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# Storing E-waste in Green Infrastructure to Reduce Perceived Value Loss through Landfill Siting and Landscaping: A Case Study in Nanjing, China

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**Abstract:** Electronic waste (e-waste) represents a severe global environmental issue due to the fast upgrading and updating of electronic products and the high environmental risk. Current low recycling technology, high economic cost, and weak disposal capability make it difficult for e-waste to be rendered 100% harmless. E-waste disposal requires new site-selection methods and site-saving technology to take into account the loss of public perceived value. This study attempts to improve e-waste disposal through siting and landscaping to reduce perceived value loss. The first step is to determine the minimum distance for landfill siting by surveying the minimum loss of perceived value and to use the geographic information system (GIS) to sketch the suitable landfill site thereafter. To optimize the landfill landscape, a landscape infrastructure and its filling process have been designed to reduce the environmental risk and ensure future reuse potential. The application case showed that the minimum distance is 521 m, which was sensitive to the educational level and occupation of residents. The key to landfill landscaping is the construction of isolation layers and the integration of the landfill and urban landscape. The method described in this paper is characterized by minimizing the perceived loss of value to the public, reducing environmental risks, and preserving the resource value of e-waste. This design could provide an alternative to current electronic waste processing methods.

**Keywords:** electronic waste; urban planning; waste disposal; public attitude; NIMBY syndrome

## 1. Introduction

Electronic products, such as computers, mobile phones, and TV sets, are indispensable equipment in people's daily lives. With the improvement of technology and heightened consumer demand, the upgrading and updating of electronic products has become notably more rapid in recent years [1,2]. On average, a personal computer had a service life of 4–5 years at the end of the previous century, but at the beginning of the 21st century, its service life was reduced to 2–3 years [3,4]. Currently, the average service life of laptops and mobile phones is less than two years, and the annual scrap rate is equal to the annual update rate of certain electronics in China [5]. Electronic waste (e-waste) mainly comes from household appliances, entertainment electronics, office equipment, communication equipment, and other electronic waste products [6,7]. The improper disposal of e-waste poses a significant threat

to water resources, soil, air, and public health, because it contains large amounts of heavy metals, such as copper, mercury, lead, gold, and silver [8–11].

China is the biggest producer and consumer of electronic products in the world. In 2015, approximately $1.68 \times 10^9$ mobile phones, $0.36 \times 10^9$ PCs, and $0.14 \times 10^9$ color TV sets were produced in China [12]. However, due to the lack of statistical data, Li et al. [5] noted that it is difficult to make a precise estimate of the volume of e-waste in China. According to an estimation method by the European Environment Agency [13], no less than three million tons of e-waste was produced in China in 2015, which has increased at an estimated average annual rate of 4–5%. Meanwhile, China is also the world's largest destination for e-waste importers. Although the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal explicitly bans the export of e-waste [14,15], China accepted over 50% of the world's total e-waste from 2001 to 2012 [16]. Guiyu, a small town in Guangdong Province, has become a globally notorious e-waste hub [8,17,18]. In addition, Longtang and Dali in Guangdong Province, Taizhou in Zhejiang Province, Huanghua in Hebei Province, Jiujiang in Jiangxi Province, and Nanjing in Jiangsu Province are considered to be main recycling and disposal cities for e-waste in China [17–21]. In 2004, the Chinese government drafted a first pilot for an e-waste disposal management scheme in Zhejiang Province [22], but the results of the pilot implementations were not satisfactory. Zeng et al. [23] considered that the failure might be due to the output of e-waste being very small, often ignored, and not even professionally classified directly into the production of waste disposal.

Sanitary landfills are the most critical method for the nondestructive treatment of solid waste [24–27]. The Environmental Protection Agency (EPA) believes that there are, at least, major natural, economic, and financial risks that arise in the process of landfill site selection. The natural risks of landfills are comprehensively assessed with respect to topographic [28], hydrological [29], geological [28], soil [30], and land use factors [31]. Moreover, agricultural land, residential areas, industrial zones, and scenic spots are involved in the risks caused by such landfill sites [32–34]. Ekmekçioğlu et al. [35] estimated the financial risks associated with landfill sites according to transportation cost. Thus, the best landfill site can be selected by considering all of the environmental, hydrological, and geological factors possible and using the combined geographic information system (GIS) and analytic hierarchy process or fuzzy logic reasoning [31]. However, landfills are still perceived as a nuisance to the public, no matter how scientifically grounded the site selection is. Simsek et al. [34] considered that landfill site selection is not a simple technical decision, and several unquantifiable political, sociological, and behavioral factors are also at stake. Therefore, above all else, public perceptions must be considered in landfill siting.

Not-in-my-backyard (NIMBY) syndrome is one result of the awakening of public awareness of environmental protection, and NIMBY is characterized by opposition to any proposals for new construction that involves potential environmental risks [36,37]. Simsek et al. [34] argued that NIMBY syndrome is also a key factor affecting public perceptions. Emotional distress [38], declines in real estate value [39], or even discrimination against the residents living in the vicinity of the landfill [40,41] frequently occur as a consequence of landfill and dump site selection. Kao and Lin [42] and Shen and Yu [36] found that the more people who live or work near potential landfill sites, the less support there is for the landfills [43]. Similarly, Pampel [44] found that the greater the media coverage and public discussion, the greater the public attention and the greater the number people who switch from indifference to the new construction proposals to opposition. In addition, Greenberg and Truelove [45] discussed the impacts of gender, age, education level, social status, and the role played by the construction project on public perception.

Unlike municipal solid waste, e-waste disposal requires more advanced technology, especially with respect to the extraction of trace elements. At present, only a small fraction of high-value metals is recycled, and most e-waste is burned, buried, or discarded randomly. Although a zero-emission solution is the best option for e-waste disposal, the proper storage of e-waste can be regarded as a stopgap for both environmental protection and future reuse in the current situation of inefficient

recycling technology, low disposal capacity, and high economic cost. However, due to a lack of detailed evaluation criteria regarding the public perception of the value loss associated with landfills, several existing landfills are surrounded by urban sprawl, leading to the misuse of these landfills. Furthermore, modern methods have less frequently accounted for the loss of subjective value, environmental risk, and resource value.

Therefore, new ideas and methods for landfill construction should be introduced to address these issues. The aims of this study are as follows: (1) to develop a method for determining the landfill site considering the loss of subjective value in order to discuss buffer distance and other influencing factors and (2) to design an e-waste landfill as landscape infrastructure to improve the overall local ecological environment.

## 2. Methodology and Data Collection

### 2.1. Landfill Siting Considering Public Perception

#### 2.1.1. Overall Technique Flow

E-waste is different from municipal solid waste and has greater environmental and health risks. Therefore, e-waste landfill site selection requires a two-step evaluation method. The first step is to follow the method of general landfill site selection, and the second step is to consider the particularity of e-waste. A flow chart for the siting of e-waste landfills based on the minimization of publicly perceived value loss was developed (Figure 1).
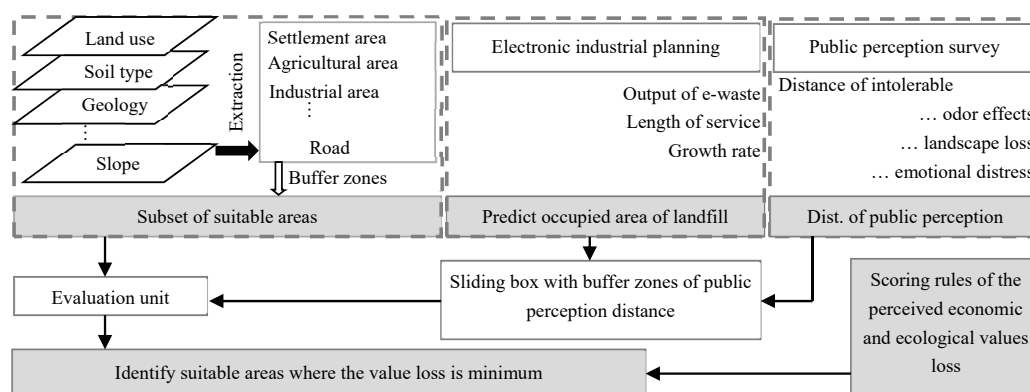


**Figure 1.** Flow chart for the siting of electronic waste (e-waste) landfills based on the minimization of publicly perceived value loss.

Two steps are shown below.

(1) Subsetting of potentially suitable areas. The method employed in this step was developed by Wilson, D.C. [40]. This method integrates analytical hierarchy process (AHP) and GIS. Several factors, such as land use, soil type, groundwater, slope, the settlement area, the agricultural area, and the industrial area, are considered by the AHP method [31,46]. Differential analysis under the ArcGIS 10.2 spatial analysis module was performed. Each criterion was weighted by AHP and mapped using GIS techniques [46–48]. The output of this step is a small region on the map that shows locations suitable for an e-waste landfill. For further determining the best landfill site in the following step, the suitable area was then rasterized with a resolution of 100 m × 100 m.

(2) Sliding box with buffer zones of public perception distance and identifying landfill units where the value loss is minimal. By referring to electronic industrial planning, the occupied area of the landfill can be predicted. A sliding box was created by using the predicted occupied area for the e-waste landfill as the size of the box. The sliding box was moved within the rasterized landfill suitability map to generate potential landfill units.

By using a public perception survey (Section 2.1.2), a buffer distance of public perception of different degrees of aversion towards an e-waste landfill can be determined. Here, four levels of buffer distance were considered during the public perception survey. As shown in Table 1, we formulated the value loss score of perceived value loss based on different levels of buffer distance and land use within the buffer zone. Combining the value loss scores of different buffer zones, we calculated the perceived value loss index of each potential landfill unit using Equation (1). Furthermore, the landfill unit where the value loss is minimal can be picked out by comparing the perceived value loss index.

$$L = \sum_{I=1}^{4} a_i F_i / \sum_{I=1}^{4} A_i F_i \times 100\% \tag{1}$$

where $L$ is the perceived value loss index, $i$ is the number of buffer zones under consideration, $a_i$ is the area of construction land or farmland within the $i$-th buffer zone, $A_i$ is the total area of the $i$-th buffer zone, and $F_i$ is the value loss score of the $i$-th buffer zone.

**Table 1.** Scoring rules of perceived value loss.

| Buffer Zone | First Buffer Zone | Second Buffer Zone | Third Buffer Zone | Fourth Buffer Zone |
|---|---|---|---|---|
| Evaluation criteria | All activities except greening | All activities except greening and agriculture | All activities except greening, agriculture, and industry | Only affects housing |
| Scoring rules | 5 | 3 | 2 | 1 |

### 2.1.2. Survey on Public Perception

The surveying of public perception is a critical step in landfill siting. The aim of our questionnaire was to understand the public perception of e-waste and its hazards and the impact of landfills. Aversion to the odor and appearance of landfills is the primary components of public perceptions. The odor is mainly due to the chemical reaction of the main components of e-waste in contact with the environment, such as water, acid, and soil. The dismantling, purification, and processing of e-waste in a recycling industrial park cannot prevent odor generation, but if buried e-waste can be guaranteed to be absolutely isolated from the environment, no odor will be produced after the closure of the landfill. Objectively speaking, it is obvious that the environment around an e-waste landfill has a huge impact on nearby residents' living environment and physical health. The first reaction of most residents to landfills is "Do not enter my backyard." However, what is the public's perception of being various distances from the e-waste landfill? Because temporary e-waste landfills are already in existence, a questionnaire about landfill distances was distributed. Due to the real existence of NIMBY, it is necessary to investigate the impact of the extent of the e-waste landfill on public perception. Public awareness of an e-waste landfill site would affect the construction of such a landfill.

To understand the attitudes and opinions held by a defined population toward the e-waste landfill, we designed a questionnaire consisting of four major parts (Table 2). If the public surveyed did not understand the ideas underlying e-waste landfills, they could consult specially trained investigators to ensure the accuracy and reliability of the results of the questionnaire. The background knowledge needed to accurately respond to the questionnaire included the spread of waste odor, urban waste disposal standards, landfill health risks, and so on. After the questionnaire design was completed, the questionnaires were tested on a small scale in the network of surrounding residents. After confirming the validity of the small-volume data of the questionnaire, a large-scale investigation was carried out. An introduction of e-waste and its hazards comprised the first part of the questionnaire. Gender, age, educational level, and related job were the primary personal demographic characteristics sought; questions on these factors formed the second part of the questionnaire. The third part of the questionnaire related to the best way to dispose of e-waste, the main hazards of e-waste landfills, and the best solution for e-waste disposal in a landfill. The fourth part was comprised of questions regarding the distance of the four buffer zones. The first buffer zone is the minimal distance within which the resident will leave the area, and it represents all livelihood activities that are severely affected

by the presence of an e-waste landfill. The second buffer zone is the distance within which the odor from an e-waste landfill can spread, and it represents the aspects of an e-waste landfill that are offensive to human olfaction. The third buffer zone is the distance within which the e-waste landfill fades to invisibility from residential or working areas. The fourth buffer zone is the distance at which no impact of an e-waste landfill is reported.

**Table 2.** Questionnaire survey on public perception of spatial distances from the e-waste landfill.

| | E-waste landfill | Distance (m) |
|---|---|---|
| Do you Know? E-waste mainly includes household appliances, entertainment electronics, office equipment, communication equipment, and other electronic waste products. | The improper disposal of e-waste poses a significant threat to water resources, soil, air, and public health. | |
| Gender | Age | | |
| Number of years of education | Is your job related to waste disposal? | | |
| What do you think is the best way to dispose of e-waste? ($\sqrt{}$) | Incineration | Dump | Recycling |
| What are main hazards of an e-waste landfill? ($\sqrt{}$) | Landscape | Noise | Odor　　Menticide |
| What is the best solution for e-waste disposal in a landfill? ($\sqrt{}$) | Absolute physical isolation | Anti-seepage treatment | Fixing agent |
| 1 | What should be the minimal distance from the landfill? From which distance will you leave your current residential place or work? | First buffer zone | |
| 2 | What is the maximal distance that the odor from landfill can spread? | Second buffer zone | |
| 3 | What is the distance at which the landfill fades to invisibility from your residential or working place? | Third buffer zone | |
| 4 | What is the landfill distance at which no impact will be produced on your daily life? | Fourth buffer zone | |

## 2.2. Criteria for Developing the E-waste Landfill as Landscape Infrastructure

Nowadays, recycled e-waste constitutes less than 30% of all e-waste in China. Most e-waste is not fully used. First, the current technology is limited, because it cannot extract all the trace elements of e-waste [49]. Second, recycling certain highly toxic heavy metals, such as mercury, cadmium, chromium, and arsenic, can be difficult due to the high cost. Thus, the recycling of such heavy metals has been abandoned by almost all informal recycling sectors, causing many serious environmental problems in China. Third, the output of e-waste is much larger than the capacity of e-waste disposal. The recycling of e-waste not only effectively alleviates the shortage of natural resources in China, but also contributes to the green development of the world. Therefore, our idea is to store e-waste that cannot be dealt with by current technologies, economic costs, and disposal capability in an airtight place instead of discarding it, so that it can be recycled effectively in the future to achieve zero wastage.

Thus, given the potential economic value of e-waste, an e-waste landfill, as a temporary bank for potentially valuable and untreated e-waste for recycling and reuse in the future, seems to be the best solution at the moment. However, e-waste must be sealed in a box for burying to prevent toxic substances of e-waste from coming into contact with water and soil. The sealed box proposed by this study is made of impermeable and durable materials with an isolation layer and special protective functions. At the bottom of the sealed box, four layers, which are referred to as the drainpipe, rainwater collection layer, impermeable layer, and filtrate monitoring layer, were designed. This sealed box could play an important role in storing e-waste without environmental interference. Due to the absolute physical isolation of the sealed box, the design of the proposed e-waste landfill is different from a municipal landfill, because there is no biogas collection system, for example. The sealed box is designed to be sealed for a period of time, ensuring absolute isolation and imperviousness for 50–100 years.

Thereafter, if e-waste landfills need to be uncovered for recyclable e-waste retrieval after closure, the sealed box greatly reduces the environmental risks and occupational health effects. We hope that e-waste can be more effectively reused when technology has advanced.

Meanwhile, e-waste landfills must not become a "forgotten space," but should rather be transformed to make the city a better place by fulfilling ecological leisure purposes. Thus, when a center of e-waste disposal is closed, it can be preserved as an industrial heritage site that can display information about e-waste disposal with the public and improve the public's awareness of environmental protection. In addition to an exhibition center, buried e-waste landfills can be used as urban green space to provide recreation services. To this end, any possible pollutant diffusion should be controlled, and the relationship between the landfill and the natural landscape should be coordinated. Based on the above considerations, the design of an e-waste landfill should adhere to the following criteria.

(1) Determining the overall future development framework based on the natural conditions of e-waste landfills. A framework for pollution control technology and vegetation repair systems should be developed. A stable ecological protection system for controlling the future land use of the site should be established. The e-waste landfill should be decommissioned and transformed into part of the urban public space under the aegis of the established landscape once urban sprawl has reached the periphery of the existing landfills.

(2) Using a sealed box for the burial of e-waste. The major benefit of a sealed box is to reduce pollution through layered burial while allowing for the reuse of the electronic waste bank. A separate sealed box can be arranged according to the terrain. After finishing the burial in one block, vegetation repair and ecological prevention should commence. To reduce the production of leachate, the leachate collection and drainage system should be designed separately for each block. Usually standing several dozens of meters high, the huge garbage mountain can be decomposed into a much lower height for proper management. The space overlying the top of the sealed box can be built into a platform for future landscape construction. In this way, the e-waste landfill will serve as an urban green space and low-carbon e-waste bank.

(3) Conducting landscape construction step by step. First, the surrounding environment should be remediated. A public–private–partnership (PPP) model can be introduced to design and operate the e-waste landfill as a landscape project. This is very important for changing the conventional negative impressions of landfills. Second, e-waste landfill can be built and operated in connection with an e-waste recycling industrial park. The park is to be designed as an integrated system of waste decomposition, selection, recycling, and burial. The e-waste recycling industrial park can be rebuilt into a museum to introduce information about e-waste recycling to the public after the closure of the e-waste landfill. Third, road transportation networks and infrastructure facilities should be perfected. There will be gradual improvements of the planted vegetation on top of the sealed box for the formation of a greening system. The installation of sports, amusement, and leisure facilities will help separate different waste burial regions. The greening system will be constantly extended outwards and linked to the existing urban green space. Finally, the e-waste landfill will be integrated into the urban ecological environment to become part of the public leisure space.

*2.3. Application Case and Data Resource*

To find a practical solution to design an e-waste landfill as landscape infrastructure, we selected Nanjing as an application case. Nanjing is the capital of Jiangsu Province and has a humid subtropical monsoon climate with an annual average temperature of 15.4 °C and an annual precipitation of 1106.5 mm. The total administrative area was 6597.2 km$^2$ in 2015, with a built-up urban area of 923.8 km$^2$ [50]. The entire municipal population was 8.24 million in 2015, and the urban population was 6.70 million. Nanjing's gross domestic product (GDP) was $147.14 \times 10^9$ dollars in 2015, and the per capita GDP was 17,865.25 dollars. Contributing $35.79 \times 10^9$ dollars of local GDP in 2015, the computer, communications, and electronic industry is one of the pillar industries of Nanjing and is ranked the

second largest such industry of all the cities in China. Nanjing has five landfills that process 8600 tons of domestic waste per day [51]. However, there is still no professional e-waste landfill in Nanjing, even though approximately 150,000 tons of e-waste is absorbed there annually.

For landfill siting, a land use map with scale of 1:10,000, a geological map with scale of 1:50,000, a soil type map, and QuickBird remote sensing images for 29 July 2015 (spatial resolution of 0.61 m × 0.61 m) were collected. For investigating public perceptions, 11 postgraduate students undertook a field survey in the form of face-to-face interviews from July to September 2015. The staff who conducted the questionnaire interviews inquired and recorded the details of the information provided by the respondents. The field survey was conducted in three types of public spaces. The first public space consisted of 300 randomly interviewed respondents in downtown streets or public places. The second consisted of 200 randomly chosen interviewees in residential areas, office buildings, and enterprises near the existing landfill. The third consisted of 100 randomly chosen respondents in unsupervised suburban waste dumping sites. A total of 600 respondents were interviewed, including 33 waste disposal workers from the second group of investigated public spaces.

In this application case, we applied the GIS-based sliding box sampling technique, social surveys, and scoring rules on the perceived economic and ecological values of the potentially suitable sites for e-waste landfills in Nanjing, China. SPSS 19.0 software was used to conduct statistical and correlation analyses on the survey results. ArcGIS 10.2 was used to conduct overlay analysis, and a buffer analysis was performed on the land use types, soil types, geological and hydrological information, and road distances. Once the site selection and design are finalized, this e-waste landfill could serve as a local natural landscape, providing the public with an ecological leisure space in addition to a landfill for e-waste.

## 3. Results and Discussion

### 3.1. Variety in Public Perception Regarding Spatial Distance from the Landfill

The survey indicates severe underestimation and overestimation of the perceived distance from the landfill in some samples, especially with respect to the estimation of the radius of the fourth buffer zone. We took the sample value with the highest distribution frequency as the baseline X to increase the relative concentration degree of the samples. Next, the samples were selected within the range of [X/4, 4X], and the results are shown in Table 3.

**Table 3.** Perceived distance from the landfill and valid samples.

| Variable | First Buffer Zone | Second Buffer Zone | Third Buffer Zone | Fourth Buffer Zone |
|---|---|---|---|---|
| Mean (m) | 521.4 | 864.5 | 1976.3 | 5170.2 |
| Standard deviation | 171.6 | 576.8 | 478.9 | 916.3 |
| Effective samples | 579.0 | 571.0 | 573.0 | 546.0 |

According to the social survey, a radius of 521.0 m constitutes the area in which the presence of the landfill is unbearable, that is, the first buffer zone. This distance is very close to the minimal required distance from a landfill specified in the Standard for Pollution Control on the Landfill Site of Municipal Solid Waste [52], which requires that landfills should be at least 500 m away from residential areas [52]. In the first buffer zone, all livelihood activities are severely affected by the landfill, and only certain vegetation and trees for landscaping or protection purposes can be planted. There is not an allowance for any agricultural, gardening, or residential areas within the first buffer zone, in which there is a complete loss of perceived value. Therefore, establishing some economic compensation mechanism would be an effective method to communicate and reach consensus with residents regarding the first buffer zone. The perceived distance of odor spread from a landfill is 864.5 m, i.e., the second buffer zone. Odor has little impact on agricultural and gardening activities but may be offensive to human olfaction. Therefore, residential areas and industrial development zones are the primary sites of perceived value loss within the second buffer zone. The perceived distance of landfill visibility is

1976.3 m, i.e., the third buffer zone, primarily impacting viewsheds. Therefore, there is a low degree of disturbance, and residential and office areas are the primary sites of perceived value loss within the third buffer zone. Corresponding to the fourth buffer zone, the perceived distance at which no disturbance exists is 5170.2 m, which was significantly higher than the perceived distance in the other three layers. In the fourth buffer zone, there are minimal effects on the productivity and life activities near the landfill aside from the psychological impact. Although the tangible impact of the landfill is absent at this point, the public still worries about the potential risks of the landfill, and there is still the existence of some psychological resistance, leading to a decline in the value of both real estate and investment attraction. In the fourth buffer zone, the impact of the landfill is considered extremely low, and residential and office areas are the primary sites of perceived value loss.

## 3.2. Landfill Site with Minimal Perceived Value Loss

GIS and the analytical hierarchy process were used to determine the suitable sites for a landfill based on the flowchart in Figure 1. Three sites qualified as a landfill site, as shown in Figure 2: Qinglongshan in southeast Nanjing, Tongjing in southwest Nanjing, and Ma'anshan in west Nanjing. The built-up urban area of Nanjing has nearly doubled, reaching 923.8 km$^2$ in the past 10 years. Because they are already surrounded by the built-up urban area, the Shuige Landfill and Tianjingwa Landfill should no longer be used (Figure 2a).
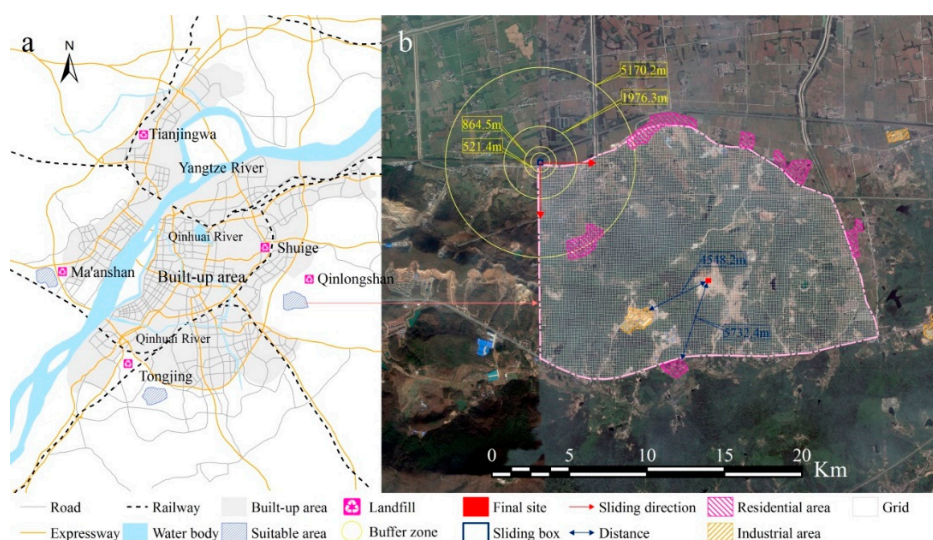


**Figure 2.** Location of (**a**) the study area and (**b**) a suitable site with minimal perceived value loss.

According to the 2015 Nanjing Bulletin on the Pollution Control and Management of Solid Waste and Overall Environmental Planning of Nanjing (2013–2030) [53], the volume of e-waste was approximately 150,000 tons in Nanjing in 2015. Within the next fifteen years, this volume is expected to grow at a rate of approximately 4% annually. In 2015, the e-waste disposal capacity of Nanjing was only 90,000 tons per year. Residues are about 1/3 of the total mass and still need to be buried after recycling. These residues contain certain highly toxic heavy metals, such as mercury, cadmium, chromium, and arsenic, which can be difficult to recycle due to cost or technology. Therefore, approximately 30,000 tons of residues and 60,000 tons of untreated e-waste need to be temporarily saved in a sealed box of an e-waste landfill each year. The design operational service life of the e-waste landfill is 20 years. Considering the available depth of the disposal of 60 m for 10-layered burial, the floor area of the e-waste landfill is estimated to be approximately 50,000–60,000 m$^2$. Thus, the size of the sliding box should be designed to be 250 m × 250 m, and the four buffer zones must be considered in the design of the landfill, with the distance thresholds being 521.4 m, 864.6 m, 1976.3 m, and 5170.2 m, respectively. The areas of different land use types within each buffer zone are obtained by sliding the

box over the rasterized suitable sites. The perceived value loss index is calculated using Equation (1), identifying the site with the minimal index value, as shown in Figure 2b.

*3.3. Landscape Infrastructure of E-waste Landfills*

According to the criteria for developing an e-waste landfill as landscape infrastructure, the process of landscaping an e-waste landfill in Qinglongshan is shown in Figure 3a. Unlike municipal waste, sealed e-waste does not produce biogas and harmful leachate. It is only necessary to collect rainwater. Therefore, in a sense, an e-waste landfill is more like an e-waste storage bank than a sanitary landfill. The section diagram of the sealed box referenced to the research of Yang and Cui [54] and detailed design specifications and dimensional standards are shown in Figure 3b. At the top of the sealed box, seven layers are designed for imperviousness and landscaping. The impermeable layer is an excellent water or vapor barrier at the bottom. The mixed territorial layer is used as a re-protection barrier and is filled in between the two impermeable layers. The drainage blanket, geotextile layer, and compacted soil are then added. The plant layer is used as the landscape element for the top layer. Only shrubs and flowers can be used as landscape elements. On one hand, it prevents the roots of tall plants from intruding the other engineering cover layers, and on the other hand, it prevents the plant layers from becoming too heavy and causing the collapse of the sealed box. Some engineering measures are performed before the landfilling process, including field preparation, which is determined using the minimal perceived value loss. Next, a landfill ditch is dug, and the spoil is piled aside with a reserved microstome. After completing these initial steps, the classified e-waste can be added. Shrubs and flowers are allowed to grow on top of the e-waste landfill, and thus, a single landfill area is completed. Finally, a landscape infrastructure will be formed, while more landfill areas are constructed and shaped into a complete terrain.
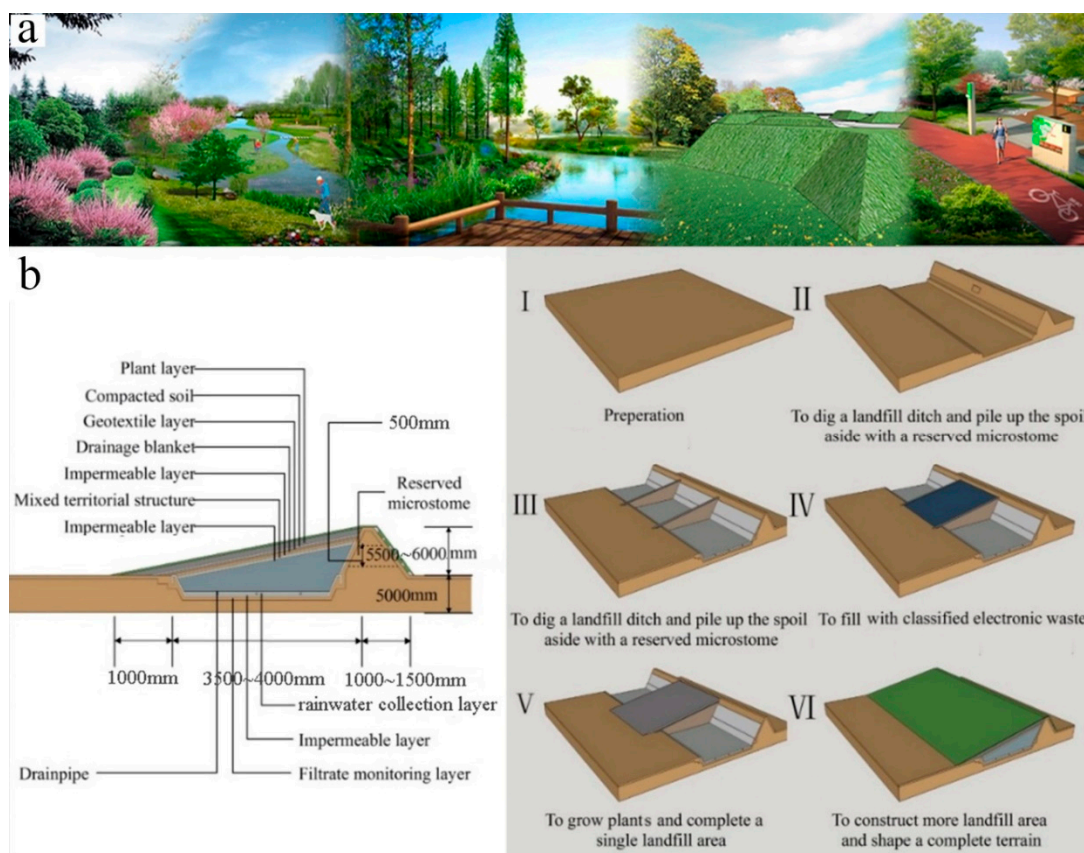


**Figure 3.** Designing the e-waste landfill as a green infrastructure (**a**) and detailed design specifications and dimensional standards of the sealed box (**b**).

　　　Because the construction of such a massive e-waste landfill requires a refined project management process, four stages of development were successively carried out (Figure 4). The first stage is planning and design. After the investigation and assessment of the e-waste site selection, the overall conceptual design of the landfill will be proposed. Moreover, in the framework of designing, regional revitalization, employment, and removal, three main principles are considered. The second stage is construction and operation. At this stage, all the materials will be transported to the site. Moreover, the sealed box will be constructed based on the design of Figure 3b. After the e-waste landfill is constructed, shrubs and flowers will be planted. Reasonable and regular water protection management measures will also be introduced. The third stage is growth and succession. With the promotion of e-waste market development and ecologic improvement, a diverse habitat will be formed. The fourth stage is adaptation and transformation. At the beginning of the design of the e-waste landfill, the long-term development has been considered. Therefore, an ecological museum will be built as an urban public space that illustrates the harmony between man and nature.
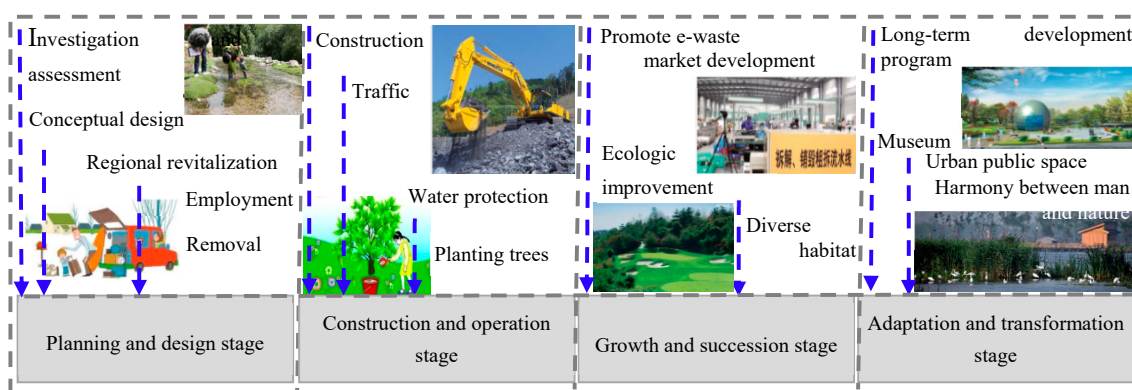


**Figure 4.** Development stages of e-waste landfill and landscape formation strategies.

## 4. Discussion

### 4.1. Influence of Individual Characteristics on Landfill Siting

　　　Landfills have a tremendous impact on their surrounding environment. However, making a reasonable evaluation of these impacts is difficult because of the diverse standpoints and interests of decisionmakers, businesses, and the general public. Because the treatment process of e-waste is a major externality under the existing economic and technical conditions, in this study, we focused on the criteria for the siting of e-waste landfills based on the public's perceived value loss from a questionnaire. The questionnaire is generally organized and implemented in strict accordance with international common practice, and the survey data is accurate and reliable. The basic personal information gathered in the questionnaire mainly included the gender, age, education level, and occupation of the respondents. The public perception of spatial distances was mainly reflected the public's requirements for the site selection of the landfill. Public perception is very subjective, and the respondents' age, gender, occupation, and educational background strongly affect the results (Figure 5). In order to make the evaluation fairer, the survey data was classified for statistical analysis. Perceived distance is not influenced by age, and there were no significant correlations in the perceived distance of different buffer zones across the age groups at a significance level of 0.05 (Figure 5a). As for the impact of gender, the perceived distance of different buffer zones showed no significant differences except for the fourth buffer zone (Figure 5b). Furthermore, in all four buffer zones, females were more sensitive to the potential risks of e-waste landfills than males. However, the number of years of education is a significant influencing factor. Compared with the age and gender of the respondents, educational background and occupation had a greater impact on the perceived distance. Compared with the respondents receiving less than six years of education, the perceived distance

differed significantly in the respondents receiving 6–9 years of education, 9–16 years of education, and over 16 years of education (Figure 5c). With the increase of educational years, the perceived distance to the landfill increases, which indicates that environmental awareness is enhanced by educational level. The survey shows that people with high education pay more attention to environmental issues. Moreover, the landfill distance perceptions vary depending on occupation, and the difference was statistically significant in all the buffers (Figure 5d). In addition, it is obvious that people who are engaged in waste disposal offer a much shorter perceived distance than those who are not. This finding coincides with the conclusions by Greenberg [55] but cannot overturn the "proximity hypothesis." In general, landfill siting is influenced by many individual characteristics. When selecting sites for landfills, we should optimize site selection to ensure that a buffer zone is chosen that does not disturb the residents, enhances effective communication with the public, and raises environmental standards.
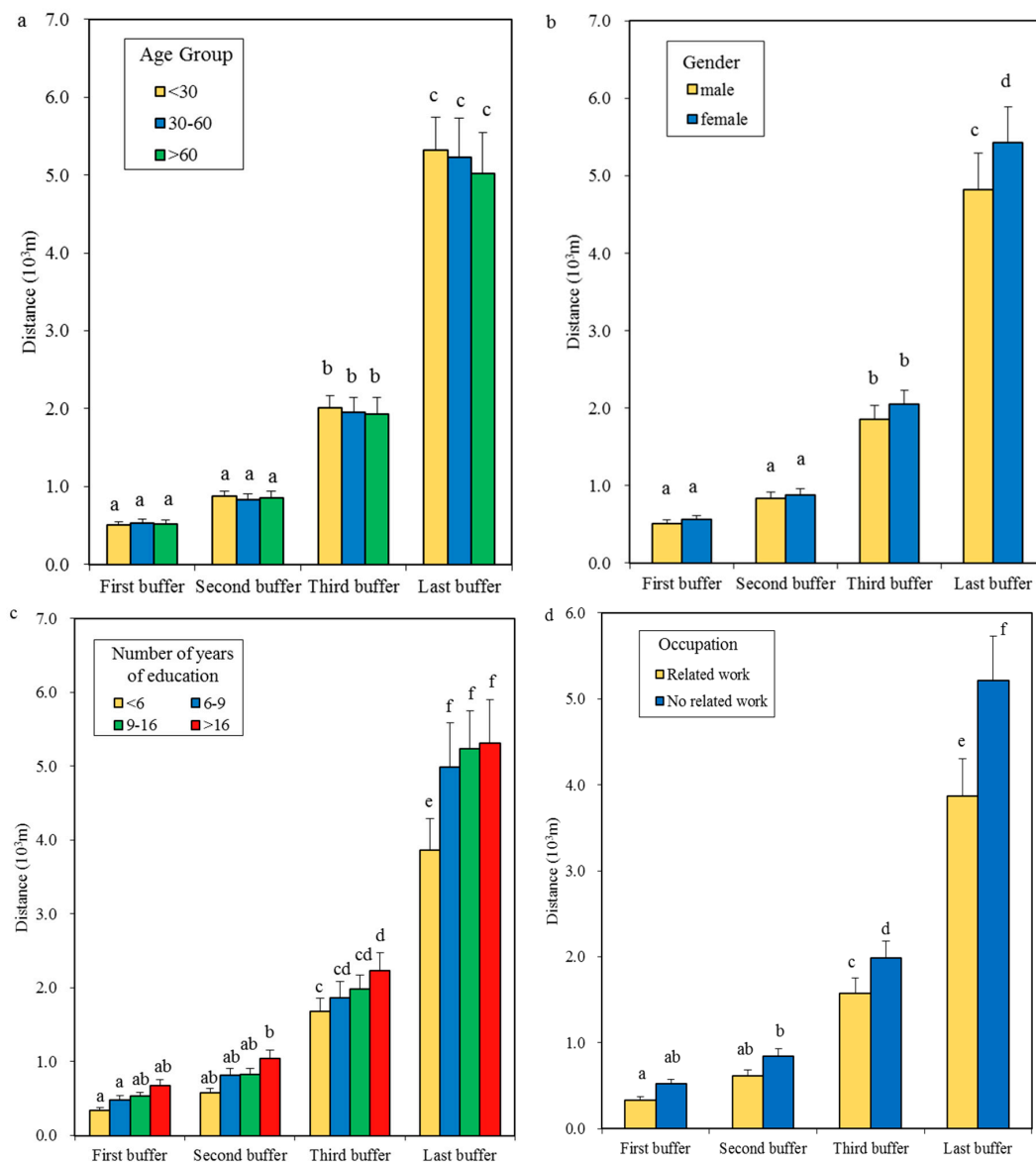


**Figure 5.** Impact of respondents' age (**a**), gender (**b**), number of years of education (**c**), and occupation (**d**) on the perceived distance to the landfill. Error bars represent the standard error, and different lowercase letters indicate significant differences at $p < 0.05$ according to Duncan's multiple range tests.

*4.2. Advantages and Disadvantages of the Design of a Sealed Box*

In this study, we propose the use of a completely impermeable sealed box, which is costlier than an ordinary landfill, but it will offer lower pollution risk and effective vegetation repair. The term "landfill mining" has long been recognized, but heavy metals, such as mercury, cadmium, and chromium, are still difficult to recycle. Burying a mixture of electronic and domestic waste is a common practice in China [56]. This process not only represents a huge potential environmental risk, but also causes the waste of resources [49,57]. The disposal of e-waste is also technically difficult and less economical, and the concept of "landfill banks" has been proposed to offset the environmental responsibility of e-waste in the future.

In this new sealed box, the risk of heavy metal leakage from e-waste will be prevented. Furthermore, as a landscape infrastructure, it provides urban residents with recreational venues. However, this sealed box also has some deficiencies, such as its high construction cost and complex maintenance management. As a new methodology, innovation and practice are necessary, and difficulties are encountered, which require global joint efforts to address.

*4.3. E-waste Landfill for a Green Future*

"Pollution first, treatment later" is a long-standing principle of economic development in China that needs to be renounced. To conform to the social trend toward harmony between man and nature, the design of environmental protection facilities should be updated. Landfills are usually constructed as a remedial measure against garbage-based disasters in developing countries [58]. The long-term development goals of landfills are rarely considered during the planning and design stage [59]. The ecological repair measures currently used are mainly for preventing environmental deterioration due to landfill pollution [46]. The ecological repair of landfills in China currently lags far behind those on the global scale, and remedial measures are not sufficient.

Throughout the world, landfills seem to be one of the most unattractive dimensions of urban development [25,41]. The primary reason for this is the profound lack of understanding of the value of landscaping in landfill siting. It is time to consider the future of landfills as more than a remedial project for environmental protection, but as a unique landscape infrastructure from the very beginning [41]. The landfill construction process should integrate the ecological repair of the landfill. From siting, burial, pollution management, and vegetation planting to habitat reconstruction, every step of landfill construction must be placed under overall planning. This is the inevitable pathway leading to the integration of e-waste landfills into urban green public space. In fact, an e-waste landfill design was published in March 2016 and has received widespread public and media discussions in Nanjing, China. The local community has actively supported the planning scheme, as they see a more beautiful future than the current situation. After the innovation of the e-waste landfill, the recycling and disposal of e-waste have become a reality, and we have moved closer to a green future.

## 5. Conclusions

E-waste is the fastest-growing category of garbage around the world. Residual burial after recycling specific valuable materials seems to be the only solution for e-waste management. However, an e-waste landfill should not be a forgotten and unattractive place in a city, and it must be integrated into the future urban space. The combination of three methods, namely, a GIS-based sliding box technique, social surveys on the public perception of landfill distance, and the scoring of the perceived values of lost biology and plants, can help us identify landfill sites with minimal public perceived value loss. An independent sealed box not only stores residual e-waste as valuable materials for the future, but also prevents soil and groundwater pollution. By designing e-waste landfills as landscape infrastructure, e-waste landfills will become part of the urban public green space. The results showed that the minimum distance accepted by local residents is 521 m, an opinion which was mainly influenced by the respondents' educational level. The key to landfill landscaping is the construction

of isolation layers and integration of the landfill and urban landscape. This study highlights that in the process of creating an e-waste landfill, it is key to minimize the perceived value loss to the public, reduce the environmental risk, and preserve the resource value of e-waste. Our study provides an alternative option for the improvement of e-waste landfills in developing countries, especially where e-waste has grown substantially.

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