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Greening the Browns: A Bio-Based Land Use Framework for Analysing the Potential of Urban Brownfields in an Urban Circular Economy

Shaswati Chowdhury *, Jaan-Henrik Kain, Marco Adelfio, Yevheniya Volchko and Jenny Norrman *

Department of Civil and Environmental Engineering, Chalmers University of Technology, SE-41296 Göteborg, Sweden; kain@chalmers.se (J.-H.K.); adelfio@chalmers.se (M.A.); yevheniya.volchko@chalmers.se (Y.V.)

* Correspondence: shaswati@chalmers.se (S.C.); jenny.norrman@chalmers.se (J.N.); Tel.: +46-317-726-462 (S.C.); +46-317-722-182 (J.N.)

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Abstract: The Circular Economy (CE) is expected to accelerate the use of resources with bio-based origin. Cities have an important role in such an economy, not only as main consumers but also because vegetation provides numerous ecosystem services essential for the well-being of urban dwellers. Urban lands are, however, heavily burdened with both past and present activities and ongoing urbanization. Retrofitting obsolete and potentially contaminated brownfields provides an opportunity to engage with bio-based land uses within the city. At the same time, plants are an important part of Gentle Remediation Options (GROs), a more sustainable alternative for managing contamination risks and restoring soil health. This paper (1) provides a tentative selection of Urban Greenspaces (UGSs) relevant for brownfields, and a compilation of ecosystem services provided by the selected UGSs, and (2) presents a framework covering the 14 selected bio-based land uses on brownfields, including GRO interventions over time. This framework provides three practical tools: the conceptualization of linkages between GROs and prospective UGS uses, a scatter diagram for the realization of 14 UGS opportunities on brownfields, and a decision matrix to analyze the requirements for UGS realization on brownfields.

Keywords: circular economy (CE); brownfields; urban greenspace (UGS); gentle remediation options (GROs)

1. Introduction

Cities are growing at an accelerating rate, with half of the world population living in urban areas and with a ratio that may increase up to 66% by 2050 [1,2]. To support this influx of new inhabitants, cities spatially expand even faster, twice the rate of their population growth rates, on average [3]. This global demographic transition has an enormous impact on the environment. The ecological footprints of cities are often 500–1000 times larger than their land area, as the city inhabitants typically depend on resources from outside of the city limits: food, water, and other consumables [4]. With planetary boundaries [5] being surpassed for most resources and climate change threatening to worsen the situation, a transition towards a resilient urban system would require not only resource efficiency but also a certain degree of resource sufficiency within the urban periphery. This adds even more pressure to the already burdened urban land use [5–7]. Retrofitting brownfields, the now obsolete urban lands that were previously exploited, is key to adequately facing this challenge.

Urban brownfields are often centrally located, supported by existing infrastructure and are often the only available option for redevelopment in the densely developed cities of Europe [8]. This surplus of the bygone industrial era is now the scope for urban regeneration and ecological restoration [9]. However, bringing brownfields back in use is both an extensive and expensive process which is often complicated by the prospect of pollution from the previous activities. Greening, as in vegetation, is a flexible strategy that can be an alternative to common remediation processes to regain soil health, as well as increasing the much-needed vegetation cover in the dense urban fabric [8,10]. With the many ecosystem services greenspaces already provide, they also play a key role in the emerging Circular Economy (CE). The CE aims to redefine growth by shifting economic activity from the consumption of finite resources towards the use of renewable ones [11]. If plants were the main source of renewable raw materials, more and more products would be of bio-based origin as the industrial system adapts to the CE [12]. As the pressure on the agrarian landscape is expected to grow in such a scenario, the role of urban greenspaces in the bio-based CE is yet to be discussed and explored in the context of brownfields.

In this paper, we elaborate on the past and present trends of repurposing brownfields, emphasising the use of vegetation throughout the process. We then explore this subject from the perspective of bio-based land use in a CE to further signify its relevance. We finally present a framework to assess the feasibility of various bio-based land use opportunities on brownfields across different time frames. The purpose of this study is to propose practical tools for practitioners and researchers in the brownfield domain, consisting of:

- an overview of possible bio-based land use options on brownfields and their specific sets of benefits;
- a general conceptualization of how the potential for bio-based production on brownfields is linked to soil contamination, soil remediation options, and time;
- a graphical representation of realizing bio-based land uses on brownfields in relation to the involved interventions and time spans;
- a decision matrix showing how site-specific brownfield conditions affect the realization of different types of bio-based land uses.

2. State of the Art—The Past and Present of Bio-Based Land Use on Brownfields and Its Future Role in a Circular Economy

2.1. Definition of Brownfield

The term "brownfield" encompasses a range of meanings, from derelict industrial sites to heavily contaminated properties, depending on the context [13,14]. Countries with low population densities tend to associate brownfields with contamination, but in Western Europe, with high population densities and land competitiveness, the term is mainly related to previously developed but abandoned or underused land [15,16]. The institutionalization of the "concern over contaminated sites" (i.e., Superfund Act, 1980) and the introduction of the term "brownfield" as a reference (i.e., Brownfield Act, 2002) both first originated in the US [17–20]. Although the term was soon accepted in the UK, other labels have been used across Europe (Germany: brachflächen, France: terrains abandonnés, Hungary: felhagyott területek) [16,21]. The lack of consensus is not limited only to terminology since there is neither a common definition for brownfields nor a centralized policy commonly agreed upon within the European Union (EU) [22,23].

Notwithstanding, the European Environment Agency (EEA) has introduced the indicators "Contaminated Sites" (CS) and "Potentially Contaminated Sites" (PCS) and has maintained an inventory for such sites since 2011 [24,25]. The closest to an overarching European definition of brownfields came via the Concerted Action on Brownfield and Economic Regeneration Network (CABERNET), a research project funded under the Fifth Framework Programme of the European Commission (FP5, 1998 to 2002) [26,27]. This definition was further adopted by subsequent research projects under the Seventh Framework Programme (FP7, 2007 to 2013), Tailored Improvement of Brownfield Regeneration in Europe (TIMBRE), and Holistic Management of Brownfield Regeneration (HOMBRE) [28,29]. CABERNET defined brownfields as sites that:

- have been affected by former uses of the site or surrounding land;
- are derelict or underused;
- are mainly in fully or partly developed urban areas;
- require intervention to bring them back to beneficial use, and may have a real or perceived contamination problem [27,30].

Considering the 200 years of industrial history of the EU, the continent is affected by numerous Contaminated Sites (~340,000) and Potentially Contaminated Sites (~2.5 million) [25]. Their restoration has been a major issue in many European countries since the 1980s [24,31]. By 2017, every EU member state adopted the "polluter pays principle" in their national policy [32]. About 15% of the Contaminated Sites have been remediated, which still leaves plenty of room for the remediation market to grow [25,32]. The issue of brownfield regeneration is receiving further attention as an important agenda to achieve the "no net land take by 2050" goal, which was launched by the EU in 2011 [33].

2.2. Remediation for Repurposing Brownfields

Brownfield redevelopment is considered both sustainable and necessary at a time when "greenfields", i.e., previously undeveloped land, are both scarce and expensive [34,35]. Remediation processes can be categorized in various ways: grouped by approaches (e.g., engineering, process-based, and hydraulic/natural) [36], type of technology used (e.g., biological, chemical, or physical) [37], or location (e.g., in situ or ex situ) [38]. Basically, remediation options are selected based on their ability to achieve the required risk reduction level for future use and, at the same time, satisfy time, cost, and place restrictions [37]. In this paper, we categorise brownfield redevelopment based on two key aspects: the availability of time and resources, both financial and physical, for redevelopment (Table 1).

Table 1. Categorisation of brownfield redevelopment including the examples described in the text.

Time Span / Resources	Short Term	Long Term
High	Conventional remediation Examples: Bawtry Gasworks, UK; Tubize plastic. Belgium	Gentle Remediation Options (GROs) Example: Duisburg Nord, Germany
Low	Temporary use Example: Berlin Tempelhof Airport, Germany	Ruderal/derelict Examples: Solventul plant, Romania; Chatterley Whitfield colliery, UK

In situ containment was used in famous examples of environmental scandals like Love Canal in the USA in 1978 and Lekkerkerk in the Netherlands in 1980 [37]. Both cases generated massive negative public attention which forced the political authorities to take immediate action and establish policy and regulation [39]. Containment, even though immediately effective, carries the risk of failure in the long term due to a lack of proper design or maintenance. For example, contamination on the site may cause groundwater contamination through leakage, which typically is more expensive and complicated to clean than contamination in soil [36]. In more recent examples, mentioned in Table 1, such as the Bawtry Gasworks in the UK and the Tubize plastic processing site in Belgium, transportation of the contaminated soil from the site for its ex situ treatment off site or disposal has been applied to achieve a fast yet vastly safer condition. Such "dig and dump" remediations are typically followed by the extensive development of brownfields for residential or infrastructure purposes [40]. Bawtry Gasworks was already developed as a housing estate when the contamination was detected and remediation took place, while in Tubize, the developer cleared the site to build a large housing complex [32,41,42]. Today, sites that are situated in or near densely populated areas with high land value, and which pose unacceptable human health risks, are, in high-income countries, typically quickly dealt with and are funded swiftly by the liable party [43–45]. In fact, almost every land development in inner city areas is expected to deal with contamination due to its previous use or surrounding activities, including heavy traffic. Isolation- and relocation-based strategies, such as in situ containment or ex situ dig and dump, are essentially quicker alternatives for stopping the migration of the contaminants rather than separating them from the soil [46]. Since the late 1980s, treatment-based remediation strategies have been encouraged both on and off sites to reach a permanent solution but can be more time- and resource-consuming than conventional strategies. Remediation by excavation is still a preferred method for many contaminants, such as metals [46,47], especially when the remediation is followed by construction, as new developments typically require excavation as part of their construction.

When brownfields do not pose an immediate threat to human health, but at the same time, are not attractive to developers, e.g., because of stigma associated with contamination or low land value, and there is no responsible party that the authorities can act against, sites risk being underused and untreated for a long time. Some, such as the abandoned Tempelhof Airport in Berlin, can still self-regenerate as a hub for local gatherings and spontaneous activities [48]. Nevertheless, most sites, like Solventul petrochemical plant in Romania and Chatterley Whitfield colliery in the UK, remain derelict, as the benefit is too uncertain in comparison to investments in expensive and extensive dig and dump remediations [49,50].

Despite being quick and safe in terms of contaminant removal, conventional remediation processes may cause a lot of secondary negative impacts due to the remedial activity, e.g., traffic risks due to transport, emissions of CO_2, noise, and the consumption of non-renewable resources such as fossil fuels and gravel as refilling material [51–53]. The international consensus on promoting alternative, more sustainable methods and low cost, low impact remedial measures for bringing abandoned brownfields back into use is growing [53–55]. For example, the UK Sustainable Remediation Forum (SuRF-UK) framework adopts a multiple stakeholder approach to assess the sustainability of remediation action by reviewing and evaluating a wider set of benefits and impacts [56]. The Ruhr region of Germany, one of the densest metropolitan areas in Europe, took one such step when long-term remediation through natural processes on 10,000 Ha of some of the most contaminated sites in the Emscher corridor was deployed. These sites were developed as “industrial forests” to offer the inhabitants the much needed opportunity to enjoy greenery [57–60]. Landscape architect Peter Latz’s work on Duisburg Nord layers old industrial structures with vegetation to remediate the soil (i.e., phytoremediation). The project took 22 years to realize its full potential and sets the legacy for urban derelict land reclamation, where the past is embraced, not discarded [14,61].

2.3. Gentle Remediation Options (GROs)

Plant-based systems are natural and more passive alternatives to the resource-intensive traditional remediation to address brownfield regeneration [62]. Plants are proven to be efficient remediators of both contaminated soil and water [63]. As well as being cost-effective, remediation using vegetation helps retain the biological function of the soil [64]. The use of plants for remediation (phytoremediation) is a Gentle Remediation Option (GRO); other GROs include technologies using fungi and/or bacteria-based methods, with or without chemical additives or soil amendments [47,65]. Cundy et al. [64] defined GROs as risk management strategies that result in a net gain (or at least no gross reduction) in ecological soil functions, as well as achieving effective risk management. For phytoremediation, the remediation potential varies greatly based on the type of contaminant and phytoremediation mechanism used across different time scales, where the most promising applications are phytostabilization, the degradation of chlorinated solvents and petroleum products, and evapotranspiration by phytovolatilization (Figure 1) [62,66].

Phytoremediation technologies are most applicable for “soft” reuse as opposed to “hard” built-up redevelopment of a site, for example, urban parks like Duisburg Nord, as well as for bioenergy crop production and urban agriculture [29,57,67–73]. In the case of Duisburg Nord, contaminants on the site included cyanide, arsenic, heavy metals, and polycyclic aromatic hydrocarbon (PAH), and acceptable risk levels were achieved by natural methods in some of the most contaminated areas of the site at very low cost [57]. If properly implemented, GROs in most cases have significantly lower deployment costs than conventional remediations. Smartly planned vegetation can be an end use in itself (e.g., parks, cropland) but can also be maintained temporarily until the risk level allows for more intensive land use [67]. Brownfields that are deemed unfit for development can thus still have the opportunity to be beneficial, e.g., by harvesting the vegetation while simultaneously managing the risks posed by contaminants to human health and the environment.

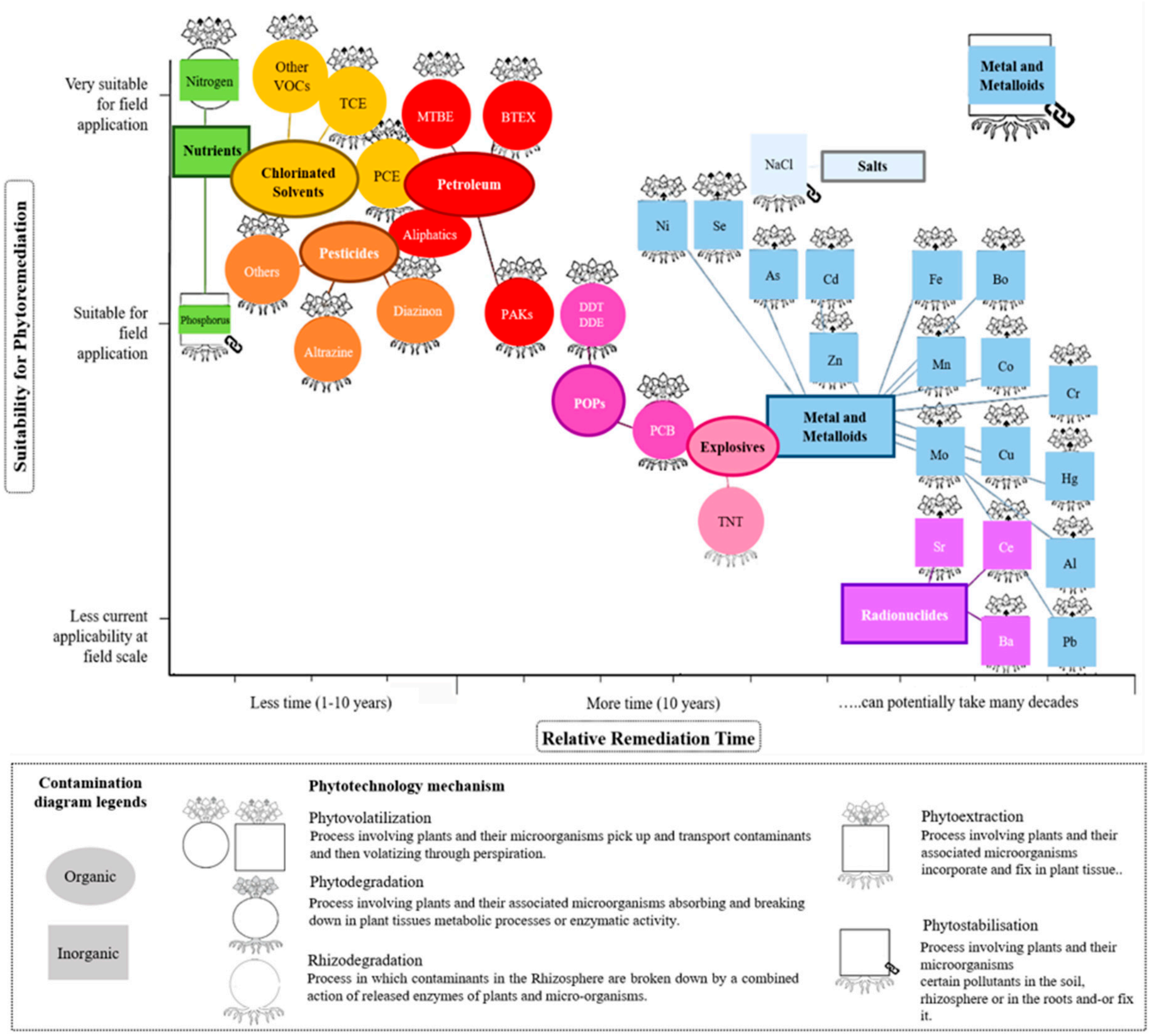


Figure 1. Overview of the phytoremediation potential of some contaminants and associated phytoremediation mechanisms; from Public Waste Agency of Flanders (OVAM) [66] and Kennen and Kirkwood [62] with a slightly adapted legend.

2.4. *Brownfields in a Circular Economy (CE)*

The arguments for optimizing urban land resources by bringing back redundant brownfields for beneficial use can be further strengthened from a CE perspective. The CE is an economic system that focuses on maintaining the value of products and materials for as long as possible. The idea is to design out waste by promoting "waste equals food" as a value that can be collected and recovered from waste [74–76]. As opposed to the "take-make-dispose" linear economy, CE generates loops where resources are in circular movements within a system of production and consumption [77]. Given this context, brownfields can be considered as valuable waste resulting from the "linear" land uses that are now to be reconsidered through the lens of a circular urban land use system. Apart from being the vehicle for extracting finite resources to support human activities, soil and land can themselves be argued to be a non-renewable resources due to the very slow soil formation process and limited surface area [78]. Repurposing brownfields is a crucial link in establishing a system that connects old places of use to new ones without wasting any land in between.

The CE is used as an operationalization tool for businesses to achieve sustainable development [79,80]. It consists of a technical cycle using mineral resources as production inputs and a biological cycle drawing on production inputs of biological origin [11,81]. Metals, plastics, and other finite resources are part of the "technical cycle" that focuses on recycling and keeping the materials within the closed loop system [82]. Biologically sourced products are the main driver of reducing fossil fuel dependence and CO_2 emissions by providing bio-renewable and biodegradable alternatives, such as biofuels or bioplastics [12,83]. Although the primary outputs of the biological cycle are still food crops, soil is nonetheless vital for plants and a core biological resource that is necessary for the production of all products of the biological cycle (Figure 2) [84]. Bio-based processes can also be used to recover resources such as energy, metals, and nutrients [85–87]. Phytoextraction is commonly discussed for biomining metals but the potential is presently very limited (e.g., limited to a few metals such as nickel and gold, complex and expensive processing of bio-ore compared to the market price and availability, etc.) [88–92]. Novel processes, such as biosorption and bioleaching, are now being explored within the CE framework for extracting metals and other resources from waste [93].

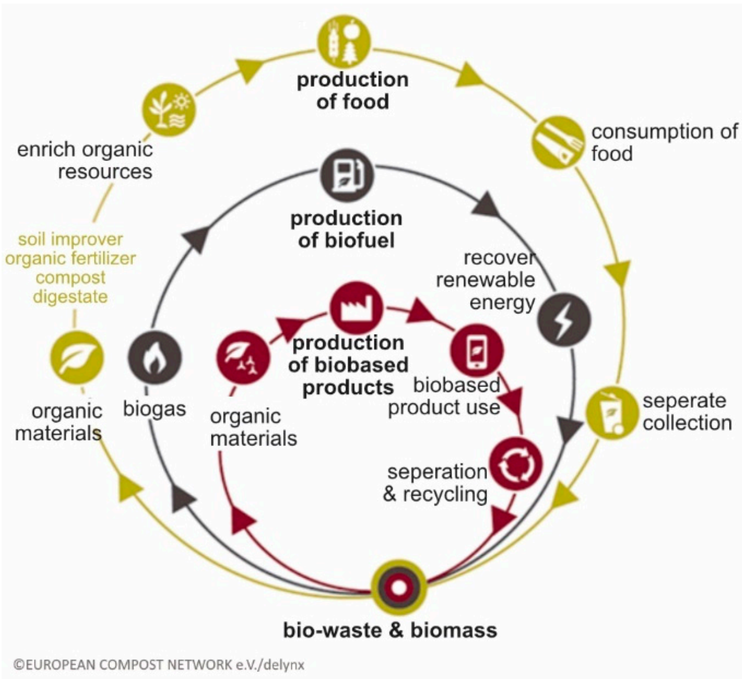


Figure 2. The biological cycle in the Circular Economy (CE); adapted from the European Compost Network [84].

Although the larger part of biological resource production takes place in rural areas, cities are consistently the biggest product consumers [94]. Europe, with two-thirds of its population already in urban areas, will also continue to urbanize, making the rural population, required to maintain the agrarian landscape, scarcer [1,95,96]. Hence, the loss of arable land will also continue in the EU region, which is expected to lose another 2.5 million ha by 2030, and where land abandonment is an additional factor due to the rural population loss [1,95,96]. Given that there will be more mouths to feed and less land available to grow food, urban agriculture may have a role to play in addressing urban food security issues [97]. Still, within the urban setting, urban agriculture plays a bigger role than food crop production by providing a place for the inhabitants to interact and educate themselves on nature and food production techniques [98].

The possibility of contaminants in urban brownfields can be a constraint on urban agriculture even though there are guidelines available for determining safe practices [99,100]. The cultivation of bio-energy crops, on the other hand, can take place directly on contaminated soil, simultaneously reducing ecological and human health risks, improving soil quality, and providing revenue [101]. The critique of growing energy crops on prime, food-producing land can be addressed by producing biomass on marginal, brownfield land [78,102,103]. This can even lead to a "self-funding land management regime," according to Andersson-Sköld et al. [104].

3. Methodology: Developing the Bio-Based Land Use Framework

Given the diversity and complexity of issues that need to be considered in the development of a bio-based land use framework, the process was divided into two methodological phases consisting of five steps in total, as elaborated below. The process is summarised in Figure 3.

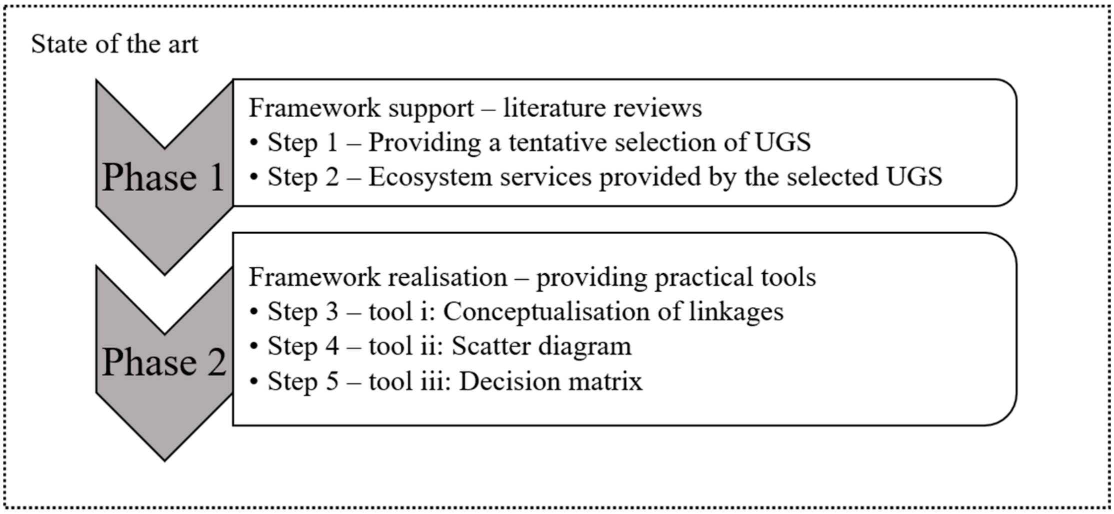


Figure 3. Methodology for developing the suggested bio-based land use framework.

3.1. Phase 1—Framework Support

The first phase of the conceptual development process created the base for the framework that builds on the findings of the state of the art (CE, brownfield remediation, GRO) by identifying relevant green land use elements, as well as the benefits of these green land uses in terms of ecosystem services.

- Step 1—Providing a tentative selection of urban greenspaces (UGSs) with potential for bio-based production on brownfields (Section 4.1). This step consisted of a literature search to develop an appropriate classification of UGSs as potential future land uses on brownfields in an urban CE context. Based on this literature search, the 44-item categorisation proposed by the pan-European Green Surge project [105] funded by the European Commission was identified as the most useful and was consequently used as the base inventory for a suggested selection of 14 potential future UGSs relevant for brownfields.
- Step 2—Linking the identified UGSs to the different types of ecosystem services they may provide (Section 4.2). Out of the 14 UGS selected from the Green Surge inventory, eight were further investigated in terms of the provision of ecosystem services. A literature survey was performed to present an inexhaustive list of ecosystem services that can be derived from the studied list of UGSs potentially relevant for brownfields. The literature review was carried out using the Scopus database and was extensive but limited to the 14 specified UGSs, using the combination of the search words "ecosystem services" and the 14 various UGSs identified.

3.2. Phase 2—Framework Realization

The second phase shaped the bio-based land use framework by providing the practical tools, consisting of a conceptualisation of linkages, a scatter diagram, and a decision matrix. The basis of the framework was the literature explored in the previous steps and built upon existing findings, including, but not limited to: phytoremediation potential mapping [62,66], the Greenland decision support framework [106], urban vacant land typology [107], models developed by the Sustainable Brownfield Regeneration project [27], stages of brownfield redevelopment [108], and the system of information categories for brownfield development [109].

- Step 3—Conceptualising the linkages between different types of gentle remediation options (GROs) and prospective UGS uses, taking soil contaminants and time frames into account (Section 5.1). The first tool of the framework was a conceptual diagram illustrating these linkages.
- Step 4—Synthesising the required interventions, time frames, and the permanency of UGSs on brownfields (Section 5.2). The second part of the framework was a scatter diagram that retained some features of the conceptual framework to provide a graphical representation for the realization of 14 UGS opportunities on brownfields, taking into consideration the required intervention level and realization time.
- Step 5—Identifying the site-specific basic conditions affecting the viability of UGSs and assessing these conditions across different types of UGSs relevant for brownfields (Section 5.3). The third tool of the proposed framework was a decision matrix for the analysis of whether or not the selected brownfield had the potential to fulfil the basic conditions for the realization of each UGS.

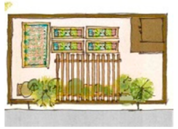
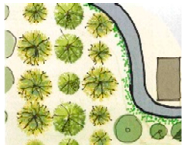
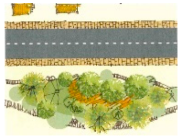
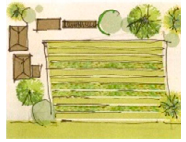
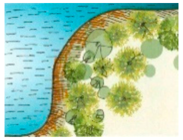
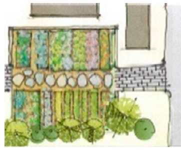
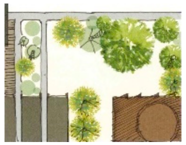
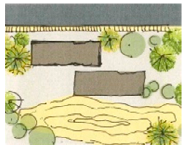
4. Result: Framework Support

4.1. Green Land Use Options: The Urban Greenspace (UGS) Typology

An inherent part of the urban fabric are urban open spaces not yet urbanized or built up: with a growing urban population, pressure is expected to mount on such less-appreciated land use [110,111]. Greenspaces are vegetated open spaces proven to be essential for the physical and mental well-being of the citizens, as well as providing a multitude of ecological functions [111–116] To capture the multiple purposes of urban greenspaces (UGSs), Sandström [117] introduced the concept of "green infrastructure" that is equally instrumental in achieving sustainable urban development as any "technological infrastructure". Green infrastructure can be understood as "an interconnected network of greenspaces that conserves natural ecosystem values and functions, and that provides associated benefits to human populations" consisting of all natural habitats in an urban area, also including blue spaces such as lakes or rivers [118], p. 5.

There are many different typologies of UGSs. The pan-European Green Surge project, funded by the European Commission, reviewed many of these and created an inventory of 44 relevant UGS elements found in European cities, further organized into eight main categories [105]. Here, brownfields are listed as one of these UGS elements, defined as abandoned, ruderal, and derelict areas, construction sites, etc., with spontaneously occurring pioneer or ruderal vegetation (UGS element 33). For this study, fourteen of the other UGS elements are identified as a tentative selection from the inventory to be examined in future case studies for their potential to be developed on brownfields, the list is presented in detail in Table 2.

Table 2. The studied list of potential future green land uses on urban brownfields derived from the Urban Greenspace (UGS) inventory by the Green Surge project [105]. Illustrations were created by the main author.

UGS Element	Image	Description	UGS Element	Image	Description	UGS Element	Image	Description
Building greenspaces		Plants on balcony/roof/façade or any place within a building.	**Institutional greenspace**		Green spaces surrounding public and private institutions and corporate buildings.	**Biofuel production/ agroforestry**		Land devoted to dedicated biofuel production, like short rotation coppice or poplar, etc.
Bioswale		Vegetated and gently sloped pit for filtering surface runoff.	**Allotment**		Small garden parcels cultivated by different people for non-commercial food production and recreation.	**Horticulture**		Land devoted to growing vegetables, flowers, berries, etc.
Riverbank green/ riparian vegetation		Greenspace along rivers, streams and canals, usually with foot or bike paths.	**Community garden**		Areas collectively gardened by a community for food and recreation.	**Shrubland**		Natural or secondary shrubland, e.g., heath, macchia, etc.
Historical park/ garden		Similar to large urban parks, but with distinct management due to heritage status.	**Grassland**		Pastures or meadows with grass cover.	**Spontaneous vegetation on abandoned, ruderal, and derelict areas**		Recently abandoned areas with spontaneously occurring pioneer or ruderal vegetation.
Neighbourhood greenspace		Semi-public greenspaces, vegetated by grass, trees, and shrubs in multi-story residential areas.	**Tree meadow/meadow orchard**		Fruit and nut trees, mixed agricultural use.			

4.2. Products of Greenspaces—Ecosystem Services

In the last few decades, ecosystem services have started becoming a part of the economic discussion, owing mostly to the seminal paper by Costanza et al. [119]. It presents a calculation of the value of ecosystem services, which is double that of the global gross national product, on average. Cities, although they generally consume more ecosystem services than they produce, still carry the potential to improve their environmental performance, with the main parameter of evaluation being the quantity and quality of the available urban greenspaces [4,120]. There are many obvious environmental and ecological benefits of greenspaces in urban areas that fall under regulating and supporting ecosystem services, as well as simultaneous psychological benefits to human societies, adding to the cultural ecosystem services [110]. However, among the four types of ecosystem services, provisioning, regulating, supporting, and cultural, only provisioning ecosystem services, such as food and biomass, have been part of the discussion so far as a biological resource in the bio-based CE [12,121]. Limiting the discourse only to food and biomass, especially in cities, would fail to capture other vital services provided by the greenspaces to urban dwellers. A literature review is done to examine the extent of the ecosystem services that can be provided by the potential future green land uses and the result is summarised in Table 3.

Table 3. Ecosystem services of the studied list of potential future green land uses. PS—Provisioning services; RS—Regulating services, CS—Cultural services; SS—Supporting services.

	Building Greens
PS:	Food: A study on the city of Bologna (Italy) showed rooftop gardens could provide more than 12,000 t year^{-1} of vegetables, satisfying 77 % of the inhabitants' requirements [122].
RS:	Reduction of urban heat island effect, air pollution, and building energy consumption: A literature review on urban green roofs found their potential for cooling at street level (0.03–3 °C), in pollution control, such as small particle removal (0.42–9.1 g/m^2 per year), and changes in annual energy consumption from a 7% increase to a 90% decrease [123]. Rainwater retention: Extensive green roofs can retain almost 75% of rainwater [124,125].
SS:	Biodiversity conservation: Green roofs can provide sites for potential bee conservation in urban areas if planted with native plants and foraging resources designed to accommodate bees [126].
	Bioswale
RS:	Nutrient cycling and water purification: A study in residential sites in California (USA) founds that bioswales significantly reduce contaminants from stormwater, including suspended solids (81% reduction), metals (81% reduction), hydrocarbons (82% reduction), and pyrethroid pesticides (74% reduction) [127]. Reduction in stormwater runoff: Another study on bioswales in a parking lot at Davis (USA) revealed a reduction in runoff of 88.8% and total pollutant loading reduction of 95.4% [128].
	Riverbank green
PS:	Food (indirect): Riverbank green provides habitat and supports aquatic life [129] which in turns supports fishing activities [130]. Raw materials: Riverbank greens can support the production of vegetative biomass [131].
RS:	Carbon sequestration and storage: A study on the riverbank green in Mexico suggests that it can store 1.5 times more carbon than oak forests [132]. Nutrient cycling: Multiple studies on riverbank green have found that it acts as a protective buffer between water bodies and land-based activities by filtering nutrients, as well as trapping nutrients for groundwater [129,133–139]. Bank stability and flood attenuation: Riverbank green helps in trapping sediment during flooding events and forms soil, slowing and spreading flood water, increasing bank stability, and minimizing soil loss in watercourses [129,133,135–141]. Water temperature regulation: Riverbank green assists in regulating the watercourse temperature by providing shade [133,138,142,143].

Table 3. *Cont.*

	Riverbank green
SS:	Habitat and maintenance of species: Aquatic and terrestrial: Riverbank green provides habitat and support for aquatic life, a refuge for wildlife in urban and rural areas, and contributes to species richness and biodiversity by maintaining wildlife movement corridors [129,133,138,142,144,145].
CS:	Recreation and aesthetic appreciation: Riverbank green helps in increasing the aesthetic value of agricultural and urban landscapes, as well as providing places for outdoor activity [136,146]. Culture and sense of place: For the locals of Central Benin, riverbank green is a source of cultural importance and traditional knowledge, cultural identity, and a source of belonging [130,147].
	Historical park
RS:	Carbon sequestration and storage: The urban areas covered by parks, gardens, tree-lined avenues, sport fields, and hedges are important sinks for carbon dioxide (CO_2) by storing carbon through photosynthesis to form plant biomass [148].
CS:	Healthy living: Urban park experience may reduce stress by providing a place to relax, enjoy peacefulness and tranquillity, and rejuvenation for city inhabitants [110,115,148].
	Neighbourhood greenspace, allotment, and community garden
PS:	Food products as raw materials: Gross benefit from food products per allotment plot in Manchester (UK) can be up to 698 pound in a year. Apart from plant produce, livestock such as chickens are also kept in the allotment garden [149]. Community gardeners in New York City (USA) manage to supply a large share of their households' food product needs with the garden produce [150]. Food security: Urban allotment gardens are a historically important source of urban resilience against food dependence, extreme weather events, or even climate change, contributing to long-term food security [149,151,152]. Medicinal herbs and tea: Several allotments in Manchester were found to have cultivated medicinal herbs both for medicine and culinary purposes [149].
RS:	Soil health: A study in the UK showed that soils in allotment gardens have 32% higher soil organic carbon (SOC) concentrations and 36% higher carbon: nitrogen ratios than pastures and arable fields [153]. Stormwater retention: The community gardens of NYC, USA are expected to retain 45 million litres of additional stormwater due to their raised beds [154].
SS:	Habitat and maintenance of species: A study found that the parks in Manchester (UK) have about 65% of the species richness of Manchester allotment gardens [149]. Allotment gardens in Poznan (Poland) were also shown to have more native varieties of flora [155].A study in Stockholm (Sweden) found the variability of bumblebee visits to urban allotment gardens to be higher than peri-urban ones [156].
CS:	Nature education: Allotment and community gardens are prime spots for education on nature and sustainable food production techniques among community groups in cities [98,149,157,158]. Health benefits from physical activities: Allotment and community gardens provide alternative and more accessible physical activities especially beneficial for the elderly population [149,158]. Knowledge production: A study in Sub-Saharan Africa found community clinic gardens to be a place for the co-production of knowledge on growing nutritious food by the involvement of multiple stakeholders [159]. Recreational benefits: The allotment gardens in Poznan (Poland) are treated like recreational retreats during the summer months [149]. In Germany and Austria, allotment gardens are also considered as recreational areas in planning regulations [157].
	Grassland and shrubland
PS:	Food, raw materials, medicinal plants: Grasslands are commonly used as grazing fields by many communities and they provide game for hunting, thatching materials for roofs and walls, and medicinal plants and fruits [160–165].
RS:	Carbon sequestration and storage: Grassland in various regions acts as soil carbon storage at the same time as providing sites for tree plantation to sequester aboveground carbon [166–169]. A study across six European shrublands shows that net carbon storage in the systems ranged from 1163 g/ m^2 to 18,546 g/m^2 [170].

Table 3. *Cont.*

	Grassland and shrubland
SS:	Water supply and storage: Grassland plays an important role in water supply by mitigating and storing runoff waters [161,166,171]. Habitat and maintenance of species: Grassland restorations in China show that biodiversity improved by 32.44% [161,172].
CS:	Maintenance of culture and tradition: Alpine grassland plays an important role in Tibetan culture and the maintenance of tradition [165,173].
	Meadow orchard
PS:	Food provision: In Berlin, fruit trees are abundantly used for ornamental reasons but can be potentially be used for consumption, as the fruits are found to pose no additional risk from pollution if washed thoroughly and stored properly [174].
SS:	Habitat support: A study suggests that the proper maintenance of living ground cover in almond orchards could provide habitat for pollinators like native bees [175]. Orchards, abandoned and functioning, are found to provide habitat and refuge to birds [176].
	Biofuel agroforestry
PS:	Raw materials: Biofuel and biomass: In a study, a Jathropa plantation was shown to produce 230 kg biodiesel for the replacement of fossil fuels per hectare, as well as produce 4000 kg of plant biomass per year [177]. Agroforestry intercropping of woody and perennial bioenergy crops increases combined biomass yield and reduces the cost of production [178].
RS:	Carbon sequestration and storage: In 4 years, Jathropa cultivation was shown to have increased the carbon content by 19%, resulting in 25,000 kg carbon sequestrated per hectare [177]. Nutrient cycling and climate change support: A strategically planted willow buffer can improve the net global warming potential (GWP) and eutrophication potential (EP) of soil, as well as cut back nutrient loading to water [179]. Water supply and storage: The water holding capacity of the soil under a Jathropa plantation was shown to increase by 35% compared to adjacent soil [177].
SS:	Habitat and maintenance of species: Agroforestry with combined grass cover and perennial biofuel planting is expected to support a larger and more diverse bee community, as well as many other beneficial insects [180].
	Horticulture
PS:	Food and raw materials: Horticulture contributes directly to urban economics through the production and sale of horticulture products [181]

Even with limited capacity and even less exploration in the literature, there is still plenty of evidence supporting the food provisioning ability of urban greenspaces. For example, Orsini et al. [122] found that the rooftop gardens in the city of Bologna (Italy) have the potential to meet 77% of the inhabitants' fresh vegetable demand. Communal agricultural greenspaces (e.g., allotments, community gardens, neighbourhood greenspaces) are historically important sources of urban resilience, ensuring long-term food security and reducing food dependence on external sources. Their importance is even more heightened due to climate change and the consequent increase in extreme weather events [149,151,152]. Though the urban environment is notorious for pollution, a study in Berlin (Germany) found no additional risk in the consumption of fruits grown in the city if washed thoroughly and stored properly [174]. Greenspaces can also indirectly support food provisioning, as grassland and shrubland are primary grazing spots for cattle, as well as providing game for hunting, and riverbank greens provide habitat for fishes among other aquatic fauna [129,161,162,165]. Apart from food, greenspaces, especially when fitted with bioenergy crops, are capable of providing biomass that can turn into fuel or bio-based products [178].

Urban greens are important regulators as carbon sinks, as well as retaining water, as extensive green roofs may retain almost 75% of precipitation [124,125,148]. Green roofs can also potentially reduce the urban heat island effect with cooling on the street level of temperatures ranging from

0.03–3 °C [123]. Bioswales perform important regulating services by nutrient recycling, and a study on a parking lot bioswale in Davis (USA) revealed a reduction of total pollutant loading in runoff water by 95.4% [128]. Riverbank greens also act as protective buffers between land-based activities and waterbodies and filter nutrients, as well as stop seeping into the groundwater, and they also play an active role in bank stability and flood regulation [133,135–137]. Moreover, introducing greens improves the overall health of the urban soil, with urban allotments showing a 32% higher soil organic carbon (SOC) concentration than pastures [153].

Cities are designed for humans as their primary users, but urban greens can still play an important role as a necessary refuge for other species, supporting biodiversity. A study of urban allotments in Stockholm (Sweden) found the variety of bumblebees to be higher there than in peri-urban areas, and in Manchester (UK), allotments were found to support a greater spontaneous flora species variety than urban parks [149,156]. Bee communities are also found to be provided with habitats on green roofs and biofuel plantations, whereas meadow orchards can support refuge for birds [126,175,176,180].

The most important service urban greens perform is perhaps cultural. They are instrumental in the mental well-being of citizens, as park experience has been found to reduce stress, provide a place for citizens to relax and rejuvenate [110,115,148]. Providing communal agricultural green land use gives city dwellers opportunities to learn about nature and sustainable food production, as well as creates an alternative and more accessible physical activity option, which is especially beneficial for the elderly population [98,149,157,158]. For example, in Germany and Austria, allotments and community gardens are designated as recreational areas [157]. Natural greenspaces, such as riparian greens and grasslands, can be a source of traditional knowledge and of cultural importance whilst being a place for recreational outings as well [130,136,146,147,165,173]. Still, for some greenspaces, there are not many examples in the literature, although not likely because they are any less useful, but simply less investigated.

5. Result: A Bio-Based Land Use Framework for Urban Brownfields

5.1. Conceptualization of Linkages

Green land uses, unlike intensive urban development, offer the flexibility for brownfields to simultaneously undergo a remediation process. Such processes depend on the level and type of contamination, but nevertheless, some green land uses, with interlinked bioremediation options, are always possible as long as risk sources are sufficiently contained. A conceptual bio-based land use framework for urban brownfields to assess the viabilities of future green land uses, considering their remediation potential over time, is outlined in Figure 4. Typically, a certain green land use interplays with certain bioremediation processes that, over time, change the composition of soil contaminants and make room for new types of green land uses. Subsequent green land uses facilitate new types of GROs that lead to possibilities for other land uses, and so on.

Building greens, as well as vertical agriculture land uses, can use the benefit of sealed surfaces to operate until a more intensive remediation process is scheduled [122]; for example, land use 1 in Figure 4. Bioswales are another possibility for contaminated sites with a concurrent remediation potential [128] and it is possible to produce biofuels on contaminated soil, while, at the same time, remediating the same soil [104] (for example, land use 2). Natural land uses, such as riverbank greens, have shown effectiveness in cycling, trapping, filtering, or stabilizing certain types of contaminants [133]. Moreover, green land uses can be applied temporarily and bring abandoned land back in use immediately, while a more extensive remediation project can be planned or funded. However, more extensive agricultural land use, such as horticulture and meadow orchards, need the soil to be sufficiently safe for food production (for example land use n-1).

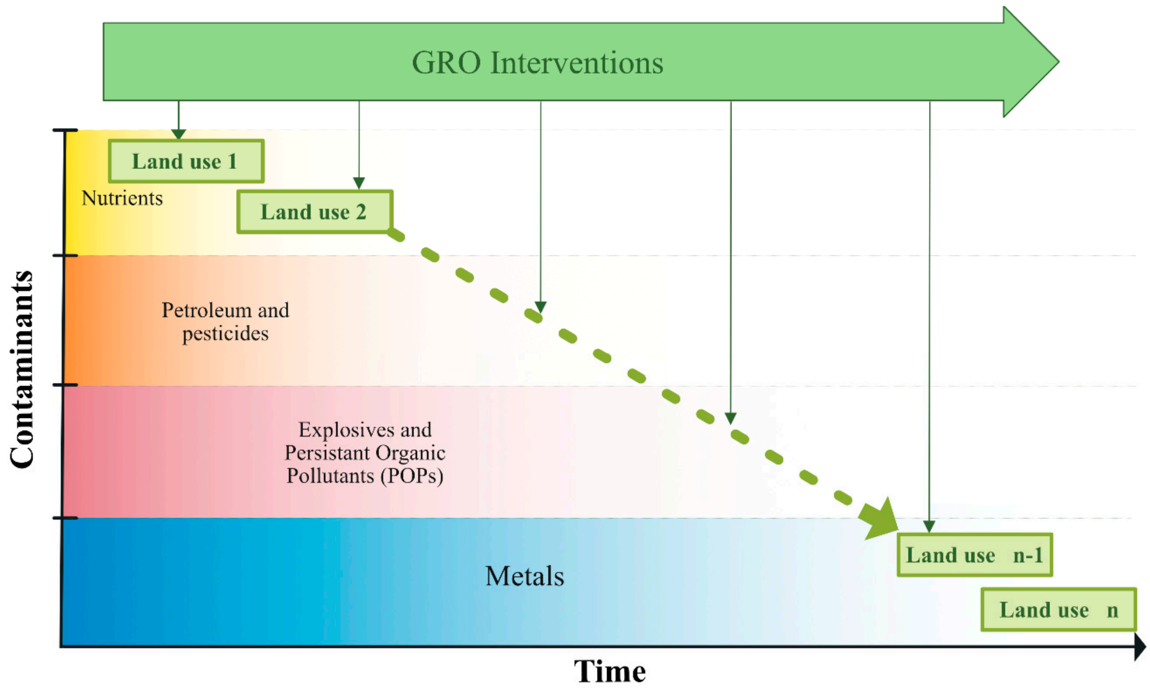


Figure 4. Conceptualization of linkages regarding how different types of gentle remediation options (GROs) relate to prospective UGS land uses, taking soil contaminants and time frames in account. Reduction in color intensity within a band symbolizes the reduction of contaminants in the soil over time. Reduction in metal concentrations in the soil by GROs typically takes a very long time, whereas risk reduction by means of stabilization may be achieved much faster.

5.2. Required Interventions, Time Frames, and Permanency of UGS on Brownfields

The bio-based land use framework further includes a scatter diagram that puts different UGSs in the perspective of the fulfilment of the required interventions and time frames needed for UGS implementation and which basic conditions need to be fulfilled. The scatter diagram in Figure 5 was developed as an intermediate step to provide a graphical representation of different green land use opportunities (the studied list of Table 2) on brownfields. The diagram is elaborated as follows:

- Potential future green land uses (the identified UGS elements in Table 2) are analysed in the context of two basic requirements: intervention and time needed to realize them.
- The *Y* axis of the diagram represents the required intervention which can be understood as the resource intensity requirements of, e.g., information, stakeholder commitment, and capital. This acts as a general understanding of the bulk of the work entailed by the upcoming development, of which part is later covered in detail by the list of basic conditions (Table 4). The vertical position of each land use in the figure depicts the relative scale of the intervention required, low, medium, or high, for an UGS to be realized.
- The *X* axis of the diagram indicates the relative time frame in years (Y) estimated for realizing the future green land use. The axis is scaled in three parts: immediate (<2 Y), intermediate (2–10 Y), and long term (>10 Y). The land uses are positioned horizontally according to the expected time needed for implementation. Again, it needs to be stressed that the time frame provided here is for initial understanding, as it is expected to be impacted heavily by site-specific criteria, such as site conditions, size, location, and the level and types of contamination.
- The diagram finally incorporates the permanency of the green land uses based on their position in the diagram. The more time and resources required, the more likely the green land use is to be permanent. Vice versa, land uses with low time and resource requirements can be considered as more temporary interventions.

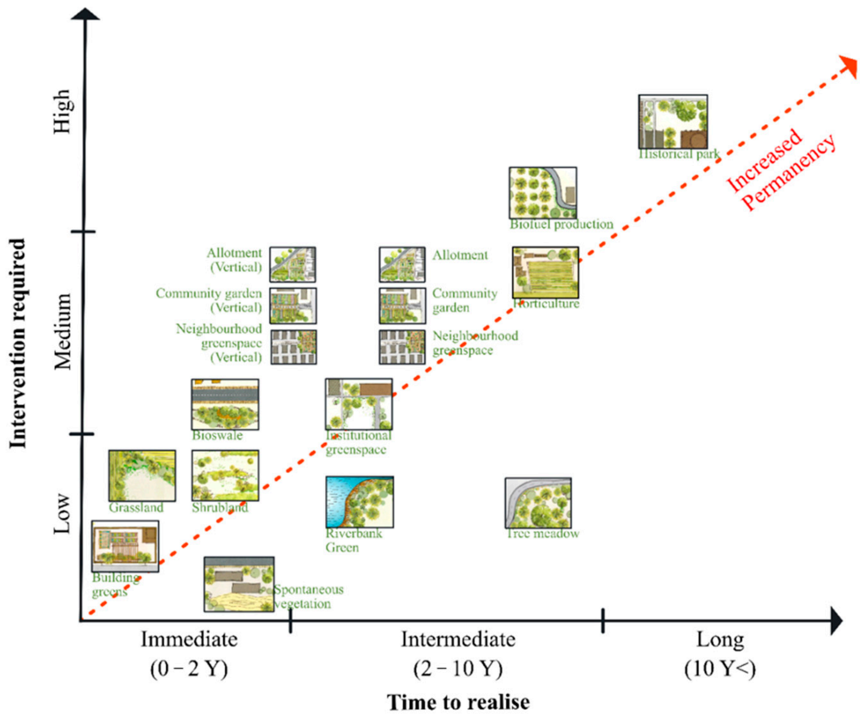


Figure 5. The scatter diagram of future green land use on urban brownfields with provisional positioning of the icons.

Table 4. The suggested list of basic conditions affecting green land use on brownfields.

Basic Conditions	Description
Pre-conditions	Building greens—Presence of built infrastructures Institutional greenspace—Institutional ownership or interest Riverbank greens—Presence of a waterway Historical park—Historical relevance Neighbourhood greenspace—Adjacent neighbourhood Spontaneous vegetation—Derelict site conditions
Density	The density in the urban context, having either a dense or sparse character of building stock within the site or positioned either in a dense or sparse neighbourhood.
Sealing	The presence of sealing on soil that, e.g., may function as an exposure barrier on contaminated soil and provide a surface for vertical plantations.
Size	The size of the land parcel available for development further categorized as large (>1 ha), medium (0.1–1 ha), small (<0.1 ha). For some land uses, the available size is affected by the share of sealed and non-sealed areas on the site.
Access	The degree of (future) public access to the site.
Management	The type of management involved in or required for bio-based production in the future green land use.
Profit	The need for profit generation linked to the biological resources to be produced on the site.
GRO potential	The possibility of the green land use to facilitate soil remediation with GROs. It always implies that a risk assessment is needed and whether the risks are very high (for humans or ecosystems).
Regulations	The regulations and policies by authorities (local, national, or global), that need to be adhered to when realizing a new land use.

The potential of green land uses depends on required intervention and the time needed to realize the land use. A provisional positioning of the selected types of UGSs (see Figure 5) can be accomplished based on the literature but will evidently be affected by local conditions.

If there is existing built infrastructure on the site and demolition is undecided or distant in time, building greens can be an added as an immediate circular action with no or little structural modifications needed [182], in this way, providing beneficial use of the structure. The roofs, providing structural integrity, can be fitted with gardens where plants can be grown without much concern for the potential contamination of the base soil [183]. Permanency is thus not an issue but may be retained if desired.

As brownfields can remain abandoned for a considerable amount of time depending on the local land development pressure, they often gradually generate a cover of spontaneous vegetation over time [184]. Even when the sites seem to be too contaminated for anything to grow, a green cover grassland, which would also work as a phytostabilizer of contaminants, can still be achieved by carefully selecting specific grasses suitable for the site [185]. Shrubland would require similar consideration but a canopy growth can be expected to take a longer time for such land use compared to grassland [186]. Again, permanency is not a primary concern, although spontaneously developed biodiversity from ruderal vegetation [187] might lead to calls for conservation.

Bioswales require a thorough understanding of the needs of the site surroundings and the types of contaminants, as they primarily work as a filter for runoff water purification. The vegetation selection and landscaping interventions likely need to reflect this input of contaminants [128], e.g., by not allowing water to infiltrate [188].

Institutional greenspaces require rigorous safety precautions due to a greater likelihood of being be accessed by people, where a careful design of such spaces needs to prompt people towards behaviour that avoids remnant contamination [57].

Riverbank greens, with their riparian vegetation, however, might not require such intensive interventions due to being more sparsely visited, but as the site areas are expected to be much larger, this would influence both capital requirement and time. Furthermore, proximity to rivers also brings the risk of increased exposure to contaminants due to flooding events [189] which potentially requires significant preventive interventions. Short rotation willow biofuel plantations as buffer strips along the river bank can provide significant ecosystem services in as little as three years [179].

Greenspaces that require community involvement for maintenance or agricultural activities (e.g., neighbourhood greenspace, community gardens, allotments) are usually subjected to stricter regulations for contaminant exposure, as food consumption becomes an added exposure pathway, as well as active user exposure [190]. If the exposure source is sealed under a solid surface, then the surface itself can still be used immediately through low-cost intervention, e.g., for vertical farming in raised boxes (an urban agriculture scenario recommended as a best practice on brownfields by U.S. EPA) [100]. If such green space activities take place directly on the soil, ensuring safety is both time- and resource-consuming, as it requires testing, amendments, or remediation to make sure the site is secure for both human users and the surrounding environment [191]. Additionally, community-based interventions need to be scaled according to the multitude of users involved and the required and/or aspired levels of community engagement, especially since participating children may directly ingest soil [192]. Neighbourhood greenspaces, community gardens, and allotments with an already engaged group of users can be expected to require few resources but community-based greenspaces on a larger scale would need public or private investments and interventions to be viable [193], thus requiring more time to develop.

Tree meadows or orchards mainly consist of fruit trees which take a long to mature, have long and varied fruiting times, and require more intensive care, such as pruning [194]. Additionally, there can be a significant uptake of soil contaminants into fruits [195].

In horticulture, crop production is targeted for commercial purposes, which requires the soil to be safe for such use, and the food produce to meet health standards to be marketable. If the soil is healthy, this does not necessarily need more interventions, but if not, it might require different types of detached cultivation technologies (e.g., vertical agriculture or hydro/aero/aquaponics [196]), or simply time for the brownfields to be safe enough to engage in active use.

Biomass production can easily be practiced on brownfields with less pressure from safety regulations, as the produce is not for direct human consumption [197]. Additionally, biofuel production is not as affected by soil contaminants and is suitable as a use of marginal lands [104]. If land is contaminated with metals, particular plant species that are resistant to metal uptake (e.g., sunflower, prairie grass) can be selected to produce clean feedstocks [104,198–200]. Although there is a potential market outlet for urban biomass, this potential will still need significant interventions to be realized [201]. For example, if feedstocks are contaminated, there needs to be bioenergy or biofuel production plants that are both able and willing to safely handle biomass with a higher concentration of contaminants.

Historical parks may contain soil contamination due to previous economic activities [202], posing significant risks to visitors [203]. If used for recreational purposes, such parks do not only require facilities to accommodate a large number of users but may also need significant soil remediation [204] if not designed to protect visitors from exposure [57].

5.3. A Decision Matrix for the Potential Future Green Land Uses on Urban Brownfields

Urban land use is a complex system that is constantly adapting to new necessities, more recently to accommodate the rising challenges of sustainable development [205,206]. Increasing greenspace per capita is a standard strategy with often immediate but subtle impacts. Integrating such spaces in the urban fabric is, however, a challenge [207]. Retrofitting brownfields does provide a response to the first step of this problem, which requires finding a place for greenspace but, at the same time, it complicates the following steps with several inherent obstacles, such as public stigma or possible contamination [13,208].

As admitted by previous studies, it is difficult to produce a definite list of basic conditions for the evaluation of future land use on brownfields, as there are many local and site-specific variables likely to be influential in decision making and which are hard to generalize. Each parcel of land is unique and so are the challenges associated with developing it [100,107]. An inexhaustive list of challenges that can be faced is provided by U.S. EPA [100] in their interim guidelines to facilitate urban agriculture in brownfields: soil type, likely contaminants, crop type, garden size, climate, who enters the garden, individual gardener/farmer practice, how long they spend in the garden, growing for individual or family use, donation or market, state regulations, etc. Kim et al. [107] followed a simpler set of hierarchical criteria while proposing development on urban vacant land: previous development, presence of contamination, historical importance, remediation feasibility, and existing vegetation quality. The European project CABERNET kept it even simpler by using only land value and reclamation costs to categorize brownfields [16,27,40].

Although the challenges can vary and can be miscellaneous, it is still helpful to have a short list of basic conditions to facilitate a screening assessment for the potential for the realization of different green land uses on brownfields. For some of the green land uses to be considered as a valid option for realization in the future, mandatory pre-conditions are required at the site. For example, riverbank greens cannot be considered as a potential future land use on a brownfield lacking the presence of a water body. A suggested short list of basic conditions, including the pre-conditions required for green land uses, is presented in Table 4, to be revised and complemented in future case studies. This is not intended as a complete set but rather a starting point for a shortlist used to trigger the process of greening by indicating the potential of a brownfield.

The next step is to connect the different types of UGSs to the basic conditions affecting green land use on brownfields, resulting in a screening matrix (Table 5), pairing the potential future green land use options (Table 2) with the selected set of basic conditions (Table 4). The degree of fulfilment of the basic conditions for a particular brownfield site can be marked using green (fulfilled), red (not fulfilled), yellow (unsure), blue (can be changed if needed) or purple (not applicable). At this point, this decision matrix is exploratory and needs to be applied and assessed through future empirical work. The matrix is exemplified using the Fixfabriken site in Gothenburg (SE) and presented in Figure 6 (details on the site can be found in Garção [209]).

Table 5. Decision matrix for potential future green land uses on urban brownfields. If the condition in the box is fulfilled for a specific site: mark green. If not fulfilled: mark brown. If unsure: mark grey. If it needs to (or can) be changed: mark yellow. If not applicable: mark blue.

UGS Basic Conditions		Building Green	Bioswale	Riverbank Green	Historical Park	Neighborhood Greenspace	Institutional Greenspace	Allotment	Community Garden	Grassland	Meadow Orchard	Biofuel Production	Horticulture	Shrubland	Spontaneous Vegetation
Pre-condition		Buildings	-	River	History	Adjacent housing	Institution	-	Community	-	-	-	-	-	Derelict
Density	**Site**	Preferably dense	Dense or sparse	Sparse	Sparse	Dense or sparse	Dense or sparse;	Dense or sparse	Dense or sparse	Sparse	Sparse	Sparse	Sparse	Sparse	Dense or Sparse
	Surroundings	Dense or sparse	Dense or sparse	Dense or sparse	Dense or sparse	Dense	Dense or sparse	Preferably dense	Preferably dense	Dense or sparse	Dense or sparse	Dense or sparse	Dense or sparse	Dense or sparse	Dense or sparse
Sealing		Sealed, butunsealed is possible	Unsealed, but sealed is possible	Unsealed	Unsealed	Unsealed, but sealed is possible	Unsealed, but sealed is possible	Unsealed, but sealed is possible	Unsealed, but sealed is possible	Unsealed	Unsealed	Unsealed	Unsealed	Unsealed	Unsealed, but sealed is possible
Size		Preferably small	Preferably small or medium	Large, but medium is possible	Medium or large	Preferably small or medium	Medium or large	All sizes	Preferably small or medium	Large	Large, but medium is possible	Large, but medium is possible	Medium or large	Large	All sizes
Access		Private, semi-public, or public	Preferably public	Preferably public	Public	Semi-public or public	Semi-public or public	Semi-public or public	Semi-public or public	Preferably public	Private, semi-public, or public	Private	Private or semi-public	Preferably public	Private, semi-public, or public
Management		Individual, communal, private, or public	Private or public	Private or public	Private or public	Communal, private, or public	Private or public	Communal, private, or public	Communal, private, or public	Private or public	Communal, private, or public	Private or public	Communal, private, or public	Public	Individual, communal, private, or public
Profit		Needed, there is a market	Not needed	Not needed	Not needed	Not needed or needed, there is a market	Not needed or needed, there is a market	Not needed or needed, there is a market	Not needed or needed, there is a market	Needed, there is a market	Needed, there is a market	Needed, there is a market	Needed, there is a market	Not needed	Not needed
GRO potential		Yes, if unsealed	Yes, if unsealed	Yes	Yes	Yes, if unsealed	Yes, if unsealed	Yes, if unsealed and the produce is not for consumption	Yes, if unsealed and the produce is not for consumption	Yes, if not used for cattle grazing	Yes, if the produce is for consumption	Yes	Yes, if the produce is not for consumption	Yes	Yes, if unsealed
Regulation		Depends on site specifics and local regulatory systems													

UGS / Basic Conditions	Building green	Bioswale	Riverbank green	Historical park	Neighbourhood greenspace	Institutional greenspace	Allotment	Community garden	Grassland	Meadow orchard	Biofuel production	Horticulture	Shrubland	Spontaneous vegetation
Precondition														
Density: Site			n.r.	n.r.		n.r.								
Density: Surroundings			n.r.	n.r.		n.r.			n.r.	n.r.	n.r.	n.r.	n.r.	
Sealing			n.r.	n.r.		n.r.			n.r.	n.r.	n.r.	n.r.	n.r.	
Size			n.r.	n.r.		n.r.			n.r.	n.r.	n.r.	n.r.	n.r.	
Access			n.r.	n.r.		n.r.			n.r.	n.r.	n.r.	n.r.	n.r.	
Management			n.r.	n.r.		n.r.			n.r.	n.r.	n.r.	n.r.	n.r.	
Profit			n.r.	n.r.		n.r.			n.r.	n.r.	n.r.	n.r.	n.r.	
GRO potential			n.r.	n.r.		n.r.			n.r.	n.r.	n.r.	n.r.	n.r.	
Regulation	Depends on site specifics and local regulatory systems													

Figure 6. An example of the decision matrix for the future green land use at the Fixfabriken site. See the legend in Table 5 for explanation of the colour codes (n.r. = not relevant). The decision maker could rank the UGS alternatives based on the number of the fulfilled basic conditions. In this example, building greens and spontaneous vegetation would be the highest-ranked UGS alternatives.

Future green land use on urban brownfields depends on the *density* of the urban area. For example, in compactly developed parts of a city, both vertical building greens and bioswales on roadsides could still be manageable within a tightly weaved urban fabric, while building greens make less sense in more sparsely built areas. Additionally, urban agriculture practices that traditionally take place in sparse parts of cities can be done vertically in dense neighbourhoods. Though there is high pressure on land in many cities, legislative or financial issues can hinder the pace of brownfield development. In such cases, spontaneous vegetation can bring abandoned land back into also delivering ecosystem functions in dense areas.

Sealing becomes important since most greenspaces require open soil but, again, vertical greens as well as allotments and community gardens can take place on sealed surfaces, e.g., overriding the safety precautions needed for contaminated soil exposure. Obviously, UGSs such as grassland, shrubland, meadow orchards, and horticulture cannot take place on sealed surfaces.

Though the *size* of the brownfield is somewhat subjective, natural green land uses, such as riverbank green, grassland, and shrubland require rather large parcels of land, as do commercial agriculture practices, such as horticulture and biofuel. Meadow orchards and historical parks may take place on both large- and medium-sized sites. In contrast, communal green space practices, such as neighbourhood greenspaces, community gardens, and allotments, can be managed on medium to small land plots. Building greens are not dependent on the size of the soil surface but on the floor or wall area of the built infrastructure. Spontaneous vegetation will grow on any brownfield irrespective of its size.

Greenspaces such as riverbank greens and shrubland, and possibly also grassland and meadow orchards, are expected to have public access. Bioswales are usually also public, typically being part of other public spaces, such as roadsides or parking lots. Access to agricultural uses ranges from semi-public to private, depending on the flexibility and interests of the responsible authority, owner, or active users.

The number and type of involved stakeholders in developing and maintaining a green land use also depends on how the *management* is carried out for the type of activity. Commercial agriculture is commonly practiced as a private business, while neighbourhood greenspaces, community gardens, and allotments are typically for communal usage. Meadow orchards can be accessed during harvesting seasons both privately and communally.

For the products of the agricultural activities in the greenspaces, *profit* requirements may play a critical role. The products from horticulture and biofuel production are for commercial purposes and require buyers and a functional niche market. Environmental improvements through, e.g., building greens, can also be seen to bring commercial benefits. In contrast, food produced from communal agricultural practices is for personal or shared use and typically does not require a commercial outlet.

Two criteria need to be checked to realize the *GROs potential* in parallel to the green land use. Firstly, for GROs such as phytoremediation to be effective, it needs to take place in the soil itself, thus the soil cannot be sealed. Secondly, as GROs would take place on contaminated sites, the edible produce grown directly in the soil can be considered unsafe for consumption. Grassland and meadow orchards can also be considered unsafe, as they can be used for cattle grazing and could affect the cattle, and consequently humans, by biomagnification. There may be specific types of crops in combination with specific types of contaminants that still make it possible to grow edible crops, but such a scenario would need an in-depth risk assessment to be accepted. If the produce is not for human consumption and the site is unsealed, GRO intervention can in principle take place parallel to green land use. However, human activities at contaminated sites always implies some human exposure to soil, dust, and vapours, and a risk assessment should always be carried out.

Local, national, and transnational *regulation* strongly affects what can and cannot be done on brownfields but is site specific, as the level of contamination will be site specific.

6. Concluding Remarks

The overall aim of this study was to initiate the development of a framework that will function as decision support to facilitate the greening of urban brownfields, combined with GROs if possible. The bio-based land use framework is an attempt to incorporate Circular Economy values with urban greenspace, to bring wasted marginal urban lands back into beneficial use. The usability of this framework, however, needs to be tested in various urban contexts, for further modification and refinement to efficiently identify the bio-based potential of brownfields. At the same time, it is equally instrumental to (1) develop policy guidelines to allow more room for bio-based solutions and (2) develop knowledge on the usefulness and effectiveness of GROs. The future land use options and the decision matrix for implementation can, in the meantime, assist the relevant stakeholders in developing brownfields for green land use where the output has the potential to initiate the dialogue necessary for policy negotiation.

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