiality is the degree of environmental quality improvement, which includes monitoring of air and water quality and waste quantity. Most information on environmental quality in open data sources contains only county-level information. The IoT has been widely used in various fields in Taiwan; therefore, air sensors and groundwater quality monitors can downscale and supplement information to strengthen the lack of environmental quality data. As a result, this study uses the real concentration, measured by air sensors with the most abundant spatial coverage, and the affected buffer of the monitoring sensor (250 m radius) to reorganize the instantaneous concentration and recalculate the days of being suitable moderate level (yellow and green light) of Air Quality Index (AQI) into affected town-ship level information. The environmental potentiality, big data, and IoT potentiality of weight are integrated and set to 26.29% because a vast amount of IoT information is used for environmental and carbon emission monitoring, such as AQI in Taiwan. According to Article 5 of the Greenhouse Gas Reduction and Management Act, an increase in renewable energy supply ensures national energy security (20% of electricity through renewable energy in 2025) [48]. Although the installed capacity of renewable energy can respond to the electricity public service infrastructure, the improvement of carbon emissions and the impacts of climate change on renewable energy facilities are also crucial for environment potentiality. Therefore, this study adds this indicator to the environment potentiality.

This study pre-explores the regional development potential target maps by normalizing the analyzed indicator data, as shown in Table 2. The study first normalizes the value of each indicator at the township-level data and evaluates the average of the analyzed data with the same potentiality. For example, the value of public service potentiality results from the normalized average of SDG 1 and 3. The study then uses the geometric interval classification of geographical statistics to identify the five grades as the analyzed score for each potentiality. Finally, the integrated value of the five levels of regional SDG scores is calculated using the weight setting of four potentialities

Table 2 Indicators and data source of mapping sustainability used in this study

Item	Weighted value	Score	Indicators	Sub-indicators	Target maps
Public service potentiality	15.96%	Level 1 (0.00–0.35) Level 2 (0.36–0.45) Level 3 (0.46–0.80) Level 4 (0.81–1.90) Level 5 (2.00–5.50)	Goal 1. Strengthen social care services and economic security for the disadvantaged	1.3 Optimize the coverage of all citizens and constantly provide living assistance for the senior citizens, children, and youth in the vulnerable group	Community care
			Goal 3. Ensure healthy lives and promote well-being for all at all ages	3.4 Promote the healthy lifestyle for citizens	Average service patient per hospital
Land potentiality	23.76%	Level 1 (0.00–0.47) Level 2 (0.48–0.85) Level 3 (0.86–1.18) Level 4 (1.19–1.45) Level 5 (1.46–1.68)	Goal 2. End food security, eradicate huger and promote sustainable agriculture	2.4 Progressively improving land and soil quality	Agricultural land
			Goal 6. Ensure environmental quality and sustainable management of environmental resource	6.6 Accelerate polluted site improvement to ensure the sustainable use of soil and groundwater resources and protect public health	Decontamination land area
			Goal 15. Conserve and sustainably use terrestrial ecosystems to ensure the persistence of biodiversity and prevent land	15.3 Restore degraded land and soil	
Developing potentiality	34.00%	Level 1 (0.06–0.14) Level 2 (0.15–0.38) Level 3 (0.39–1.05) Level 4 (1.06–2.94) Level 5 (2.95–8.25)	Goal 4. Ensure inclusive and equitable quality education	4.3 Ensure all people have opportunities to accept equal, affordable and quality higher education	Student statistics
			Goal 8. Promote sustained, inclusive and sustainable economic growth	8.1 Sustain appropriate economic growth	Average income
				8.2 Increase the value of industries	Enterprise
			Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	11.3 Promote inclusive, sustainable and full participatory cities	Population growth
Environment potentiality	26.29%	Level 1 (0.00–0.46) Level 2 (0.47–0.90) Level 3 (0.91–1.32) Level 4 (1.33–1.72) Level 5 (1.73–2.11)	Goal 6. Ensure environmental quality and sustainable management of environmental resource	6.1 Supply adequate quantity of quality water	Tap water supply
				6.c Improve air quality to protect public health	Air Quality Index
				6.d Reduction of general waste and promote resource recycling	Waste recycling
			Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all	7.2 Increase the installed capacity of renewable energy	Renewable energy supply

Resources: [43–45]

in the study. The integrated SDG map was used to evaluate the sustainable potentiality for each brownfield's location. The higher the grade, the higher the sustainability score: Level 1 (red), 0.03–0.49; Level 2 (orange), 0.50–0.72; Level 3 (yellow), 0.73–1.18; Level 4 (light green), 1.19–2.08; and Level 5 (dark green), 2.09–3.85.

2.2 Brownfield redevelopment query model

To provide land developers and regulators with an evaluation tool for assessing the environmental, economic, and social impacts of brownfield redevelopment, this study has developed the Brownfield Redevelopment Query (BRQ) model (Fig. 1). Stakeholders can examine changes over the years based on the factors of interest by leveraging the open database, thereby gaining necessary insights into the impacts of brownfields in the three major stages of remediation, redevelopment, and reuse. The model can be used to convert environmental, economic, and social impacts into the benefit-cost ratio (BCR) as a unified evaluation benchmark. According to research on the brownfield sustainability index (BSI), an evaluation tool for environmental analysis (the cost of pollutant removal and the amount of resource consumption, including carbon emissions and water usage), economic analysis (land value, residential rent, and average income of enterprises' operations and employees), and social analysis (employment increases) must be considered [14]. The benefit parameters are $B_{ex}(t)$, $B_{lvi}(t)$, $B_{bvi}(t)$, $B_{res}(t)$, and $B_{si}(t)$. The cost parameters are $C_c(t)$, $C_{exi}(t)$, $C_l(t)$, and $C_{ri}(t)$. The meaning of each parameter is listed in Table 3. The BSI is the subtraction value based on benefits and costs, and the index uses net value (externality) divided by net value (internality). However, the main investment viewpoints of the different stakeholders are dissimilar. For example, land investors and developers consider internality BCR, which is a gain in earning income per land investment cost. For the government or public, externality benefits, such as environmental and social improvement, are the most important considerations for evaluating brownfield redevelopment. The net external benefits in BSI include only environmental issues and not social benefits (added employment income). However, social benefits are attributed to the externality issue and do not exist among investors or developers. Therefore, the BRQ model modifies BSI evaluation and applies consolidation, externalities, and internalities of the BCR to different stakeholders. The calculation formulae are as follows:

$$\mathrm{BSI} = \frac{(\mathrm{A} - \mathrm{C})}{(\mathrm{B1} + \mathrm{B2} - \mathrm{D})} \tag{1}$$

$$\mathrm{BCR}\left(\mathrm{externality}\right) = \frac{(\mathrm{A} + \mathrm{B2})}{\mathrm{C}} \tag{2}$$

$$\mathrm{BCR}\left(\mathrm{internality}\right) = \frac{\mathrm{B1}}{\mathrm{D}} \tag{3}$$

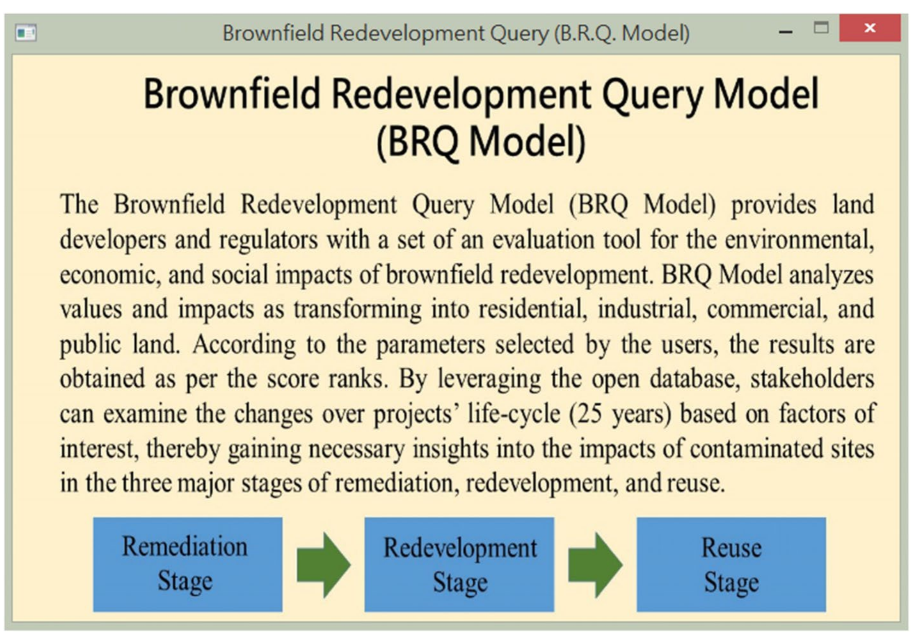

Fig. 1 Brownfield Redevelopment Query (BRQ) model

Table 3 The meaning of each parameter for the BRQ model

Category	Parameters	Meanings
A	$B_{ex}(t)$	total external benefits from carbon mitigation of i type
B1	$B_{lvi}(t)$	total increased land value of i type
	$B_{bvi}(t)$	total business value of i type
	$B_{res}(t)$	total renewable energy subsidy of i type
B2	$B_{si}(t)$	total employment incomes of i type
C	$C_c(t)$	sum of cleanup costs and remediation costs
	$C_{exi}(t)$	external costs from water and carbon emissions of i type
D	$C_l(t)$	total land value of i type
	$C_{ri}(t)$	total redevelopment cost of i type

$$\mathrm{BCR(consolidation)} = \frac{(\mathrm{A} + \mathrm{B1} + \mathrm{B2})}{(\mathrm{C} + \mathrm{D})} \tag{4}$$

The cost-benefit analysis uses the net present value (NPV) in this study; the discount rate was set at 6%, which is within the range of discount rates (4.8–6.5%) used by commercial real estate developers in Taiwan [49]. The NPV of the brownfield was calculated over a 25-yr period. To approximate real cases in Taiwan, the remediation, redevelopment, and reuse terms were 10, 5, and 10 yr, respectively. Users can flexibly modify the life-cycle period of brownfield redevelopment according to real conditions. The BRQ model evaluates the BCR of contaminated sites as transforming into residential, industrial, commercial, and other public land (renewable energy facilities). The evaluation outcomes enable consolidation, externalities, and internalities BCR for the four scenarios to incorporate the information in a map. Users can select a better brownfield redevelopment scenario with the highest consolidation index or impact of externalities and internalities on the BCR for each scenario.

As shown in Fig. 2, the design of the BRQ model comprises data storage, calculations, and output results. Users can obtain open data and input relevant information from the government in three major stages (remediation, redevelopment, and reuse). Upon the input of information, the embedded operational system links to the database containing parameter data with key factors, calculates the BCR for the four scenarios, and presents the output results from the BRQ model. Due to poor data availability, users may be reluctant to use the model, particularly for redevelopment and reuse processes of a long duration. To overcome this problem, the user can first input the coordinates of the contaminated site to identify the township location, and the BRQ model will obtain the analyzed information linked to the management information system (MIS) and geographic information system from an open data source, as shown in Table 4. In some cases, users must assess various possible scenarios before choosing the most appropriate one. Therefore, relevant environmental, social, and economic data from the open database, using the information sources are same as the source in Table 2, were imported into the BRQ model database. The BRQ model used open data, including land-use types in urban and regional planning, average employee income, number of enterprises, tap water supply, and renewable energy supply. The information entered by users, database entries, and data sources are listed in Table 4. The BRQ model has automatic operations and output features. Freeware that compiles and generates BASIC language-style script programs can run automatically on a Windows GUI. It can control interface operations and run calculations according to the parameters selected by users.

2.3 BRQ model screen

The BRQ decision-making model is designed to apply the evaluation tools for investors and the government for the three stages of remediation, redevelopment, and reuse. For each stage, the model includes features for inputting basic site information, selecting and setting criteria, and output results. The basic information input field is designed for site-specific information, such as the site code, section number, site number, coordinates, site area, floor area, and building floor for site identification (Fig. 3). Once the criteria are set by the users, the model can perform calculations based on the database layers and coefficients, as shown in Table 4.

An examination of land transformation cases shows that green building codes are not mandatory in Taiwan. The BRQ model applies to real general buildings as a residential scenario evaluation. Users can decide whether to adopt green building types, and the cost estimates should be increased accordingly. Type 1 in

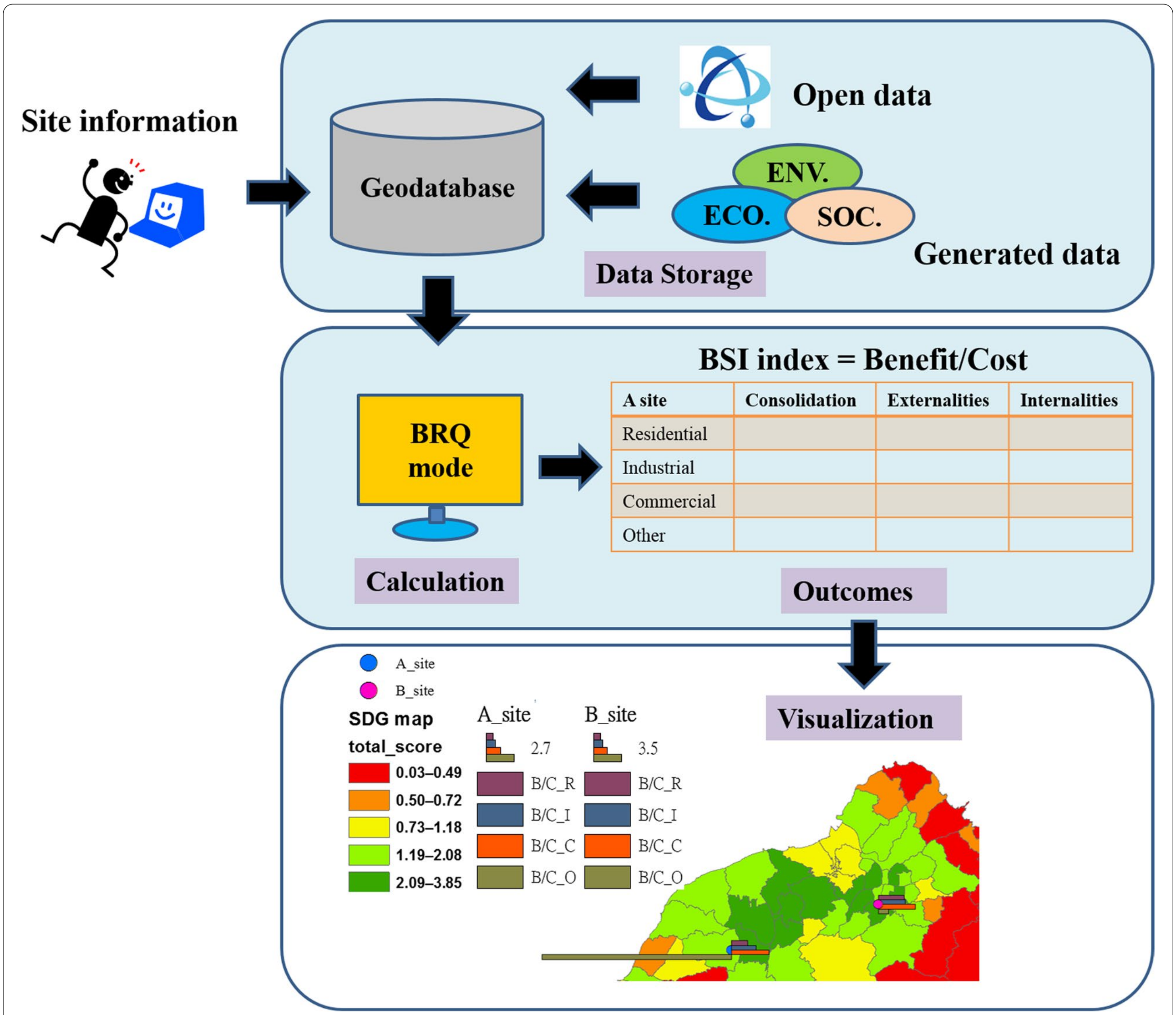

Fig. 2 The design of the information system in the BRQ model

Taiwan's Urban Planning Law (UPL) is the main type of residential buildings. This type of building should be constructed with reinforced concrete. Most economic profits are available from residential rent or increased land prices. According to an industrial survey report, most industrial land changes in land type for electronic component manufacturing [50]. Accordingly, the main type of industrial building is UPL Type 2, which should be constructed with reinforced concrete. According to a commercial survey report, most of the repurposed land is used to build department stores, and the main type of commercial building is UPL Type 2. Considering the efforts of the Taiwanese government to promote renewable energy strategies, the model assumes the scenario that redeveloped public land will be used for solar panel installations [51].

In Fig. 3a, the BRQ model presents the criteria for the remediation stage, including the pollution industry category and geological characteristics such as soil properties. These criteria are used to link the MIS database for soil and groundwater pollutants for a specific industry, remediation technology, and level of energy consumption developed from the government research investigation [50] and estimate the environmental and economic impacts. The criteria for the redevelopment stage, including the urban planning district, development of new buildings, and land redevelopment purposes, are shown in Fig. 3b. These criteria are used to link land-use

Table 4 Data sources and entries for the BRQ model

Stages	Items	Information entered by users	BRQ database entries	BRQ data sources
Remediation	Environment	• Pollution industry • Remediation targets • Electricity consumption • Water consumption • Waste production	• Categories of pollutants removed • Area and volume removed • Influence of geological characteristics • Remediation technology • Carbon emission coefficient • Water footprint coefficient	• User input • Model generated data
	Economy	• Remediation period	• Plan funds • Clearing unit price • Remediation unit price • Remediation subsidy • Electricity, material, and water price	• User input • Model generated data
	Society	• Number of employees in the remediation industry	• Salary level	• Open database
Redevelopment	Environment	• Floor area • Number of floors	• Building coverage ratio • Floor area ratio • Energy and water supply rate • Carbon emission coefficient	• User input • Open database
	Economy	• Present land value • Original land use type • Planned term	• Floor area ratio incentives • Urban and regional planning • Plan funds • Electricity, material, and water price	• User input • Open database
	Society	• Number of employees in the development industry	• Salary level	• Open database
Reuse for residential scenario	Environment	• Residential land use zoning category • Consider green building if necessary	• Size of residential • Rental population • Electricity and water consumption • Building carbon emission coefficient • Building water footprint coefficient	• User input • Model generated data
	Economy	• Operational term • Present land value	• Ratio between the registered value and the announced present land value • Rent level by district • Land value-added tax • Electricity, material, and water price	• User input • Open database
	Society	• Number of employees in the property management industry	• Salary level	• Open database
Reuse for industrial scenario	Environment	• Redevelopment industrial category	• Carbon emission coefficient • Water footprint coefficient • Electricity and water consumption by industry	• Model generated • Open database
	Economy	• Operational term • Present land value	• Ratio between the registered value and the announced present land value • Output by industry •Land value-added tax • Electricity, material, and water price	• User input • Open database
	Society	• Number of employees in electronic component manufacturing	• Salary level	• Open database

Table 4 (continued)

Stages	Items	Information entered by users	BRQ database entries	BRQ data sources
Reuse for commercial scenario	Environment	• Redevelopment commercial category	• Carbon emission coefficient • Water footprint coefficient • Electricity and water consumption by industry	• Model generated data
	Economy	• Operational term • Present land value	• Ratio between the registered value and the announced present land value • Output of department stores • Land value-added tax • Electricity, material, and water price	• User input • Open database
	Society	• Number of employees in warehouse and department stores	• Salary level	• Open database
Reuse for other and public land scenario	Environment	• Renewable energy category	• Solar energy installation capacity • Solar power conversion efficiency • Solar energy intensity by district • Solar carbon emission coefficient • Solar water footprint coefficient	• Model generated • Open database
	Economy	• Operational term • Present land value	• Urban and regional planning • Renewable energy feed-in tariff • Electricity, material, and water price	• User input • Open database
	Society	• Number of employees in renewable energy industry	• Salary level	• Open database

characteristics in different urban plans to the MIS open database for building coverage ratio, floor area ratio, floor area ratio incentives, and water and electricity supply to estimate the environmental and economic impacts in the redevelopment stage. In Fig. 3c–f, the BRQ model shows the criteria for the reuse stage for residential, industrial, commercial, and public land scenarios, including the land zone selection (residential, industrial, and commercial), green building use, building structures, land and rent prices, and land reuse type. For residential land, these criteria are used to link to the MIS open database for building coverage ratio, floor area ratio, and floor area ratio incentives and to calculate the size of the residential development and rental population. These criteria were used to link to an open database for industrial and commercial employees for industrial and commercial land, respectively. After selecting the population size and building structure for each purpose, it is possible to estimate the environmental impact due to the total energy and resource consumption in the reuse stage. The green building option can be used to adjust the impact, and land-use zoning criteria can be used to link to the open database of the advertised present land value to estimate the economic impact. Figure 3f presents the criteria for the reuse stage for public land, including the selection of the renewable energy category and installation capacity, the solar panel types link to solar energy intensity by the district in Taiwan, and solar power conversion efficiency. With information on the land-use pattern in the urban plan selected in the redevelopment stage, it is possible to estimate the installed capacity and power output of the solar system, thereby estimating the environmental impact. By combining solar power output with the open database of renewable energy's feed-in tariff, one can estimate the economic impact. In social impact analysis, it is possible to estimate the employment growth rate at each stage for the average salary and industry-specific employees by consulting the open database.

3 Results and discussion

3.1 Regional development potential and sustainability of brownfield

This study corresponds to Taiwan's sustainable development indicators and establishes an SDG map by evaluating socioeconomic and environmental geo-information (Fig. 4). The results show that the cities of Nantou, Hualien, and Taitung are located in low-sustainability zones (Level 1: red zone) because of their low scores on the public service potentiality index and environment potentiality index. Eastern Taiwan is often regarded as having better environmental protection in factors such as air quality, greenhouse gas control, and green areas. These scores are better than those of other cities, but the reliable and sustainable energy supply in the environment potentiality index is not sufficient to be affordable in Eastern Taiwan. Based on the integrated viewpoints of regional sustainable development

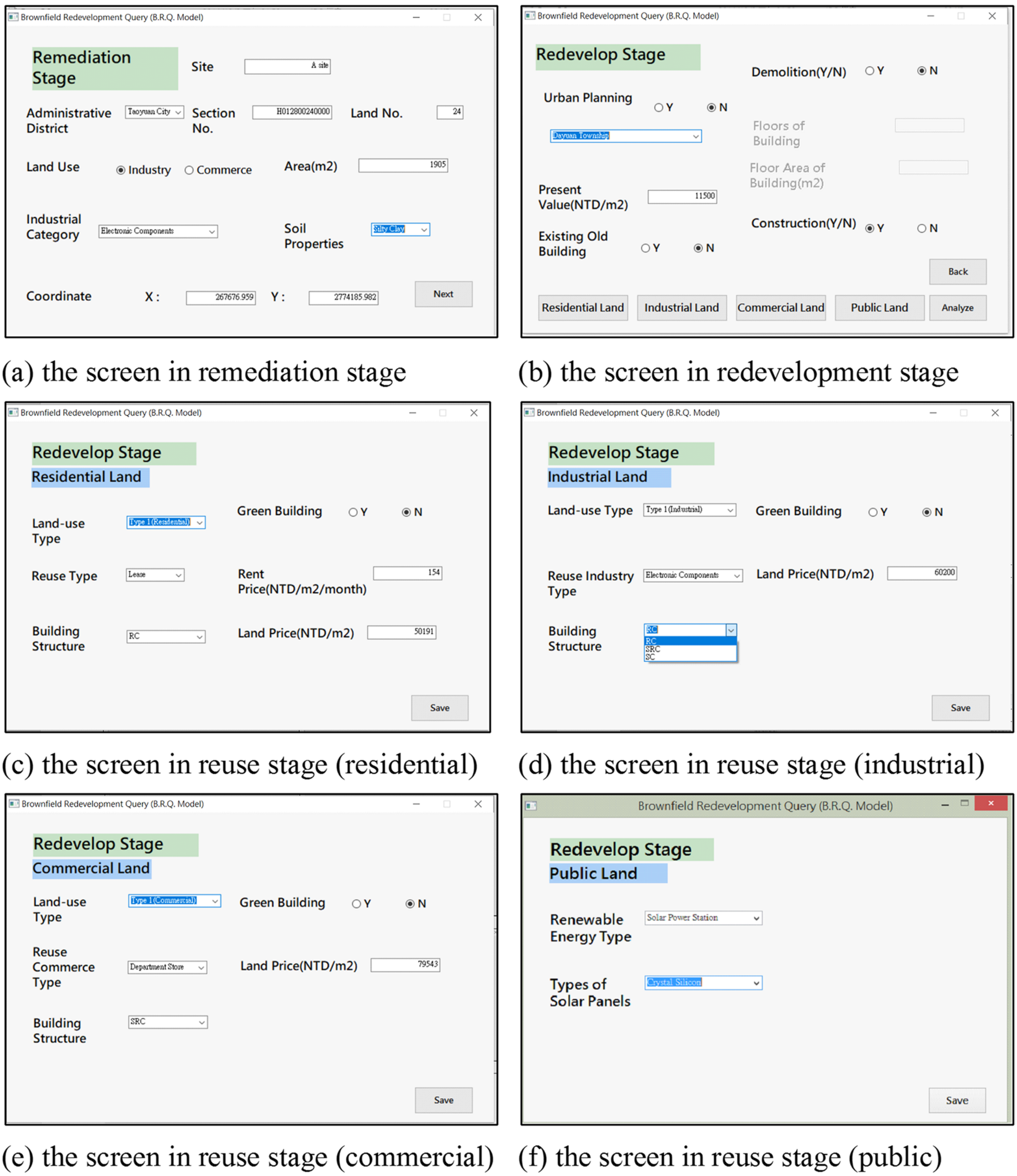

Fig. 3 BRQ model screen

from stakeholder questionnaires, the environment potentiality index is one of evaluated items, and the developing potentiality index is the most crucial in terms of the highest weighting. The health care score (public service potentiality) and education score (developing potentiality) in Nantou, Taitung, and Yilan are lower than those in other cities. Consequently, the potential for sustainable development in these regions is lower than that in other parts

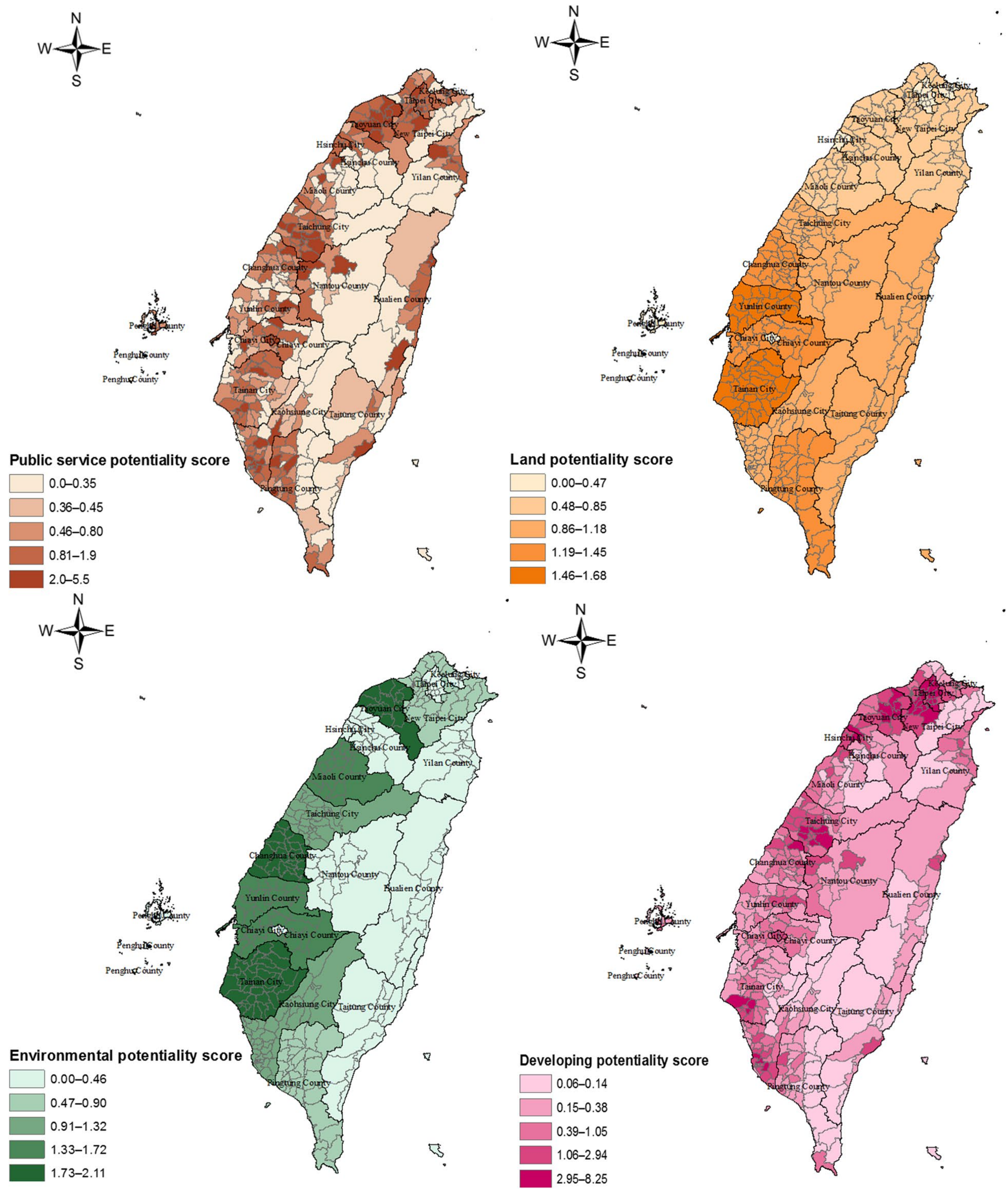

Fig. 4 SDGs map in this study

of Taiwan, based on open data information from 2018 to 2019. To reduce the bias of regional development resulting from the changed dataset from government open data, this study used a deep learning method to modify the weighting of each potentiality and dynamically extract data to determine regional sustainable changes in the future.

Figure 5 shows that the decontaminated site, control site, remediation site, and groundwater control area are in areas with sustainable development potentiality. Overall, decontaminated sites that were located in high sustainable development potential zones, namely, Level 4 (light green) and Level 5 (dark green), were as high as 67.9 and 23.9%, respectively, and most were based on agricultural land. Up to 7.8% of the control site and 0.2% of the remediation site were also located in areas of high potential for sustainable development (Level 5: dark green). The sites at Level 5 indicate that lightly contaminated sites (controlled sites) are located in the northern parts of Taiwan and heavily contaminated sites (remedial sites) are located in the southern parts of Taiwan. The control and remediation sites (SDG map: Level 5) are in the cities of Taoyuan, Kaohsiung, New Taipei, and Changhua.

When only considering the polluted factory type as an evaluation criterion in this study, Table 5 establishes that the polluted factories assigned to the control and remediation sites in Levels 4 and 5 are higher than those in Levels 1 to 3. The results show that polluted factories are in quickly developing and high sustainability zones (Levels 4 and 5) in Taiwan; however, the decontaminated factory sites located in Levels 4 and 5 account for only 19.8 and 8.5%, respectively. Therefore, understanding the changes in sustainable development to evaluate the cost and benefit value of economic, environmental, and social conditions for brownfield redevelopment is crucial. In addition, to reduce the uncertainty in spatiotemporal changes in economic, environmental, and social conditions, particularly for factories in Taiwan, the BRQ model has developed an information link system from open data sources to overcome these problems in this study.

3.2 Case study using BRQ model

The BRQ model analyses two sites, A and B, located at Levels 4 and 5 in northern Taiwan. Both sites are designated as urban plan zones by the local government and have the same lot size of approximately 1600 to 1900 m^2. However, the different land types of Sites A (agricultural land) and B (residential land) divide the different building coverage ratios and floor area ratios from the urban plans

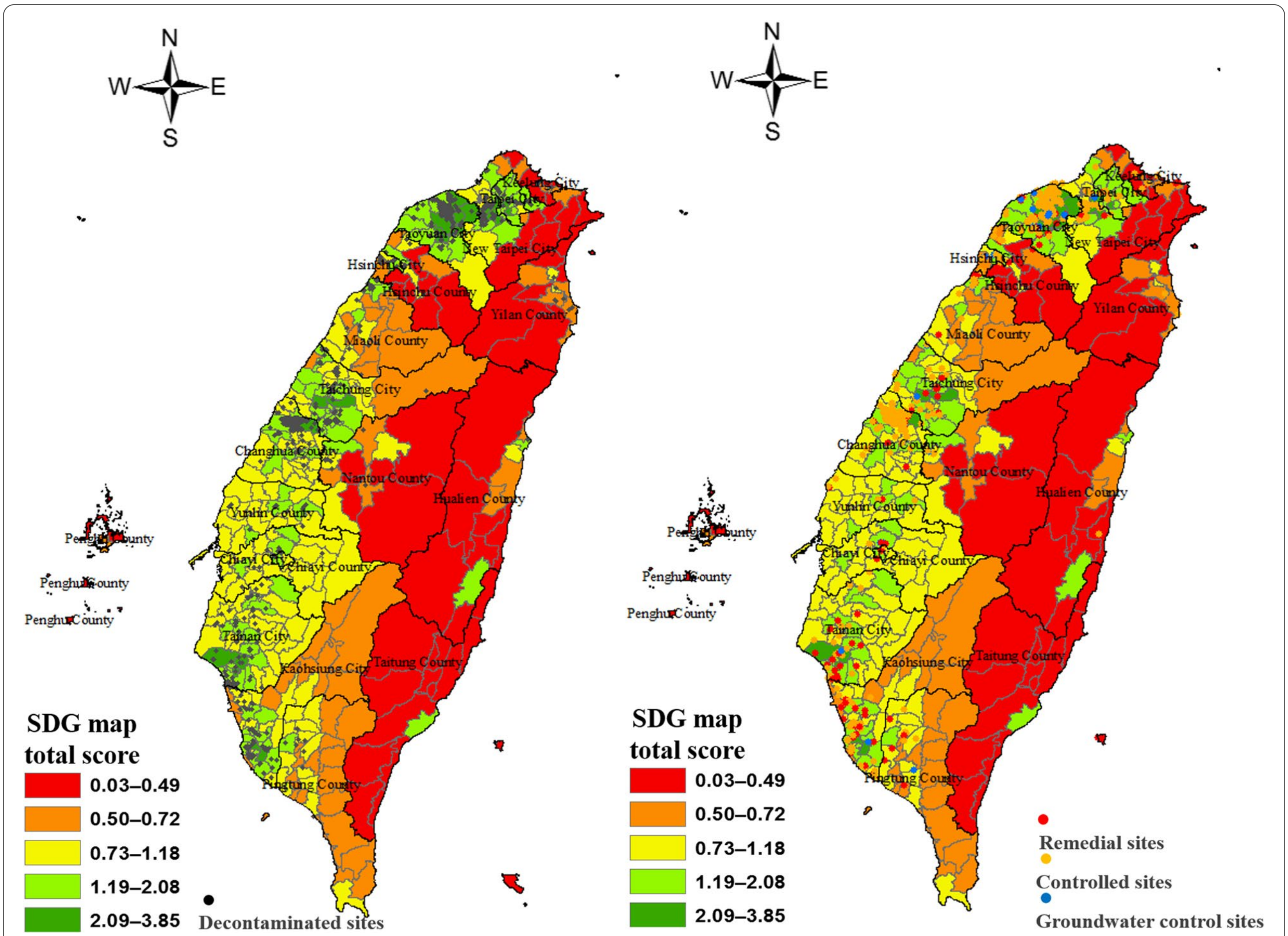

Fig. 5 Sustainable zones of brownfield redevelopment in Taiwan (until 2019)

Table 5 The proportions of contaminated factories in SDGs map levels

Level	1	2	3	4	5
Score	0.03–0.49	0.50–0.72	0.73–1.18	1.19–2.08	2.09–3.85
Decontaminated sites	0.8%	1.9%	6.9%	19.8%	8.5%
Groundwater control zone	0.0%	0.0%	0.3%	1.1	2.2%
Controlled sites	0.0%	1.4%	8.5%	22.0%	8.2%
Remedial sites	0.0%	0.5%	3.3%	10.2%	4.4%

that control the volume and height of buildings to cause different internal economic costs and benefits during the brownfield redevelopment life cycle. The environmental pollution at both sites has the same soil contamination features, including two to three types of heavy metals. Copper was the main pollutant with concentrations of 8000 and 1000 ppm at Sites A and B, respectively [33]. The Taiwan EPA assessed that both are controlled sites with the same risks to neighborhood residents and the environment, although they have different pollutant concentrations. Therefore, the external costs, including the environmental and social impacts from both sites, should be similar for the brownfield redevelopment life cycle.

Based on these situations, the BRQ model shows that the consolidation BCRs of the residential, industrial, and commercial scenarios are positive, as shown in Fig. 6. The consolidation BCR of the two sites in terms of commercial land use has the highest values. The second-best choice for both sites is industrial land use, followed by residential land or other land. Based on the brownfield redevelopment life cycle, the influence of the BCR is severe in the reuse stage because it has a maximum period compared to the other stages. Commercial and industrial land use can bring the highest economic benefits in the reuse stage because the volume of buildings in the two scenarios cause the highest operating profits in the reuse stage. The main profit from residential land use is sales revenue in the redevelopment stage. The current land policy in Taiwan allows for the construction of renewable energy facilities on contaminated land. Site A did not use the above strategy because it had the lowest building coverage ratio and the lowest economic incentives to build renewable energy facilities for original land use. As a result, the pollutants at Site A have not been removed and the site delisted because the landowner considered there to be no economic incentives.

Figure 7 shows the internalities BCR of the two sites in the four scenarios. The NPV considers the impacts in the different periods of the three stages, and the benefits and costs are significantly different. If the remediation stage period is longer than that of the reuse stage, the consolidation benefits decrease from the economic profits of each scenario in the reuse stage. In general, the results are dominated by

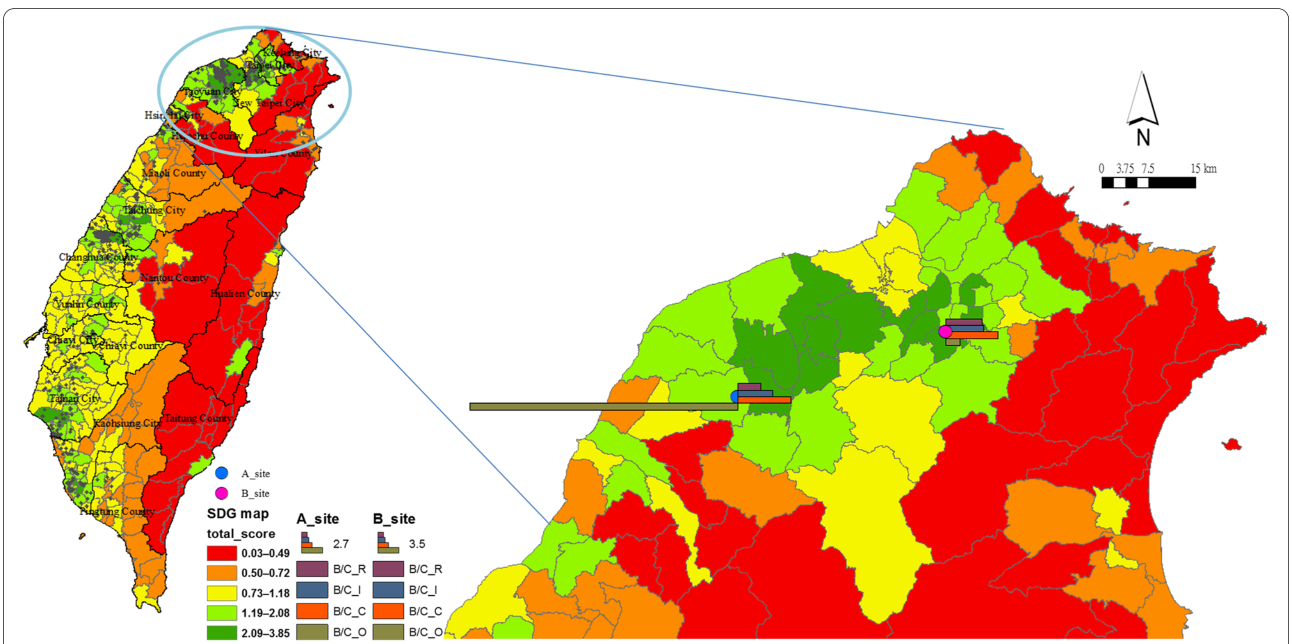

Fig. 6 The benefit-cost ratios of four scenarios for the two cases in SDGs map

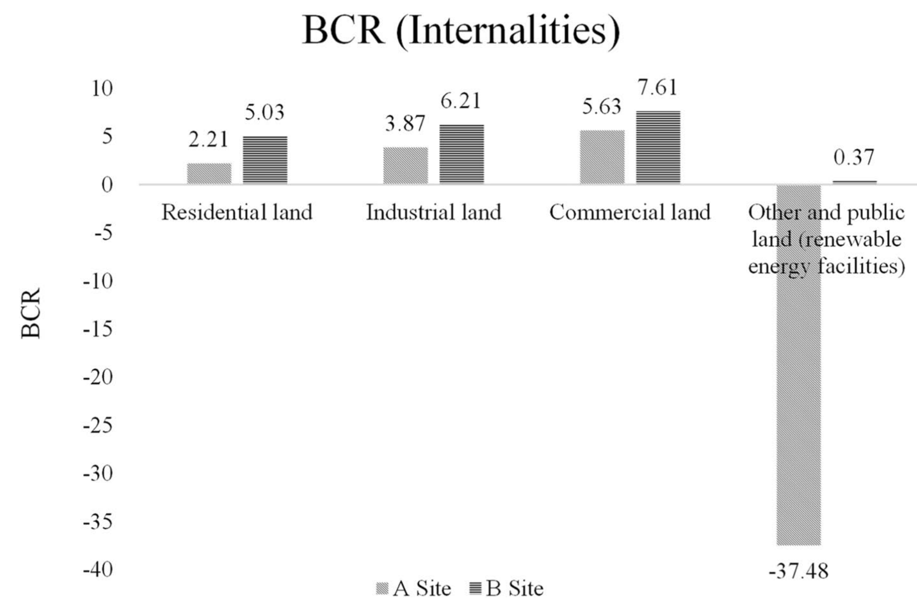

Fig. 7 The internalities benefit-cost ratios of the two sites in four scenarios

operating income in the reuse stage, such as commercial and industrial output value, residential sales or lease income, and electricity sales income from renewable energy. In addition, the settings of the building coverage ratio and floor area ratio of different land-use types impact the operation incomes in the reuse stage and the costs in the redevelopment stage. Site B is designed for residential and commercial land use in the urban plan; therefore, the internality BCR is largely positive. However, Site A has only one strategy for building renewable energy facilities in the original land-use type if the pollutants have not been removed, but a lower building coverage ratio causes a negative value in the BCR.

Figure 8 shows the positive values of the externalities BCR for the four scenarios. Taking Site A as an example, if the land is converted to residential land, the BCR in the external economy is the highest. The main reason for this is that users choose environmentally friendly designs during the brownfield redevelopment and reuse stages. New buildings use resource-efficient materials to reduce the external costs of carbon emissions and water demands. In

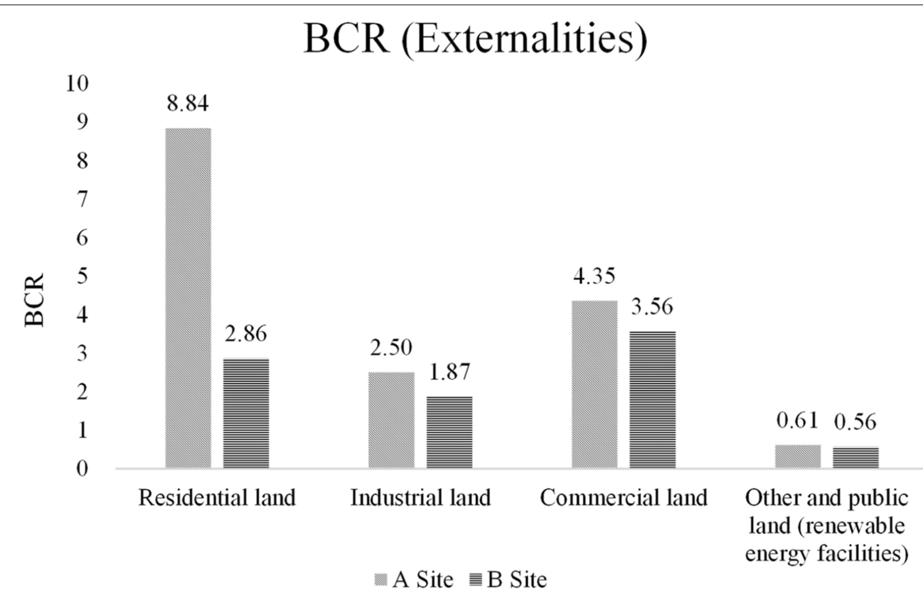

Fig. 8 The externalities benefit-cost ratios of the two sites in four scenarios

addition, new job opportunities during brownfield redevelopment improve social benefits. Stakeholders (either the government or investors) need more information or analysis tools to evaluate the optimal redevelopment strategy for Site A because there is a higher sustainable potentiality (Level 4). If the land remains idle, pollutants continue to pose a threat to the neighborhood and agricultural land. After removing the pollution, Site A proposes a new redevelopment strategy to convert residential land use, which is the highest externalities BCR. The consolidation BCR will also more than double.

The results show that Site A has been idle for 7 years due to the lack of complete information or suitable tools supplied to land stakeholders. Figure 9 shows the BCR of four

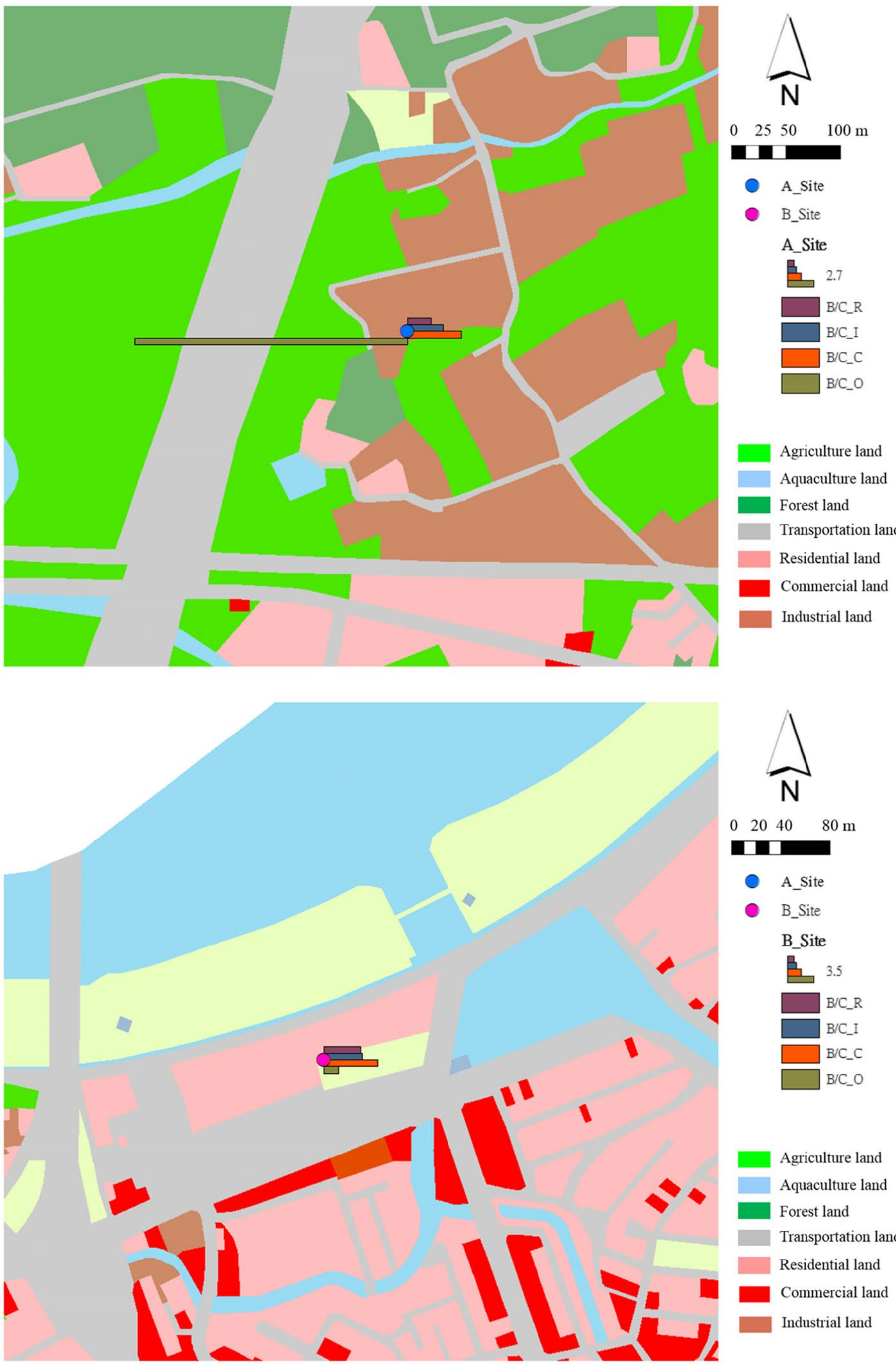

Fig. 9 The land use types and consolidation benefit-cost ratios of two cases

scenarios for two cases of different land types in the urban plan (BCR_R: residential land, BCR_I: industrial land, BCR_C: commercial land, and BCR_O: other land). The original land use of Site A is agricultural land. In contrast, with the building coverage ratio and floor area ratio rewards of Site B, the increase in the scale of redevelopment and reuse operations results in an increase in the BCR.

4 Conclusions

In Taiwan, sites with high environmental risk and land reuse incentives account for only 21.3% of the total. In contrast, sites with higher urban development and middle or low environmental risk account for 57.6% of the total [20]. Mature regions with higher development and urbanization usually have rich information to monitor changes in social, economic, and environmental aspects. However, complex and dynamic regional data cannot be reflected in current brownfield management in Taiwan. As a result, a friendly decision tool is needed to sketch out the dynamic regional development associated with social, environmental, and economic information from governmental open data to stakeholders (landowners, developers, and regulatory agencies) in Taiwan. This study applies regional sustainable potentiality maps and screens suitable brownfield locations to prioritize remediation. The sites are located at Levels 4 and 5 of the SDG map, and the integrated sustainable potentiality (public service, land protection, regional development, and environmental protection) is the highest. For stakeholders, the BRQ model developed in this study uses a large quantity of transparent information and flexible operation interface designation to reduce the possible pitfalls associated with brownfield redevelopment. Although this study extracts the analyzed dataset from 2018 to 2019, the results only explore the single regional characteristics of the sustainable potentiality of the contaminated sites, which causes a decision bias for stakeholders. To overcome this problem, the BRQ model interface links the open data source (such as urban and regional planning, average of employees, the growth of enterprises, the capacity of renewable energy facilities, etc.), as shown in Table 4, and the results show the regional sustainable changes as per real-time extracted data to support more information in the future.

If land stakeholders of the contaminated site can shorten the remediation time, in addition to reducing the external costs by removing pollutants, external benefits such as improving residents' health could be increased by the redevelopment and reuse stage. The benefits in the reuse stage are much higher than those in the redevelopment and remediation stages in the case studies. The externalities BCR value of the studied cases is positive, particularly in converting the residential land if the site is located at Level 4 and 5 of the SDGs map. The evaluation results of the two cases in the study suggest that if the stakeholder obtains more regional development information, they can use the BCRs to reduce decision uncertainty and increase the motivation for brownfield redevelopment.

Land stakeholders (government and land investors) need a suitable and flexible decision-making tool to consider the best options. The BRQ model can provide useful BCR information for different brownfield redevelopment scenarios and links with open and real datasets (social, economic, and environmental) at the township level to reduce the costs of the investigation and information uncertainty for land stakeholders.

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Authors' contributions
I-Chun Chen: Conceptualisation, Methodology, Software, Validation, Formal analysis, Resources, Writing—review and editing, Visualisation, Funding acquisition, Supervision, Project administration. Bo-Chieh Yang: Investigation, Data curation, Software. The author(s) read and approved the final manuscript.

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Availability of data and materials
Publicly available datasets were analysed in this study. The data can be found here:
https://data.gov.tw/
https://data.epa.gov.tw/
https://segis.moi.gov.tw/STAT/Web/Platform/QueryInterface/STAT_QueryInterface.aspx?Type=0

Declarations

Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Author details
[1]Department of Land Resources, Chinese Culture University, Taipei 11114, Taiwan. [2]Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, Hsinchu 31040, Taiwan.

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