Brownfield Redevelopment Query Model Based on Socioeconomic Conditions

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Research

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Abstract

Redeveloping brownfields can be considered an important step in regional urban development. With breakthroughs in information technology, Taiwan has established a number of open databases, this study uses these open datasets of regional socioeconomic and environmental geo-information to develop a regional SDG map and screen suitable brownfield locations for redevelopment. This study designs Brownfield Redevelopment Query (BRQ) model that combines big data socioeconomic geographic information to link with sustainable potentiality for evaluating benefit-cost ratios (BCR). Land stakeholders can obtain useful information prior to brownfield investment. The flexible user interface design is useful to explore the outcomes of BCR (consolidation, internalities, and externalities) for four land-use scenarios (residential, industrial, commercial, and renewable energy facilities) of brownfield redevelopment. The brownfield redevelopment BCR is positively dominated by the operating profits in the reuse stage for two contaminated sites. Besides, 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 level 5 of the SDG map. Consequently, this study uses a large quantity of transparent information and flexible user interface design to develop a useful evaluation tool and to reduce the possible pitfalls associated with brownfield redevelopment for land stakeholders.

Introduction

Land use, redevelopment, and transformation issues are complex. Decision-makers' or actors' response to urban development is driven by socioeconomic and political factors, transforming overall land use [1, 2]. Land use and regional economic growth are often mutually beneficial for urban development. Brownfield redevelopment is often regarded as a 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 the brownfield is usually high if it is 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 for facilitating the redevelopment of land reuse [6]. The motivation for brownfield redevelopment for local governments is regional development; accordingly, brownfield research has increasingly focused on the sustainability of the local environment, economy, and social conditions for determining the best approach [7–11].

Brownfield causes various environmental, social, and economic impacts before redevelopment. In the environmental dimension, the transmission and diffusion of pollutants may endanger human health and the environment and abolishes natural resources. Brownfield has reduced tax revenue, increased local unemployment rate, and hindered economic development, which reduces the value of the surrounding land. In the social dimension, brownfields are a concern for public security [12]. Brownfield potentially attracts criminals and illegal activities, which are detrimental to urban development, neighbourhood relationships, and local living standards, further depleting public resources [13]. Furthermore, the land use decision of brownfields during long-term redevelopment cannot usually respond to changes in dynamic environmental, economic, and social conditions. The brownfield redevelopment has not been linked to sustainable development then it has led to the decoupling of the redevelopment of brownfields from the national land management strategy [14, 15]. For the decision-making tool of 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 policy should make use of scientific urban research and benefits of sustainability, particularly in brownfield issues [21–23]. However, many researchers have argued that the 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 of land policy planning. Besides, 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 sustainable development goals in mega-cities [25, 26]. Therefore, further research is needed for reducing the uncertainty resulting from electronic information to land governance strategies. Some experts have explained that the diverse and complex socio-economic and environmental conditions can improve the solution of land governance according to 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 system combines rich social, economic, and environmental information derived from government open data, stakeholders, such as landowners, developers, and regulatory agencies, can effectively evaluate the land value, environmental benefits, and social impacts, thus reducing investment uncertainty [27–31]. The government can employ the decision 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 have created a large area of contaminated land. In Taiwan, industrial density is approximately 2.66 km^2 and this contaminated land of industry has resulted in approximately 120,000 abandoned factories [20]. The number of contaminated sites in Taiwan continues to grow annually under the current land use scenario. In Taiwan, the five types of contaminated sites are factories, gas stations, agricultural land, storage tanks, and others, and the numbers under each of these land use types account for 4.66%, 2.11%, 91.18%, 0.14%, and 2.00%, respectively. Environmental remediation is the main strategy for managing contaminated sites for promoting the reuse of contaminated sites in Taiwan. Polluted agricultural land accounts for the majority of land use areas eligible for Soil and Groundwater Pollution Remediation Funds. Investigating potentially high-pollution agricultural land began in 2002. Approximately 73.22% of this land was cleared by 2020 and released from government control. The government expects all polluted agricultural land to be delisted by 2021, which means that most decontaminated sites will be agricultural land and not other polluted types. Presently, site management has focused on a remediation topic but has failed to deliver deeper insights into the comprehensive governance of urban planning.

According to information published by the Taiwan Environmental Protection Agency, 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 could be flexible and depend on the results of the health risk assessment. However, for contaminated sites declared as remediation sites, the 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 contaminated sites in Taiwan are not ready for redevelopment because of the challenges in removing pollutants. Landowners and developers remain cautious about the uncertainties surrounding land investment [33]; 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 stages of remediation, redevelopment, and reuse are important information. This study contributes to improved decision-making regarding brownfield management. Large 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 the socioeconomic geographic information near contaminated land and has analysed the potential for sustainable development in Taiwan's various regions. The four goals of our research were to (1) to identify the sustainable development dimensions and factors to be considered for brownfield redevelopment planning; (2) to construct a sustainability evaluation system and linked database for brownfield redevelopment in the social, economic, and environmental dimensions, based on the open data published by the government of Taiwan; (3) to establish an evaluation tool for brownfield redevelopment queries; and (4) to present a case study of Taiwan's management strategies for brownfield redevelopment.

Materials And Methods

Sustainable development factors for brownfield redevelopment

The sustainable development of brownfields involves complex aspects. Cappai et al. (2016) 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 [34]. European Union land experts and scholars have suggested an integrated spatial planning strategy (INSPIRATION), in which they have identified sustainable development goals 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) [35]. In 2016, the government of Taiwan announced the National Land Planning Law to ensure homeland security and sustainable development. Furthermore, the Taiwan Sustainable Development Goals (SDGs) were established in 2018, and 143 sub-indicators in a report were formally announced. As a result, this study integrated Taiwan's sustainable development-oriented indicators and the most relevant literature for evaluating the sustainability of brownfield research redevelopment. Table 1 shows overlay 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) goals studied in this study.

Table 1
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 citizen and constantly provide living assistance	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

Item	Weighted value	Score	Indicators	Sub-indicators	Target maps
			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 %	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)	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	AQI
				6.d Reduction of general waste and promote resource recycling	Waste recycling

Item	Weighted value	Score	Indicators	Sub-indicators	Target maps
		Level 5 (1.73–2.11)	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: [39] Taiwan Government Opendata (https://data.gov.tw/) [40] Taiwan Environmental Opendata (https://data.epa.gov.tw/) [41] Socio-Economic Geographic Information System (https://segis.moi.gov.tw/STAT/Web/Platform/QueryInterface/STAT_QueryInterface.aspx?Type=0)					

Taiwan has established an open database project in 2013, The Advanced Action Program for Open Government Data, which includes 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. In addition, the information is provided in the form of javascript object notation (JSON), extensible markup language (XML), comma-separated values (CSV), and other file formats, and spatial shapefile data (SHP) and web map services (WMS). Therefore, this study utilised the Taiwan Open Database to present the potential for sustainable development in various regions. Besides, rich data can enhance the credibility of the data analysis [36, 37]. Socioeconomic geographic information can effectively provide extensive applications, such as urban development, residential land supply and demand planning, pollution prediction, and regional population changes. As a result, all data sources use the same geographic classification (township-level) and time series to improve the quality of the analysed dataset in this study.

According to stakeholder questionnaires addressing key factors of brownfield redevelopment potentiality, the weighted value in terms of “public service potentiality,” “land potentiality,” “developing potentiality,” “environment potentiality,” and “bigdata and IOT potentiality” are 15.96%, 23.76%, 34%, 14.17%, and 12.12%, respectively, in Taiwan [38]. The environmental potentiality, big data, and (Internet of Things) 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. This study pre-explores the regional development potential target maps by normalising the analysed indicator data in Table 1. The study uses the weight-setting principle for evaluating the regional SDG scores and explores five grades by using the geometric interval classification of geographical statistics. The integrated SDG map was used to evaluate the sustainable potentiality for the brownfield’s location. The higher the grade, the higher the sustainability grade: 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.

Brownfield redevelopment query model

For providing land developers and regulators with an evaluation tool for assessing environmental, economic, and social impacts of brownfield redevelopment, this study develops the Brownfield Redevelopment Query (BRQ) model (Fig. 1). Stakeholders can examine the 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 the research for brownfield sustainability index (BSI), the 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) have to be considered [14].

The cost-benefit analysis uses net present value (NPV) in this study; the discount rate was set at 6%, within the range of discount rates (4.75–6.5%) used by commercial real estate developers in Taiwan. The net present value of brownfield was calculated over a 25-year period. To fit the real cases in Taiwan, the remediation, redevelopment, and reuse terms were 10, 5, and 10 years, respectively. For a life-cycle period of brownfield redevelopment, users can also flexibly modify them according to real conditions. The BRQ model evaluates the BCR of the contaminated sites as transforming into residential, industrial, commercial, and other land (renewable energy facilities). The evaluation outcomes enable the consolidation, externalities, and internalities BCR for the four scenarios for incorporating the information in a map. Users can select a better brownfield redevelopment scenario with the highest consolidation index or the impacts of externalities and internalities BCR for each scenario.

As shown in Fig. 2, the design of the BRQ model comprises data storage, calculation, and output results. Users can obtain open data and input relevant information in the three major stages (remediation, redevelopment, and reuse) from government. Upon the input of information, the embedded operational system can link to the database containing parameter data with key factors, calculate the BCR for four scenarios, and present the output results from the BRQ model. Due to the poor data availability, users may be reluctant to use the model, particularly for redevelopment and reuse processes of a long duration. To overcome the above problem, the BRQ model interface links to open data sources of the management information system (MIS) and geographic information system (GIS). In some cases, users need to assess various possible scenarios before choosing the most appropriate one. Therefore, the relevant environmental, social, and economic data from the open database, using the SDGs listed in Table 1, were imported into the BRQ Model database. These used open data, including land-use types in urban and regional planning, the average income of employees, the number of enterprises, tap water supply, and renewable energy supply. The information entered by the users, database entries, and data sources is listed in Table 2. The BRQ model has automatic operation and output features. The freeware that compiles and generates BASIC language-style script programs can run on a Windows GUI automatically. It can control interface operations and calculate them according to the parameters selected by the users.

Table 2 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
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	● User input ● Open database

Stages	Items	Information entered by users	BRQ database entries	BRQ data sources
			• Output of department stores • Land value-added tax • Electricity, material, and water price	
	Society	• Number of employees in warehouse and department stores	• Salary level	• Open database
Reuse for others 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

BRQ model screen

The BRQ decision-making model is designed for the three stages of remediation, redevelopment, and reuse to apply the evaluation tools for investors and the government. For each stage, the model includes features for inputting site basic information, selecting and setting criteria, and output results. The basic information input field is designed for site-specific information, such as 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 2.

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, and users can decide whether they adopt green building types and the cost estimates should be increased accordingly. Type 1 in Taiwan's Urban Planning Law (UPL) is the main type of residential building. 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 into land type in electronic component manufacturing. Accordingly, the main type of industrial building is UPL Type 2, which should be constructed with reinforced concrete. According to the commercial survey report, most of the repurposed land is used for building department stores, and the main type of commercial buildings is UPL Type 1. Considering the efforts of the Taiwanese government to promote renewable energy, we assume that most of the redeveloped public land will be used for solar panel installations.

In Fig. 3(a), 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, to estimate the environmental and economic impacts. The criteria for the redevelopment stage, including urban planning district, development of new buildings, and land redevelopment purposes, are shown in Fig. 3(b). These criteria are used to link land-use characteristics in different urban plans, and 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. 3(c)–3(f), the BRQ model shows the criteria for the reuse stage for residential, industrial, commercial, and public land scenarios, including the selection of residential, industrial, and commercial land zones, whether there are green buildings, 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 calculating the size of the residential development and the rental population is possible. These criteria are 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, estimating the environmental impact due to the total energy and resource consumption in the reuse stage is possible. The green building option can be used to adjust the impact, and the land-use zoning criteria can be used to link to the open database of the advertised present land value to estimate the economic impact. Fig. 3(f) presents the criteria for the reuse stage for public land, including the selection of renewable energy category and installation capacity, and the solar panel types, linking 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, estimating the installed capacity and power output of the solar system is possible, thereby estimating the environmental impact. 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, estimating the employment growth rate at each stage is possible of the average salary and industry-specific employees by consulting the open database.

Results And Discussion

Regional development potential and sustainability of brownfield

This study corresponds to Taiwan’s sustainable development indicators and establishes SDG maps by evaluating socioeconomic geo-information (Fig. 4). The results show that Nantou, Hualien, and Taitung cities are located in low sustainable 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 an area with better environmental protection, such as air quality, greenhouse gas control, and green areas. The above scores are better than those of other cities, but the main reason for the reliable and sustainable energy supply is not sufficient to be affordable in Eastern Taiwan. The Developing potentiality index, which is the highest weight of assessment in this study, health care and education in Nantou, Taitung, and Yilan Cities are lower than in other cities. Consequently, the potential for sustainable development in these regions is lower than that in other parts of Taiwan.

Figure 5 shows that the decontaminated site, control site, remediation site, and groundwater control area are located in areas with sustainable development potentiality. Overall, decontaminated sites that are located in high sustainable development potential zones, Level 4: light green and Level 5: dark green, were as high as 67.89% and 23.93%, respectively, and most were based on agricultural land. Up to 7.83% of the control site and 0.22% of the remediation site were also located in areas of high potential sustainable development (Level 5: dark green). The sites at Level 5 present that lightly contaminated sites (control sites) are located in the northern parts of Taiwan, and heavily contaminated sites (remediation sites) are located in the southern parts of Taiwan. The control and remediation sites (SDG map: Level 5) are almost located in the Taoyuan, Kaohsiung, New Taipei, and Changhua Cities.

When only considering the polluted factory type as an evaluation criterion in this study, Table 3 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 located in quickly developing and sustainability zones in Taiwan; however, the decontaminated factory sites located in Levels 4 and 5 make only 19.78% and 8.52%, respectively. Therefore, understanding the changes in sustainable development for evaluating the cost and benefit value of economic, environmental, and social conditions for brownfield redevelopment is crucial. In addition, for reducing the uncertainty in spatiotemporal changes of economic, environmental, and social conditions, particularly for factories in Taiwan, BRQ model develops the information links system from open data sources to overcome these problems in this study.

Table 3
The proportions of contaminated factories in SDG 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	0.82%	1.92%	6.87%	19.78%	8.52%
Groundwater Control Zone	0.00%	0.00%	0.27%	1.10%	2.20%
Control Sites	0.00%	1.37%	8.52%	21.98%	8.24%
Remediation Sites	0.00%	0.55%	3.30%	10.16%	4.40%

Case study using BRQ model

The BRQ model analyses two sites where A and B sites are 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 1,600 to 1,900 square meters. However, the different land types of site A (agricultural land) and site B (residential land) divide the different building coverage ratio and floor area ratio from the urban plans that control the volume and height of buildings to cause different internal economic costs and benefits during the brownfield redevelopment life cycle. 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 mg/kg and 1000 mg/kg observed at A and B sites, respectively [42]. The Taiwan EPA assessed that both sites are controlled sites with the same risks to the neighbourhood residents and environment, although they have different pollution concentrations. Therefore, the external costs, including environmental and social impacts from both sites, should be similar for the brownfield redevelopment life cycle.

Based on the this situations, the BRQ model shows that the consolidation BCR of residential, industrial, and commercial scenarios are positive, as shown in Fig. 6. The consolidation BCR of the two sites in commercial land use had the highest values. The second-best choices of both sites are industrial land use, followed by residential land or other land. Based on the brownfield redevelopment life cycle, the influence of the BCR in the reuse stage is severe because it has a maximum period than other stages. Commercial and industrial land use can bring the highest economic benefits in the reuse stage because the volume of buildings for the two scenarios causes the highest operating profits in the reuse stage. The main profit of residential land use is sales revenue in the redevelopment stage. For other land type, the current land policy in Taiwan allows 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 lowest economic incentives to build renewable energy facilities in original land use. As a result, the pollutants in site A have not yet been removed and delisted because the landowner considered no economic incentive.

Figure 7 shows the internalities BCR of the two sites in the four scenarios. NPV has been consider the impacts in the different periods of the three stages, and the benefits and costs are significantly different. If the period of the remediation stage 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 the operating income in the reuse stage, such as commercial and industrial output value, residential sales or lease income, and electricity sales income through renewable energy. In addition, the settings of 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, so the internality BCR are largely positive. However, site A has only one strategy for building renewable energy facilities in the original land-use type if the pollutants are not yet removed, but a lower building coverage ratio causes a negative value in internalities 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 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 demand. In addition, new job opportunities during brownfield redevelopment improve social benefits. The stakeholders (government or investor) need more information or analysis tools for evaluating 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 neighbourhood 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 be over two times.

Conclusions

In Taiwan, high environmental risk sites with land reuse incentives account for only 21.3% of the total. Contrastingly, sites with higher urban development and middle or low environmental risk accounted for 57.6% of the total [20]. As a result, this study emphasises that brownfield market failure will not be substantially alleviated without fundamental changes in current urban planning and contaminated land management policies. Moreover, complex and dynamic regional data cannot be reflected in the current brownfield management in Taiwan. A friendly decision tool is needed to sketch out the dynamic regional development associated with social, environmental, and economic information from government open data to stakeholders (landowners, developers, regulatory agencies). This study applies regional sustainable potentiality maps and screens suitable brownfield locations to prioritise remediation.

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. The results show that site A has been idle for seven years due to the lack of complete information or suitable tools supplied to land stakeholders. Fig. 9 showed the BCR of four scenarios for two cases as the different land types in the urban plan. The original land use of Site A was agricultural land. Contrastingly, with the building coverage ratio and floor area ratio rewards of site B, the increases in the scale of redevelopment and reuse operations have resulted in an increase in the BCR. In this study, the BRQ model also shows that the benefits in the reuse stage are much higher than in the redevelopment and remediation stages and help landowners to increase the confidence of brownfields redevelopment. The redevelopment benefits of both cases result from the direct profits in the reuse stage for the landowners if the sites are located at Level 4 and Level 5 of the SDG map.

For industrial plants near agricultural land, the Taiwanese government has actively consulted to improve the legal establishment, which land stakeholders need to remove pollutants or improve environmental management in recent years. If the land stakeholders of contaminated site can shorten the remediation time, in addition to reducing the external costs by removing pollutants, it also increases the external benefits by the redevelopment and reuse stage, such as improving the residents' health. Under flexible land management in the future, land stakeholders (government and land investors) need a suitable and flexible decision tool to consider the best options. The BRQ model can supply useful BCR information for different brownfield redevelopment scenarios and links with the open and real datasets (social, economic, and environment) at the township level for reducing the costs of the investigation and information uncertainty for the land stakeholders.

Declarations

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Authors' contributions

I-Chun Chen: Conceptualization, Methodology, Software, Validation, Formal analysis, Re-sources, Writing—review and editing, Visualization, Funding acquisition, Supervision, Project administration. **Bo-Chieh Yang**: Investigation, Data curation, Software.

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Availability of data and materials

Publicly available datasets were analyzed 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

Competing interests

The authors declare that they have no known competing financial interests or personal rela-tionships that could have appeared to influence the work reported in this paper.

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Figures

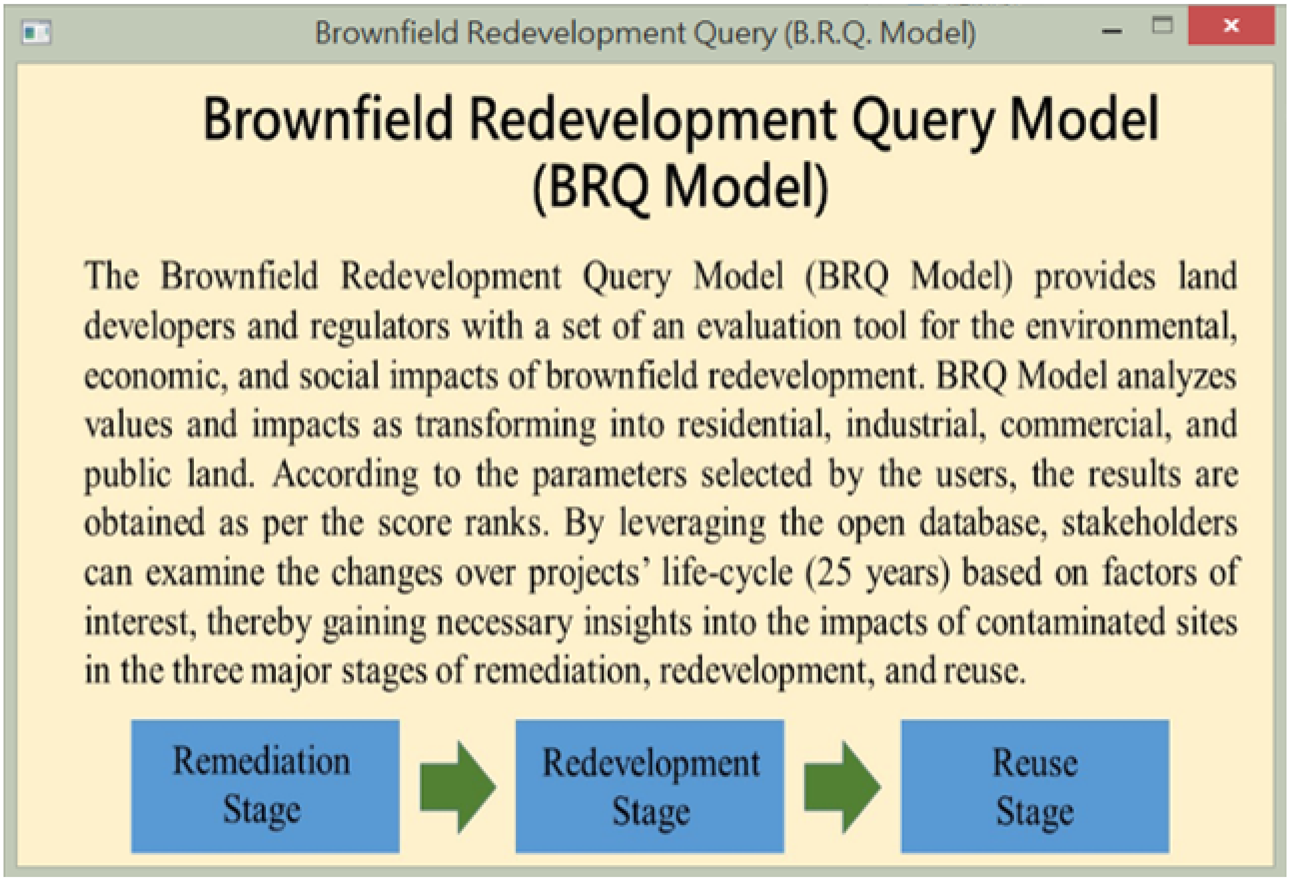


Fig. 1

Figure 1

Brownfield Redevelopment Query (BRQ) model.

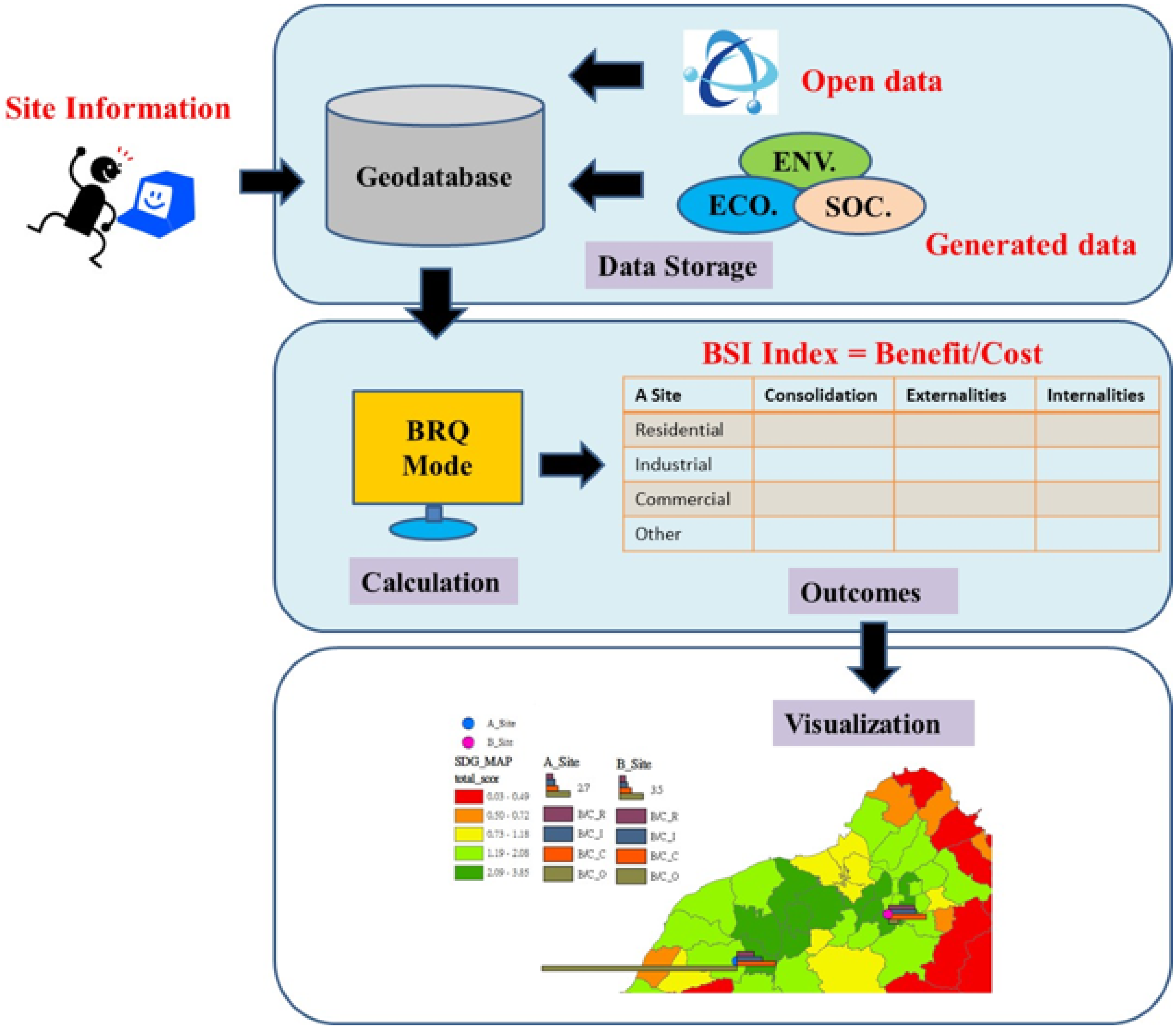
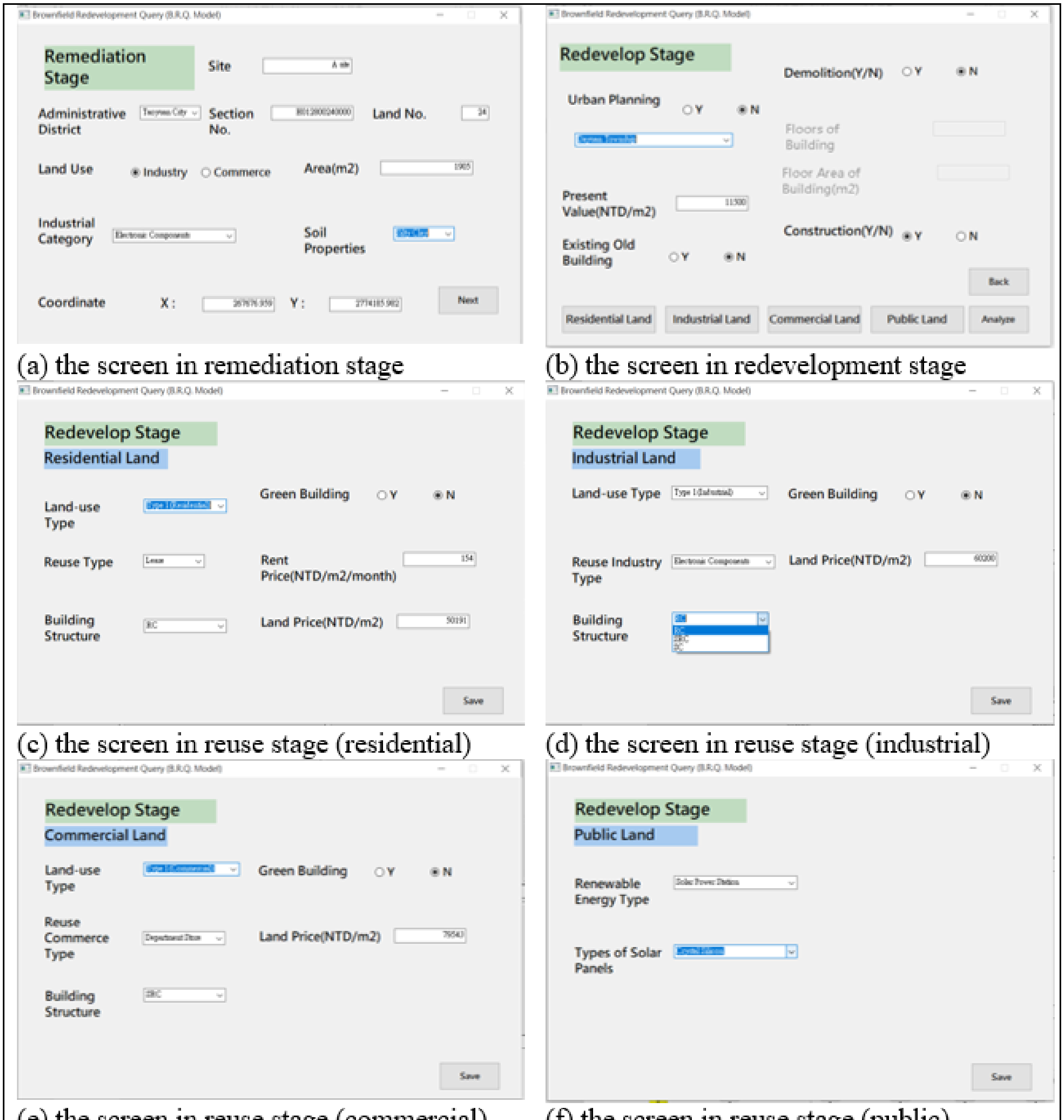


Fig. 2

Figure 2

The design of the information system in the BRQ model.



(a) the screen in remediation stage

(b) the screen in redevelopment stage

(c) the screen in reuse stage (residential)

(d) the screen in reuse stage (industrial)

(e) the screen in reuse stage (commercial)

(f) the screen in reuse stage (public)

Fig. 3

Figure 3

BRQ model screen.

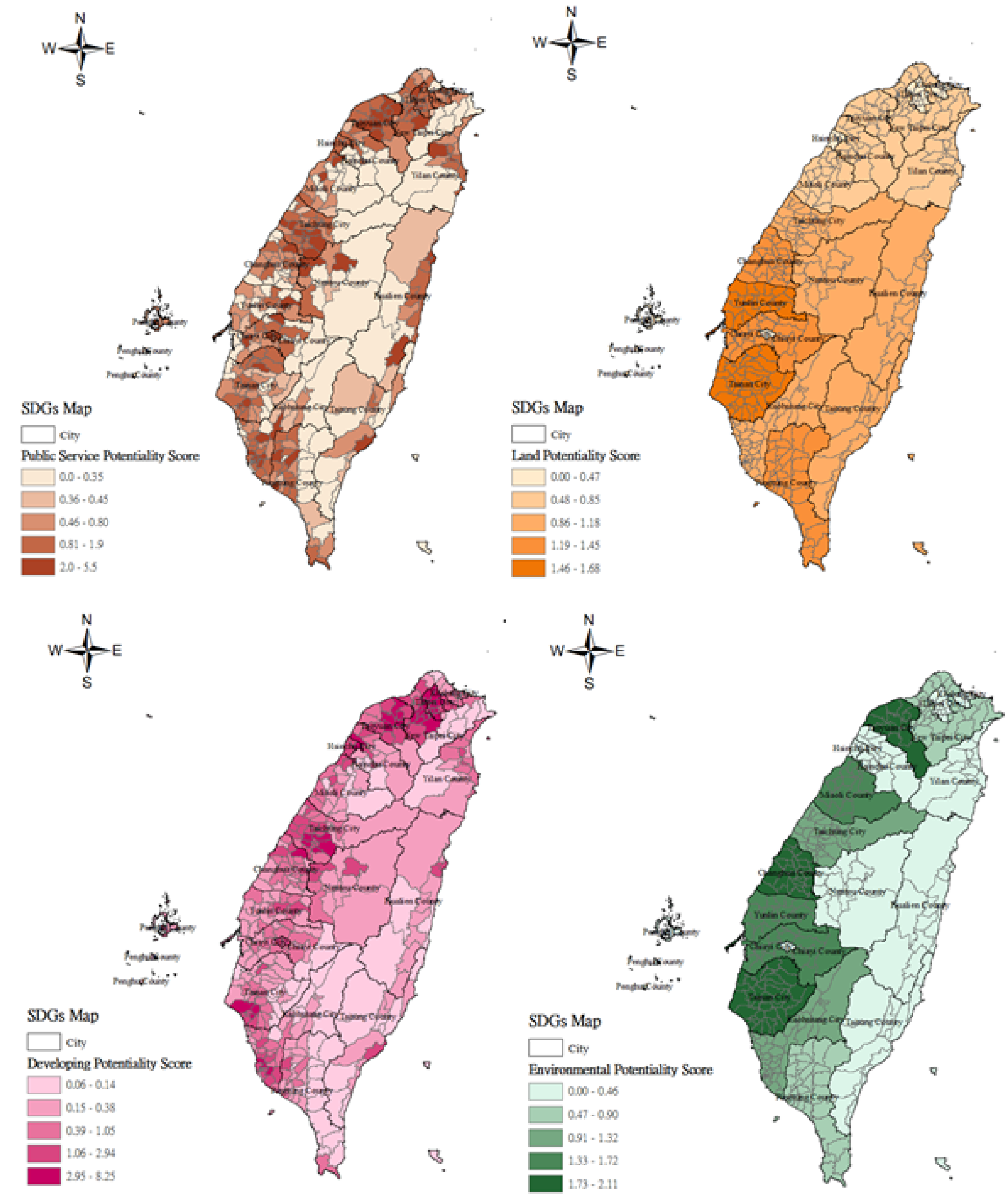


Fig. 4

Figure 4

Sustainable development maps in this study.

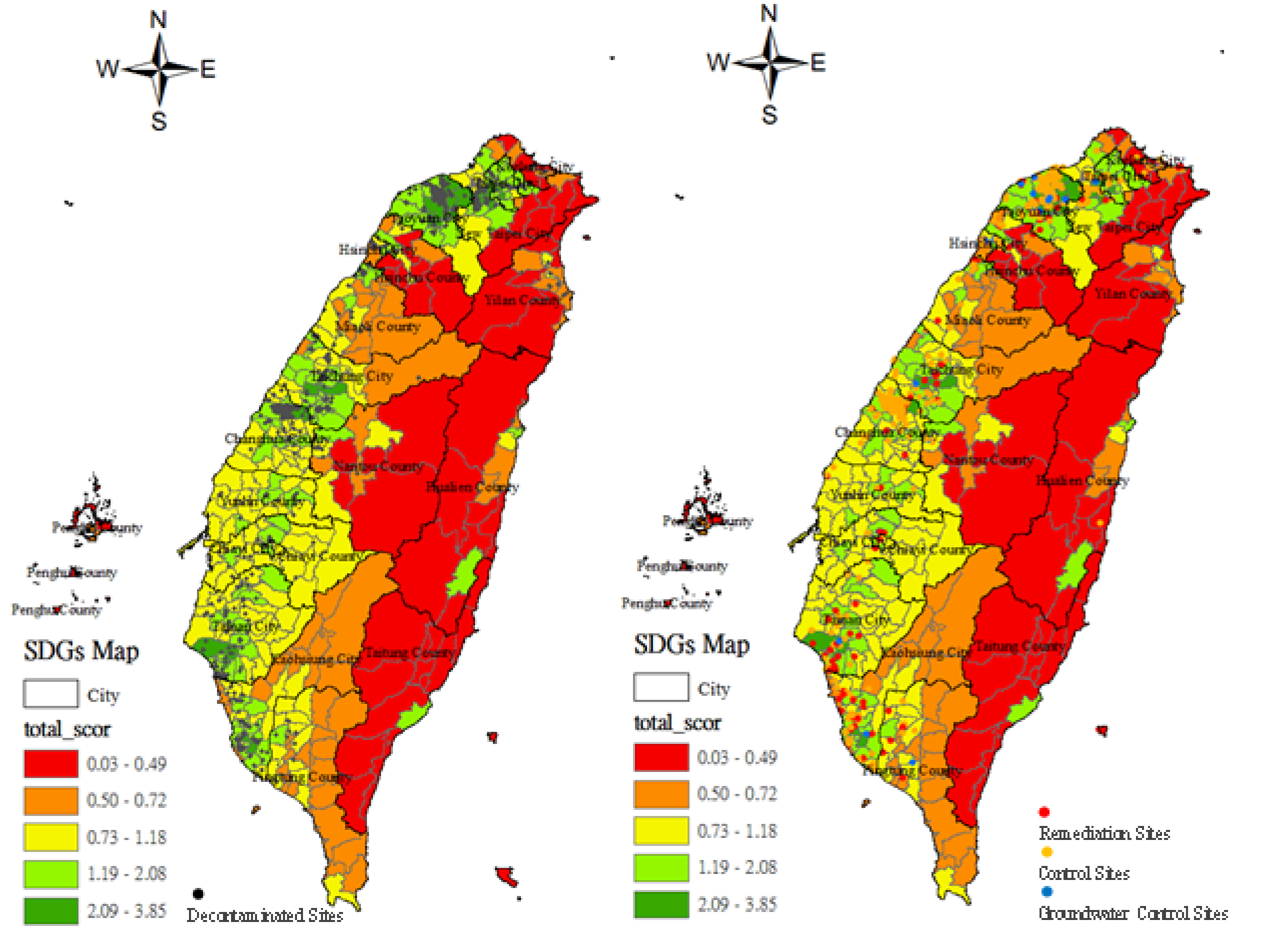


Fig. 5

Figure 5

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

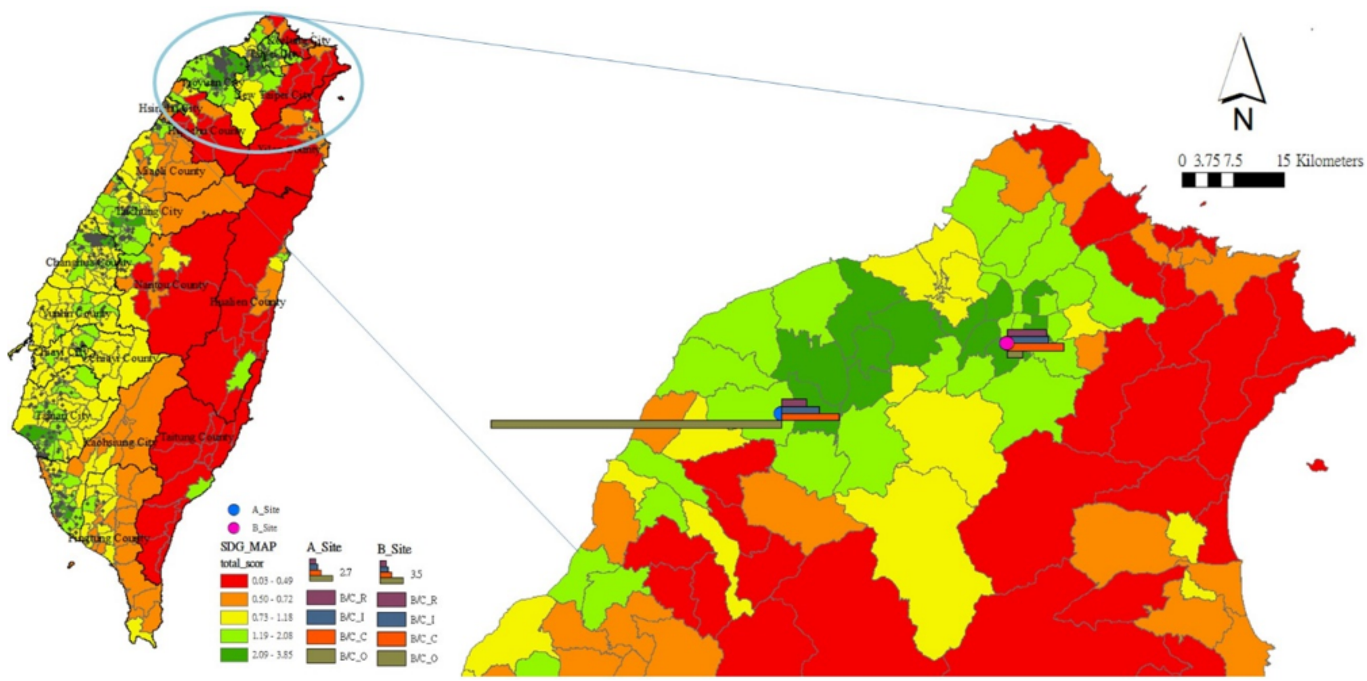


Fig. 6

Figure 6

The benefit-cost ratios of four scenarios for the two cases in SDG map.

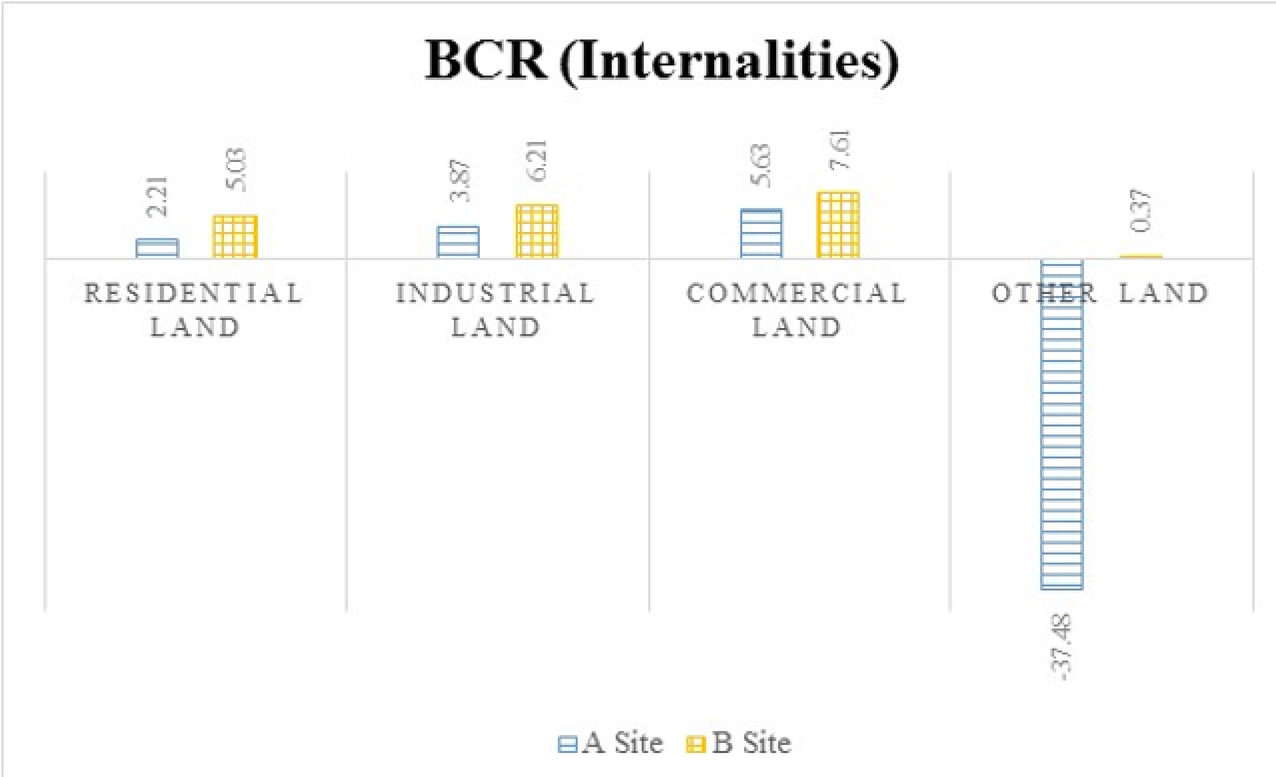


Fig. 7

Figure 7

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

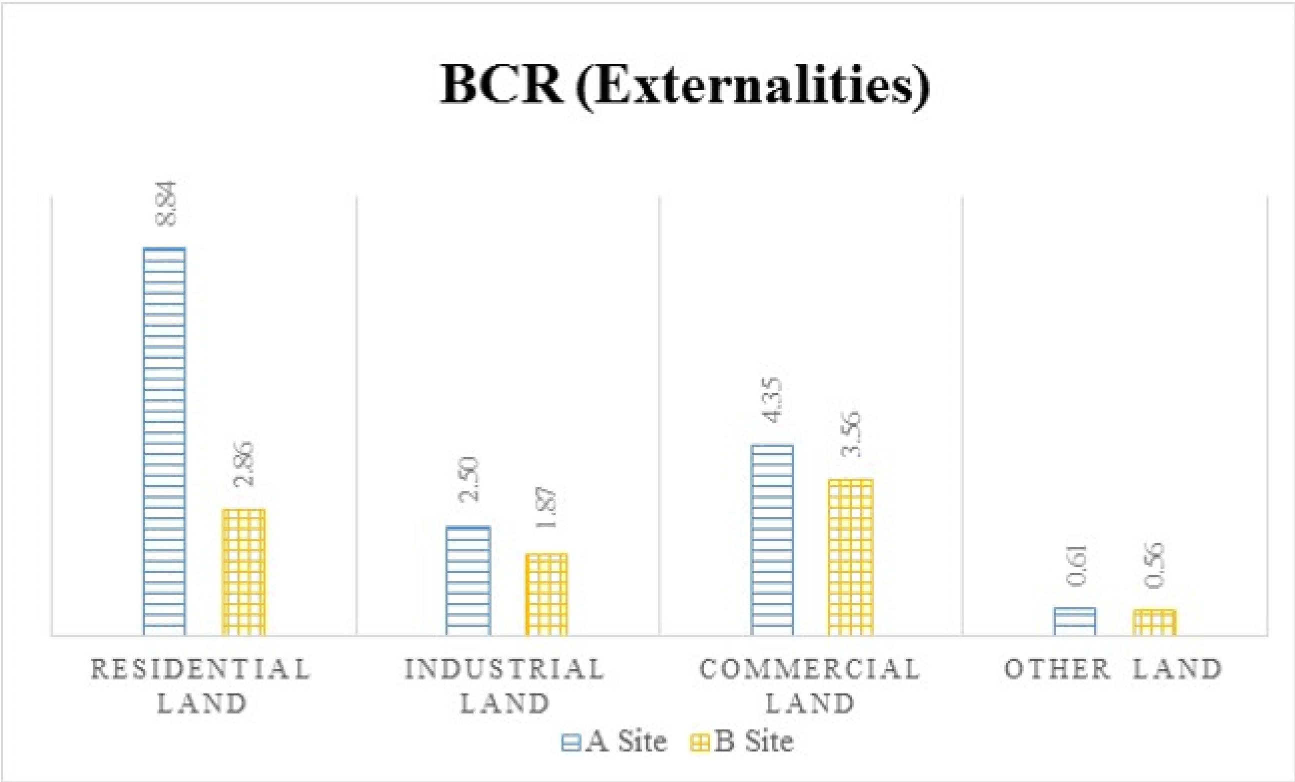


Fig. 8

Figure 8

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

Fig. 9

Figure 9

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