THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Repurposing brownfields as urban greenspace with gentle remediation options: A circular outlook

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Cover:
Illustration and visualisation of potential combinations of UGS and GRO for the case study site at Polstjärnegatan, Göteborg (SE), also Fig. 18 at page 52. Developed by author.

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ABSTRACT

Circular Economy (CE) is regarded as an efficient strategy to address the challenges arising from the linear 'take-make-use-dispose' system of exploitation of resources. Urban land and soil are among the most exploited resources wherein brownfields, the potentially contaminated and currently obsolete land, can be considered the waste of the linear land use system. Recent CE policies and action plans acknowledge soil as a finite resource and set out clear directives for circular management of both soil and land. Brownfields pose possibility to integrate Urban Greenspaces (UGS) in increasingly denser cities to provide a range of Ecosystem Services (ES) and are instrumental in ensuring the liveability of cities. To manage risks posed by contaminants present at these brownfields, UGS can be combined with Gentle Remediation Options (GRO). Gentle remediation options are remediation strategies involving plants, fungi, bacteria, and soil amendments for managing contamination risks and simultaneously improve or at least maintain the soil quality. The overall aim of this PhD project is to develop adequate tools and methods to facilitate bringing brownfields back in use by combining UGS and GRO. This thesis presents four studies: i) a framework for identification of different UGS at a brownfield, ii) a framework for identification of potential GRO strategies for a site, iii) a working process for stakeholder analysis to explore their interests, resources, and challenges related to different UGS at a site, and finally iv) a framework to support the exploration of combining UGS and GRO on a brownfield and which integrates the tools and methods in the aforementioned studies.. The final framework is demonstrated in the case study site Polstjärnegatan in Gothenburg, Sweden, and challenged in a workshop with relevant stakeholders. The necessity of such an approach is validated as it can potentially increase the value derived from the depreciated brownfields progressively and it can support the formulation of long-term goals for sites. Some additional needs are also identified to support the practical application of the framework and they are: procedures to monetise the value generation over time, tools for estimating the time required for risk reduction with GRO (and thus the cost), and tools for selecting suitable plants, bacteria, fungi and soil amendments for more detailed site design.

Keywords: Circular Economy (CE), Brownfields, Urban Greenspaces (UGSs), Gentle Remediation Options (GROs), Ecosystem Services (ES)

LIST OF PUBLICATIONS

This thesis is based on the work contained, but not limited to, in the following papers, referred to in the text by Roman numerals:

I. Chowdhury, S., Kain, J.-H., Adelfio, M., Volchko, Y., Norrman, J. (2020). Greening the Browns: A Bio-Based Land Use Framework for Analysing the Potential of Urban Brownfields in an Urban Circular Economy. *Sustainability*, *12*, 6278. https://doi.org/10.3390/su12156278

II. Drenning, P., Chowdhury, S., Volchko, Y., Rosén, L., Andersson-Sköld, Y., & Norrman, J. (2022). A risk management framework for Gentle Remediation Options (GRO). *Science of the Total Environment*, *802*, 149880. https://doi.org/10.1016/j.scitotenv.2021.149880

III. Chowdhury, S., Kain, J.-H., Adelfio, M., Volchko, Y., Norrman, J. (2022). Transforming brownfields into Urban Greenspaces: A working process for stakeholder analysis. *Provisionally accepted by PLOS One and currently with editor*.

IV. Chowdhury, S., Volchko, Y., Norrman, J. (2022). A framework for upgrading of urban land and soil by nature-based solutions: opportunities and challenges. *Manuscript.*

The division of work between authors in the papers is as followed:

- For Paper I: Conceptualisation: S.C., J.-H.K., M.A., Y.V., J.N.; Methodology: S.C., J.-H.K., M.A., Y.V., J.N.; Formal analysis: S.C.; Investigation: S.C.; Writing—original draft preparation: S.C.; Writing—review and editing: S.C., J.-H.K., M.A., Y.V., J.N.; Visualisation: S.C.; Supervision: J.-H.K., M.A., Y.V., J.N.; Project administration: J.N.; Funding acquisition: J.-H.K., M.A., Y.V., J.N.
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- For Paper III: Conceptualisation: S.C., J.-H.K., M.A., Y.V., J.N.; Methodology: S.C.; Data curation: S.C.; Formal analysis: S.C.; writing—original draft preparation, S.C.; Writing—original draft preparation: S.C.; Writing—review and editing: S.C., J.-H.K., M.A., Y.V., J.N.; Visualisation: S.C.; Supervision: J.-H.K., M.A., Y.V., J.N.; Project administration: J.N.; Funding acquisition: J.-H.K., M.A., Y.V., J.N.
- For Paper IV: Conceptualisation: S.C., Y.V., J.N.; Methodology: S.C., Y.V., J.N.; Formal analysis: S.C.; Investigation: S.C.; Writing—original draft preparation: S.C., Y.V., J.N.; Visualisation: S.C.; Supervision: Y.V., J.N.; Project administration: J.N.; Funding acquisition: Y.V., J.N.

Other works and publications not appended in the thesis

Conference contributions

- Chowdhury. S. (2022). *Circular urban land-use: Bringing brownfields back in use as Urban Greenspaces (UGS) by integrating Nature-Based Solutions* (NBS), oral presentation at 22nd World Congress of Soil Science, July 31 – August 05, Glasgow, United Kingdom.
- Chowdhury, S., Drenning, P. D., Volchko, Y., Norrman, J., Nesi, M., Calvelo, J., Gallego, J. L., & Baragaño, D. (2021). *Session summary - The accelerating need for Urban Green Spaces (UGS) in cities and how to best accommodate it*. Available at https://research.chalmers.se/en/publication/525463. Session anordnad på LANDac Annual International Conference 2021 – Land, Crisis and Resilience – June 30 – July 2, ONLINE, Netherlands.
- Chowdhury. S. (2021) *Bio-based circular economy and brownfields - Concepts and overlaps*, oral presentation at the opening session of The Scottish Contaminated Land Forum (SCLF) Conference, September 8-9, ONLINE.
- Chowdhury, S., & Norrman, J. (2020). *Evaluating contamination exposure rates in different Urban Agriculture (UA) practices*, Beyond 2020 - World Sustainable Built Environment Online Conference
November 2 - 4, Gothenburg, Sweden.
- Chowdhury, S. (2019). *Opportunities for preparing urban contaminated land for bio-based production*, AquaConSoil 2019 - Sustainable Use and Management of Soil, Sediment and Water Resources, May 20 - 24, Antwerp, Belgium,

Report

- Chowdhury, S. (2020). *Urban potential in Bio-based Circular Economy Literature review report*. Gothenburg, Sweden. Available at https://research.chalmers.se/en/publication/517806.

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Thank you.

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TABLE OF CONTENTS

1 INTRODUCTION

The first chapter of the doctoral thesis provides a brief background of the research and presents the research aim and the main objectives. It also lays out the scope of work and some limitations.

1.1 Background

Since the industrial revolution, global economy has grown exponentially in the past 100 years pushing forward the linear ‘take-make-use-dispose’ system of mass production (Prendeville et al., 2018; Winans et al., 2017), and increasing the material consumption by 800% (Krausmann et al., 2009; Lieder & Rashid, 2016; Prendeville et al., 2018; UNEP, 2011; Winans et al., 2017). Earth’s resources are stretched to its limit and as studies like ‘Planetary boundary’ (Rockström et al., 2009; UNEP, 2011) suggest, it will not be able to sustain such an economic system for long. Circular economy (CE) is considered as a solution encompassing both the prospect of economic growth and environmental protection to overcome the limitations of current ‘linear economy’ (Lieder & Rashid, 2016; Winans et al., 2017). Circular Economy (CE) proposes an economic system that keeps finite resources in a closed material flow loop and promotes the usage of renewable resources wherever possible (Ellen MacArthur Foundation, 2013; Sauvé et al., 2016). It has been regarded as an efficient strategy to address wider sustainability issues (COM/2011/0571; Domenech & Bahn-Walkowiak, 2019; Mont et al., 2018) and the European Union agrees with such potential of CE by proposing an action plan (COM(2015) 614 Final) to facilitate circular processes.

The industrial revolution has not only dictated the growth of the economy but also the growth of the cities. Half of the world population is now urbanised, and cities will represent the larger share of the global demographic which may increase up to 66% by 2050 (United Nations, 2014; Wu, 2014). Cities expand spatially even faster to accommodate the insurgence of the population, twice the times of their population growth rates on average (Angel et al., 2011). And when cities expand, it is at the expenses of the some of the most fertile land available (Döös, 2002; US Aid, 1988). In Europe, arable land represents 47 % of all land take followed by pastures (36%) (EEA, 2022). At the same time, urban land is also being degraded and abandoned. Brownfields are presently obsolete urban land that have either confirmed or potential contamination issues often due to its previous exploitation (Loures, 2015; Reddy et al., 1999).

With circular thinking applied, brownfields can be considered as valuable waste from a linear land use system and a resource that provides multifaceted opportunities in a circular urban land use system. Urban brownfields are often centrally located, supported by existing infrastructure and often the only available option for redevelopment in the densely developed cities of Europe (Loures, 2015). Even when brownfields are brought back in use, it might be done so in a way that disregards the circular use of another associated resource, soil. ‘Dig and dump’ is often the preferred choice in remediating brownfields with contamination issues where the contaminated soil is removed to be replaced with new clean new soil (Carlon et al., 2009). Breure et al., (2018) discusses how soil can be considered a non-renewable material due to its slow formation and recovery processes as well as being the source of most finite resources. Even though soil or land is largely absent in the early European CE policies (such as (COM(2015) 614 Final)), the new EU soil strategy (COM(2021) 699) recognises soil as a circular resource and sets out clear steps to ensure the circular use of both soil and land. The EU soil strategy for 2030 (COM(2021) 699) outlines ‘restoring degraded soils and remediating contaminated sites’ as one of its key actions as well as reinstating ambition to achieve the previously set ‘No net land take by 2050’ (COM/2011/0571) target.

Urban brownfields are often pockets of degraded land centrally located in the densely developed cities of Europe and now provides the opportunity for urban regeneration and ecological restoration (Loures & Panagopoulos, 2007a; Loures, 2015). Presence of vegetated greenspaces, i.e. Urban Greenspaces (UGS), is essential for the liveability of the city by providing numerous ecosystem services essential for its inhabitants' wellbeing (Wolch et al., 2014). Vegetation provides an opportunity to not only introduce much needed UGS in the dense urban fabric but also as a potential remediation strategy to reduce the ecological and human health risks posed by the potential presence of the contaminants (Dickinson et al., 2000, 2009; Diplock et al., 2010). Gentle Remediation Options (GROs) are a subset of nature-based solutions (NBS) for contamination risk management. Gentle Remediation Options (GROs) are defined as risk management strategies or technologies that result in a net gain (or at least no gross reduction) in soil function as well as achieving effective risk management (Cundy et al., 2013, 2016). Apart from the aforementioned more recent EU soil strategy, the need for more sustainable remediation practices have already been in discussion as many current remediation practices result in reduction of soil functions and often worst, disposal of soil (i.e. excavation and removal) (HOMBRE, 2014a; Volchko et al., 2014). Such nature-based remediation strategies, combined with UGS, when used to restore brownfields can not only provide a multitude of ecosystem services, but also ensure circular management of urban soil and land to support the related EU wide policies. However, in Europe and beyond, contamination issues are rarely taken into consideration in spatial planning processes and are usually dealt with when the land use is already decided on and the development work is in progress (Dick et al., 2017; Mielby et al., 2017; Norrman et al., 2016, 2020). This leaves room for exploring the possibilities of a process that supports holistic upgrading of contaminated land and soil and ensuring their circular use by integrating UGS with GRO.

1.2 Aim and objectives

The overall aim of this thesis is:

to facilitate bringing brownfields back in use as Urban Greenspaces (UGS) using Gentle Remediation Options (GRO), a subset of Nature-based Solutions (NBS).

The specific objectives of this thesis to reach the overall aim are to develop and demonstrate tools and methods for:

i. identification of potential UGS on brownfields,
ii. identification of potential GRO strategies,
iii. identification and categorisation of stakeholders and their interests, resources, and challenges, and
iv. supporting exploration of UGS integrated with GRO on brownfields by suggesting and challenging a framework which integrates the tools and methods developed in (i) – (iii).

1.3 Scope of work

The overall aim of this thesis is achieved through theoretical studies and development of tools and methods. The tools and methods are applied, tested, and evaluated in a case study located in Gothenburg, Sweden. The work resulted in the following four publications, one for each specific objective, appended to the thesis:

- Paper I: A bio-based land use framework consisting of a set of three tools is developed to facilitate selection of UGS at brownfields;
- Paper II: A framework for risk management is developed facilitate identification of potential GRO strategies to mitigate contamination risks at brownfields;
- Paper III: A working process for stakeholder analysis consisting of a set of five methods to identify and categorise relevant stakeholders and their interests, resources, and challenges when it comes to regenerating brownfields to UGS;
- Paper IV: A framework that combines the tools and methods developed in the previous papers is suggested to bring brownfields back in use incrementally as UGS using GRO.

Fig. 1 illustrates the connection between the papers and the research objectives and what each paper focuses on. This study has four individual themes within the overarching theme of CE, brownfields, UGS, GROs, and stakeholders. The themes can be either in focus in a paper where they would be addressed in detail and would be essential in driving the research or be peripheral where they would be discussed in the background or may be in the discussions but would not play any central role in the paper. Brownfields are in focus in all the publications. UGS are in focus in Paper I where their typologies and the ecosystem services they can provide are discussed in detail alongside developing tools to support their selection as potential reuse of brownfields. Nature-based solutions for managing risks at brownfield, in particular, GROs are the focus of the Paper II which also examines how different GRO strategies work to reduce risk using different risk mitigation mechanisms. Moreover, the same paper includes a proposal for a framework to support their selection and communication. Stakeholders relevant for UGS realisation are discussed in detail in Paper III, thus both stakeholders and UGS are in focus in this publication. Paper IV has all the themes in focus as it combines the output of the previous publications to put forward a holistic approach to explore the potential to bring brownfields back in use incrementally as UGS using GRO.

The rest of the thesis is structured as follows. Chapter 2 presents the theoretical background, including a description of the concepts of CE and how soil and land fit within the circular concept, UGS, GRO as part of nature-based solutions, and stakeholders and their role in realising UGS. Chapter 3 discusses in brief the methodologies adopted to achieve the research objectives. Also included in this chapter is a description of the case study used for demonstration. Chapter 4 presents the outputs of the research, the developed tools and methods and the case study demonstration. The results are discussed in Chapter 5 from a more localised research context and a more general context to capture a broader perspective. Chapter 6 summarises the conclusive remarks and implications of this study for practice and for future research.

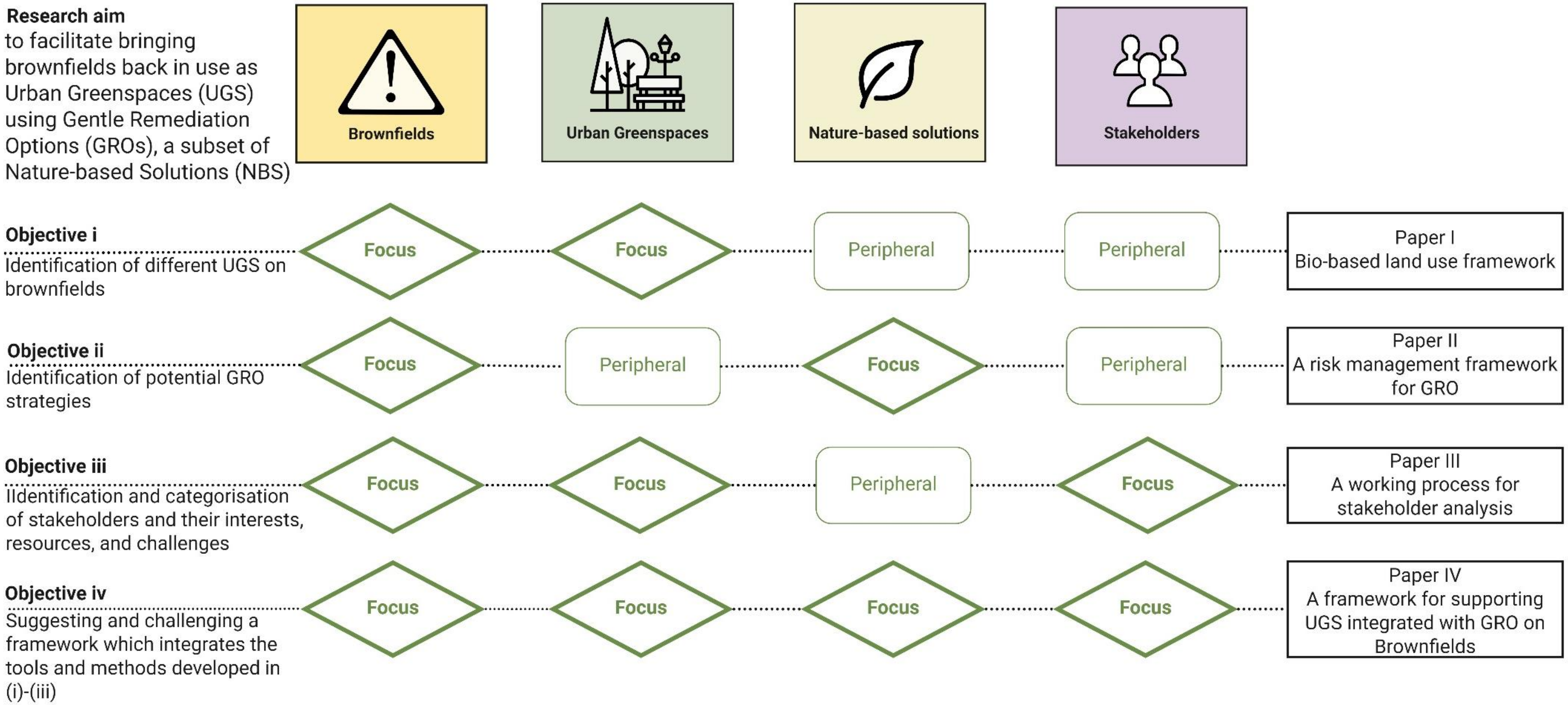


Figure 1. Schematic representation of how the appended publications relates to the research objective and what themes they have in focus.

1.4 Limitations

The main limitations of this thesis are summarised below:

- As it is multidisciplinary research, the focus has been put on linking different fields of interest rather than an in-depth exploration of each topic. Thus, the thesis provides a limited investigation in some parts, but the possible implications of the study in practice and future research are outlined in Chapter 9.
- CE is a rather new and developing concept and the outlook of CE, especially regarding policy measures, is constantly getting updated. Only discussions on the topics published prior to the writeup have been considered in this thesis.
- The tools and methods developed in Paper III as part of this study draw heavily from the case study. The study thus has contextual limitations due to the location of the case study site, at Polstjärnegatan in Gothenburg, Sweden. Ideally, these methods and tools are generic but the case study application for most has helped in refining them so in that regards, the geographical context of this study has some implications. Swedish standards, methods, and nomenclature regarding contamination and contaminated sites have been used in Paper II and Paper IV for determining soil guideline values, but similar models are available in other countries and most of the nomenclature is interchangeable.
- The tools and methods developed as part of this research are developed targeting to support exploration in early-stage planning processes for brownfield regeneration in an urban setting. Some of the tools and methods can, however, still be appropriate for a later stage brownfield redevelopment (i.e. the bio-based land use framework presented in Paper I) or for rural contexts (i.e. the GRO framework presented in Paper II).

2 THEORETICAL BACKGROUND

This chapter firstly explains different concepts related to the research, secondly connects them to provide the necessary arguments, and thirdly builds on the findings to elaborate the specifics of the research scopes. Content of this chapter draws heavily from the literature reviews done for the literature review report, licentiate thesis, paper I, and paper III.

2.1 Circular Economy (CE)

The present economic system is dominated by a linear 'take-make-use-dispose' model where virgin resources are extracted to create products that are destined for landfills after their end of usefulness (Ellen MacArthur Foundation, 2013; Franco, 2017; Pitt & Heinemeyer, 2015). This mode of consumption considers the nature's resource as limitless but empirical evidence suggests otherwise (Franco, 2017). The impact of this relentless consumption coupled with explosive population growth has pushed planetary boundaries to their limits (Pengra, 2012; Sauvé et al., 2016).

Circular Economy (CE) is a response addressing the limitations of the linear economic system. It takes place in a loop where resources are in circular movements within a system of production and consumption to optimise the use of resources and reduce waste at each step by recovering, reusing, or recycling (Sauvé et al., 2016). Circular Economy (CE) is considered a credible sustainability operationalising tool for balancing ambitions for both economic growth and environmental protection (Ghisellini et al., 2016; Kirchherr et al., 2017). One prominent concept of CE, Cradle to Cradle, distinguishes two material cycles within CE, biological and technical (Braungart EPEA, 2018). The Ellen MacArthur Foundation builds on that to create the CE systems diagram that is more commonly known as the 'Butterfly diagram' to map the flows and interconnections of the two material systems (Fig. 2) (Ellen MacArthur Foundation, 2013).

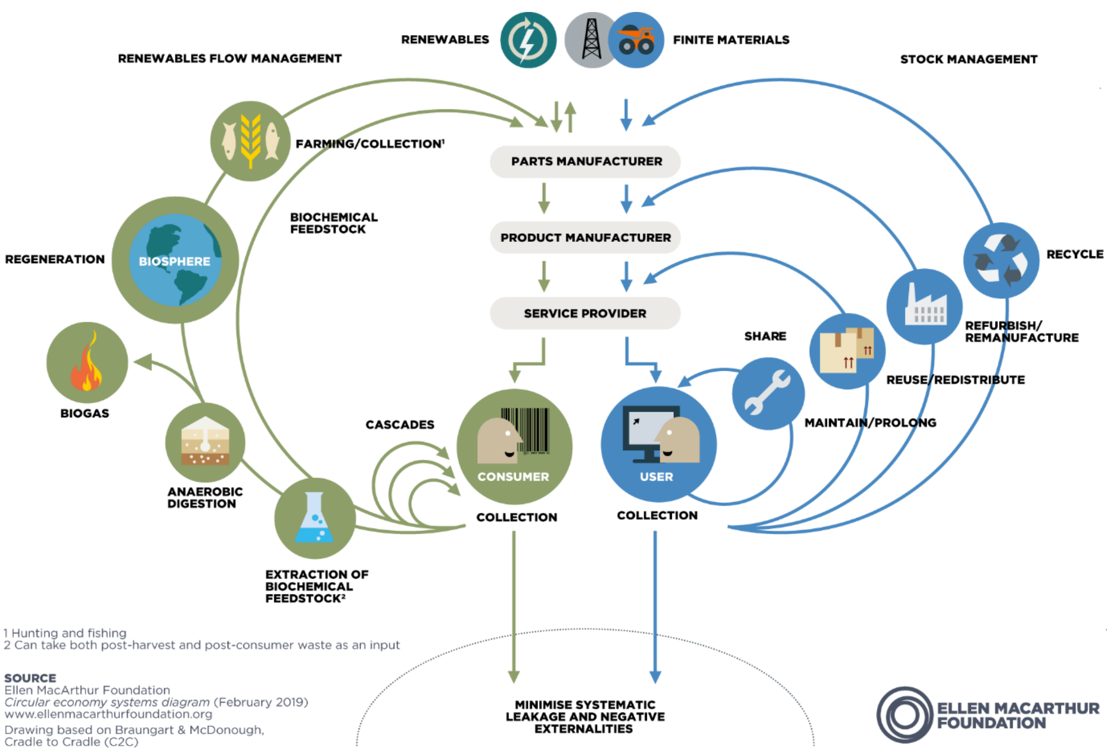


Figure 2. The Circular Economy systems diagram. From the Ellen MacArthur Foundation (2019).

The green cycles on the left side of the diagram represent the biological materials that are sourced from the biosphere and can safely re-enter the natural world (Ellen MacArthur Foundation, 2013, 2020). The blue cycles on the right side of the diagram, instead, represent the technical materials (Ellen MacArthur Foundation, 2013, 2020). These materials, such as metals and plastics, are finite resources and cannot re-enter the environment safely and thus, should continuously cycle through the system for maximising their value (Ellen MacArthur Foundation, 2013, 2020).

2.2 Soil and land in a Circular Economy - a case for Brownfields

Urban land is getting increasingly burdened as the urban population is expected to grow from the current 3 billion to 6 billion by 2050 (Bučienė, 2003; European Commission, 2017; United Nations, 2014). Even with three-quarter of the population living in urban areas, many cities in Europe are still expanding both spatially and, in the population, (United Nations, 2014). Such expansion results in the loss of fertile farming land in two ways: land encroachment due to urban sprawl (EEA, 2018), and abandonment because of lack of maintenance due to rural population loss (Bučienė, 2003). As the urbanisation process will continue to surge, the EU region is set to lose another 2.5 million hectares of land by 2030 (European Commission, 2017). Apart from supporting the influx of the growing population, urban land will also have an important role in the CE. To accommodate such growing needs, land in the cities needs to be utilised to the maximum. The abandoned, barren, underutilised, and often contaminated land commonly known as 'brownfields' can potentially provide the opportunity to meet the increasing need. Brownfields can be defined 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 real or perceived contamination problem' (Dixon et al., 2007; Ferber et al., 2006).

Given the context of CE, soil and land use is conceptualised in three scenarios (Fig. 3). Brownfields can be considered as valuable wastes resulting from the 'linear' land and soil use, where land and soil that were once in use get abandoned. But repurposing brownfields is both an expensive and extensive process due to real or perceived contamination related to previous uses (Reddy et al., 1999) and thus, developments risk being moved to 'greenfields' instead, i.e. exploiting previously undeveloped land. In this scenario both soil and land are left unrecycled. The EU region is projected to lose another 2.5 million hectares of mostly fertile farming land by 2030 (Copernicus EU, 2020a; European Commission, 2017) to such developments. Soil and land are, however, limited resources (Breure et al., 2018), and land consumption in particular are monitored under existing policy implementations, such as the 'No net land take by 2050' goal which was launched by the EU in 2011 (COM(2011) 571).

Remediating brownfields and repurposing them for development is considered both sustainable and necessary at a time when land resources are scarce, expensive, and land exploitation being monitored (COM(2011) 571; UNCCD, 2022). Remediation by excavation and disposal of excavated masses at a landfill is the most common method in Sweden and in many other countries (SGI, 2018). This 'dig and dump' method of remediation focuses on achieving safety standards stopping the migration of contaminants within and between environmental media (Dermont et al., 2008) and often requires refilling with a new clean soil for the development of the brownfield. Scenario 2 (Fig. 3) depicts a situation where the land is being recycled but the soil is still treated as a 'waste' and being dumped and replaced. Such non-circular treatment of the soil is not only wastage of a valuable resource that is limited but also results in immense loss of ecosystem services that soils might support if treated properly. Excavated masses are today often classified as waste rather than a resource and combined with complicated regulations and a lack of guidelines for recycling makes this challenging (Hale et al., 2021). The EU Soil Strategy for 2030 (COM, 2021)

699) highlights the issue and calls for prioritising recycling or some other form of recovery of contaminated soils rather than their landfilling.

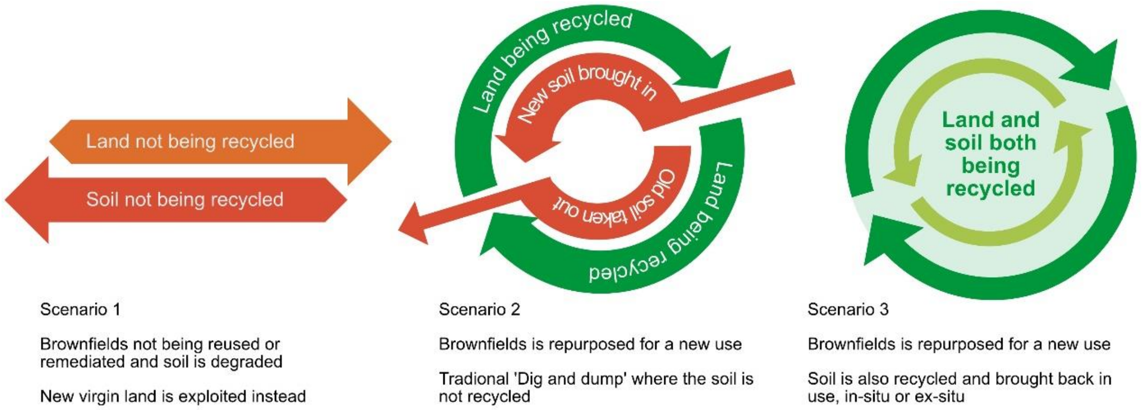


Figure 3. Conceptualising brownfields in linear vs circular soil and land management (from Paper IV).

In scenario 3, not only brownfields are repurposed for new uses, but contaminated soils are also regarded as valuable resources and thus, recycled. In addition to the circular soil use, the EU soil strategy suggests further detoxification and if possible, restoration of soil health of the contaminated soil if possible at reasonable costs (COM(2021) 699; van Gaans & Jan Ellen, 2014). The contaminated soil can be repurposed in two ways, ex situ - soil is excavated, treated on-site or off-site for being safely reused for other purposes (e.g construction), and in-situ– soil is treated using remediation technologies in-situ. Traditional in-situ remediation measures, however, often focuses on meeting the safety target rather than restoring soil health. GROs on the other hand, are nature-based solutions that treat the soil in-situ and result in risk reduction and a net gain (or at least no gross reduction) in ecological soil functions (Cundy et al., 2013). Gentle Remediation Options (GROs) can offer an overall sustainable remediation alternative due to lower use of natural resources (e.g. fossil fuel use for excavation and transportation, and less use of new soil resources for refilling), lower impact on the environment (less air emissions and waste generation), and significantly lower remediation costs compared to traditional excavation and disposal methods (Cundy et al., 2013). Although GRO strategies are time consuming and requires regular maintenance, combined with appropriate UGS, it also has the potential to bring contaminated sites back in use much earlier, as it can provide multiple benefits in the form of ecosystem services while the remediation is on-going. Furthermore, the remedial action itself in combination with UGS may increase the market value of land on site and in the surroundings (Söderqvist et al., 2015). In such way, a combination of UGS and GRO may gradually increase the market value of a site at a low cost to the site owner (low remediation costs) and to the society (low air emissions, consumption of natural resources and waste generation).

2.3 Urban Greenspaces (UGS) as potential reuse of brownfields

Brownfields in the cities are often centrally located due to being previously used (Frantál et al., 2012). Hence, brownfields are the potentially lucrative location for future development but the main detriment of these lands remaining abandoned is the possibility of the actual and potential contamination (Coffin, 2003). Bio-based production in such undervalued locations not only provides opportunities for CE integration within the cities but also scope for providing much-needed vegetation in the often dense urban fabric (Loures & Panagopoulos, 2007b; Loures, 2015). Contamination, proven or alleged, can also be limiting for certain types of bio-based production, such as food crops, but guidelines are being developed for safe practices (Hahn, 2013; U.S. EPA, 2011). Other types of bio-based production, like cultivating biofuel feedstocks, can now even take place directly on contaminated soil (Enell et al., 2016). Bio-based production will inevitably result in bio-based land uses and the urban context carries the possibility to heighten and diversify their purpose and necessity. Bio-based land uses in cities can be understood as Urban Greenspaces (UGSs), i.e. basically vegetated open spaces that provide an array of ES essential for maintaining the health and wellbeing of the urban dwellers and the urban environment (Perino et al., 2011; Ståhle, 2010). Urban Agriculture (UA) can be categorised under the UGS typology and in itself represents a selection of land uses with a different purpose and user intensity. UGS and UA are described briefly in the following sections.

2.3.1 Different types of UGS

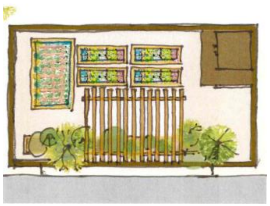
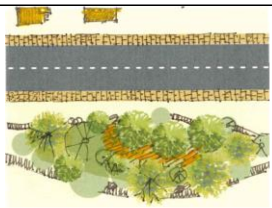
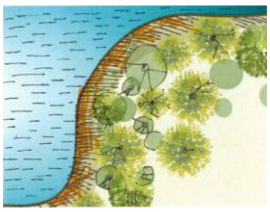
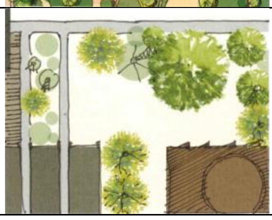
The importance of UGS as an indicator of liveability has come to the forefront during the 19th century when the cities started to grow spatially and in population (Swanwick et al., 2003). With time, UGS in the cities have been growing both in number and variety. The wide variety of greenspaces that can be observed in European cities has been identified and categorised by Green Surge, a pan-European research collaboration of 24 institutes of 9 countries funded by European Union (Haase et al., 2015). Green Surge developed an inventory of 44 UGS elements that are further categorised in 8 categories (Cvejić et al., 2015). The study used existing pan-European data sets, the Urban Atlas, and Corine land use/land cover (CLC) to create the inventory (Copernicus EU, 2020a, 2020b; Cvejić et al., 2017). Brownfields can be considered listed as the UGS element 33, i.e. an abandoned, ruderal and derelict area (Cvejić et al., 2015). The inventory is summarised in Table 1.

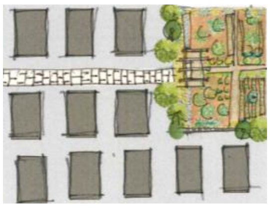
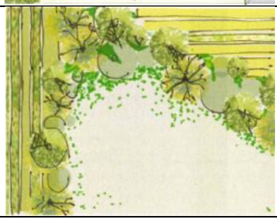
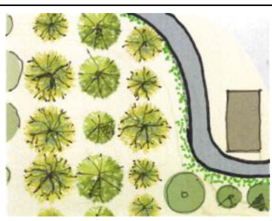
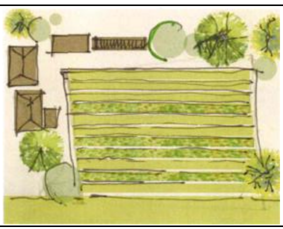
Table 1. The UGS elements inventory. Adapted from Cvejić et al. (2015).

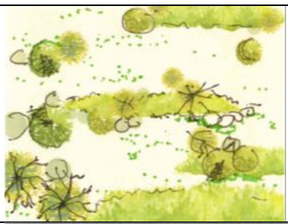
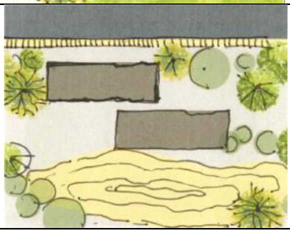
UGS categories	**List of UGS elements**
Building greens	UGS elements 1-6 Balcony green; Ground-based green wall; Facade based green wall; Extensive green roof; Intensive green roof; Atrium; Bioswale.
Private, commercial, industrial UGS, and UGS related to grey infrastructures	UGS elements 7-12 Tree alley, street tree, and hedge; Street green and green verge; House garden; Railroad bank; Green playground; School ground.
Riverbank green	UGS element 13 Riverbank green.
Parks and recreation	UGS elements 14-23 Large urban park; Historical park/garden; Pocket park; Botanical garden/arboreta; Zoological garden; Neighbourhood green space; Institutional green space; Cemetery and churchyard; Green sports facility; Camping area.
Allotment and community greens	UGS elements 24-25 Allotments; Community gardens
Agricultural land	UGS elements 26-30 Arable land; Grassland; Tree meadow/orchard; Biofuel production/agroforestry; Horticulture
Natural, semi-natural, and feral areas	UGS elements 31-37 Forest (remnant woodland, managed forests, mixed forms); Shrubland; Abandoned, ruderal and derelict area; Rocks; Sand dunes; Sandpit, quarry, pen cast mine; Wetland, bog, fen, marsh
Blue spaces	UGS elements 38-44 Lake, pond; River, stream; Dry riverbed, Rambla; Canal; Estuary delta; Sea coast

Urban Agriculture (UA) is instrumental in instilling a degree of self-sufficiency in food production necessary for a resilient and sustainable city (Barthel & Isendahl, 2013) and can simply be explained as growing food crops within the city. It is practised by around the world by about 800 million people where most urban farmers grow food largely for self-consumption (FAO, 2019; Mougeot, 1999). UA varies in size, intensity and practice – from backyard vegetable patches to large allotment gardens with thousands of plots under city administration – all falling within the boundary of UA. From the Green Surge UGS inventory, 6 most commonly practised form of UA can be identified among the UGS elements: roof garden (UGS elements 4 and 5), house garden (UGS element 10), neighbourhood greenspace (UGS element 19), allotment garden (UGS element 24), community garden (UGS element 25), and meadow orchard (UGS element 28), (Cvejić et al., 2015). The UGS inventory created by Green Surge (Cvejić et al., 2017; Haase et al., 2015) has a total of 44 UGSs and among them, 15 has been selected to be investigated in this study as potential bio-based land use options at brownfields. The selected 15 UGSs are elaborated in Table 2.

Table 2. The studied list of potential future UGS on brownfields adapted from the UGS inventory by Green Surge (Haase et al., 2015). *Illustrations are created by the author.*

UGS name	Description
	**Building greens** Building greens refer to plants on a balcony, roof, or any place within a building (Cvejić et al., 2017). They are mostly potted plants but the use of planter boxes are not uncommon, especially for rooftop gardening if the building is large enough (Cvejić et al., 2017; Livingroofs, 2020).
	**Bioswale** Bioswales are defined as 'vegetated, shallow, landscaped depressions designed to capture, treat, and infiltrate stormwater runoff as it moves downstream' (NACTO, 2020). Bioswales are greater in length than width, often designed with engineered soils and vegetated mainly with both drought and flood withstanding plants (SSSA, 2020).
	**Riverbank green/ Riparian vegetation** Riparian vegetation or riverbank greens, also known as fringing vegetation, grows along banks of a waterway extending to the edge (WA Water, 2020). Wetland vegetation can include trees, shrubs or a ground layer consisting of herbs, grasses or their combination in shallow aquatic areas while submerged aquatic vegetation can be found in deeper wetlands (Wetland Info, 2020). For public use, these areas usually made accessible with foot or bike paths (Cvejić et al., 2017).
	**Urban Park** Urban parks are characterised as larger green areas within a city intended for recreational use by urban population and can include different features, such as trees, grassy areas, playgrounds, water bodies, ornamental beds, etc. (Cvejić et al., 2017).
	**Historical Park/garden** Historical parks are similar to urban parks, but with elements that are necessary to ensure the heritage status and thus requires distinct management (Cvejić et al., 2017). Examples of abandoned industrial sites turned into parks include the Seattle gasworks park, the Duisburg Nord park, and the Emscher Park.

	**Neighbourhood greenspace** Neighbourhood greenspaces are characterised by (Cvejić et al., 2015) as ‘semi-public green spaces, vegetated by grass, trees and shrubs in multi-story residential areas.’
	**Institutional greenspace** Institutional greenspaces are green spaces in and around public and private institutions and corporation buildings (Cvejić et al., 2017).
	**Allotment** Allotments are small parcels rented to people for mostly non-commercial production of fruits, vegetables, flowers, etc. (Cvejić et al., 2017; NSALG, 2020). Allotments were first conceptualised in the 19^{th} century to help the urban labouring poor to cultivate their food, but more recently the recreational purpose is also dominant (Boström, 2007; NSALG, 2020). As of 2007, there are about 42,000 allotment renters in Sweden alone (Boström, 2007).
	**Community garden** Community gardens are defined as sections of land collectively gardened by a community for the specific purpose of growing fruits, vegetables and/or herbs for self-consumption (Egli et al., 2016; Ginn, 2012).
	**Grassland** Grasslands are open and mostly flatlands with a grass cover that exists in every continent except Antarctica and relative to the definition, 20-40% of the land area of the world consists of grasslands (Nunez, 2019). Grazing land for cattle, as well as grass lawns, are also considered in this category.
	**Tree meadow/meadow orchard** Tree meadows or orchard meadows are composed of scattered fruit trees within semi-natural grassland which in turn can be used for grazing (i.e. mixed agricultural use) (Cvejić et al., 2017; Plieninger et al., 2015; Rabenhorst, 2020). Scattered trees cover almost 55,000 km^2 of farmlands in Europe (Plieninger et al., 2015).
	**Biofuel production/agroforestry** Biofuel production refers to land specifically devoted to energy crop production, such as short rotation coppice or poplar (Cvejić et al., 2017). Some food crops can essentially be used as biofuel feedstock and in Europe, most of the cultivation (80-85%) of rapeseed is for biodiesel production (Ericsson et al., 2009).
	**Horticulture/arable land** Horticulture or arable land are defined as land devoted to commercial production of vegetables, flowers, berries, etc. (Cvejić et al., 2017).

	**Shrubland** Shrublands are made of shrubs (i.e. short trees or hedges) with grass covers in between and thrive on areas where the climate is not favourable to support tall trees (NASA Earth Observatory, 2020).
	**Spontaneous vegetation** Spontaneous vegetation refers to spontaneously occurring pioneer or ruderal vegetation, more specifically those occurring on brownfield sites (Cvejić et al., 2017).

2.3.2 Products of UGS: Ecosystem Services

Ecosystem Services (ES) can be understood as 'the benefits human population derive, directly or indirectly, from ecosystem functions' (Costanza et al., 1997). The values and services provided by ecosystems can be categorised in many ways and the categorisation provided by The Economics of Ecosystems and Biodiversity (TEEB) is among the most widely used ones:

- Provisioning services – food, raw materials, freshwater, and medicinal resources;
- Regulating services – local climate and air quality, carbon sequestration and storage, moderation of extreme events, waste-water treatment, erosion prevention and maintenance of soil fertility, pollination, and biological control;
- Habitat or supporting services – habitats for species and maintenance of genetic diversity; and
- Cultural services – recreation, mental and physical health, tourism, aesthetic appreciation, an inspiration for culture, art and design, and spiritual experience and sense of place (TEEB, 2020).

UGS provides many essential non-material educational and recreational benefits to the urban dwellers and, most importantly, greenspaces in the cities can be directly associated with the overall wellbeing of the citizen (Chiesura, 2004; Maes et al., 2016). Still, only the provisioning services, such as food and biomass, has been part of the discussion so far as a biological resource in the bio-based CE (European Commission, 2019; TEEB, 2010). Limiting the discourse only to provisional services, especially in the cities, would be constraining in capturing many other vital services provided by greenspaces in cities. A literature review was carried out (see Paper I) to better understand the extent of ES that can be provided by the 15 selected UGSs. The result is summarised below in Table 3. It is worth mentioning that the review was conducted to match ES with specific UGS. A lot of the research is conducted for the provision of ES of urban greenery in general and was not covered. There are certain ES that can be potentially generalised to all UGS, e.g. increased amount of urban greens would help in urban cooling (Aminipouri et al., 2019), even though specific literature evidence cannot be found.

Table 3. Ecosystem services of the studied list of potential future green land use (from Chowdhury et al., 2020).

Building greens	
Provisioning services	
Food	A study on the city of Bologna (Italy) shows rooftop gardens could provide more than 12,000 t/year of vegetables, satisfying 77 % of the inhabitants' requirements (Orsini et al., 2014).
Regulating services	
Local climate and air quality control	A literature review on urban green roofs finds their potential in cooling at street level to be 0.03–3 C° and in pollution control, such as small particle removal, 0.42–9.1 g/m^2 per year (Francis & Jensen, 2017).
Energy consumption control	Urban green roofs can potentially impact annual building energy consumption from a 7% increase to 90% decrease by contributing to indoor cooling, surface temperature differences and heat flux change (Francis & Jensen, 2017).
Rainwater retention	Extensive green roofs can retain almost 75% of rainwater (Scholz-Barth, 2001; Villarreal & Bengtsson, 2005).
Supporting services	
Biodiversity conservation	Green roofs can provide sites for bee conservation in urban areas if planted with native plants and foraging resources designed to accommodate bees (Tonietto et al., 2011).
Bioswale	
Regulating services	
Nutrient cycling and waste-water treatment	A study in residential areas in California (USA) finds bioswales to significantly reduce contaminants from stormwater, including suspended solids (81% reduction), metals (81% reduction), hydrocarbons (82% reduction), and pyrethroid pesticides (74% reduction) (Anderson et al., 2016).
Reduction in stormwater runoff	Another study on a bioswale on a parking lot in Davis (USA) reveals it to reduce runoff by 88.8% and total pollutant loading by 95.4% (Xiao & McPherson, 2011).
Riverbank green	
Provisioning services	
Food (indirect)	Riverbank greens provide habitat and support aquatic life (Ozawa & Yeakley, 2007) which in turns supports fishing activities (Ricaurte et al., 2017).
Raw materials	Riverbank greens can support production of vegetative biomass (Koopman et al., 2018).
Regulating services	
Carbon sequestration and storage	A study of a riverbank green in Mexico suggests that it can store 1.5 times more carbon than oak forests (Mendez-Estrella et al., 2017).
Nutrient cycling	Multiple studies show that riverbank greens act as a protective buffer between the waterbody and land-based activities both by filtering nutrients and by trapping nutrients for groundwater (de Sosa et al., 2018; Hill, 1996; Hunter et al., 2006; Meek et al., 2010; Mikkelsen & Vesho, 2000; Ozawa & Yeakley, 2007; Pert et al., 2010).
Bank stability and flood attenuation	Riverbank greens help in trapping sediment during flooding events and form soil, slow down and spread flood water, increase bank stability and minimise soil loss in watercourses (de Sosa et al., 2018; McKergow et al., 2004; Meek et al., 2010; Ozawa & Yeakley, 2007; Pert et al., 2010; Zaimes et al., 2007).
Water temperature regulation	Riverbank greens assist in regulating the watercourse temperature by providing shading (de Sosa et al., 2018; Naiman et al., 2010; Pert et al., 2010; Pusey & Arthington, 2003).
Supporting services	
Habitat and maintenance of species (aquatic and terrestrial)	Riverbank greens provide habitat and support for aquatic life, a refuge for wildlife in urban and rural areas, and contribute to species richness and biodiversity by maintaining wildlife movement corridors (de Sosa et al., 2018; Gray et al., 2014; Matos et al., 2009; Naiman et al., 2010; Ozawa & Yeakley, 2007; Pert et al., 2010).
Cultural services	
Recreation and aesthetic appreciation	Riverbank greens help in increasing the aesthetic value of agricultural and urban landscapes as well as provide places for outdoor activity (Meek et al., 2010; Postel & Carpenter, 1997).
Culture and sense of place	For the locals of Central Benin, riverbank greens are a source of cultural importance and traditional knowledge and provide cultural identity and a source of belonging (Ceperley et al., 2010; Ricaurte et al., 2017).

Urban park/Historical park/Institutional greenspace	
Regulating services	
Carbon sequestration and storage	The urban areas covered by parks, gardens, tree-lined avenues, sports fields, and hedges are important sinks for carbon dioxide (CO_2) by storing carbon through photosynthesis to form plant biomass (Gratani et al., 2016).
Air quality maintenance	A study in Pudong district, Shanghai (China) demonstrates the effect on air pollution by urban parks: 9.1% of total suspended solids (TSP) removal, 5.2% of SO_2 removal, and 6% of NO_2 removal (Yin et al., 2011).
Temperature regulation	A study conducted on 15 mid-size urban parks in Athens (Greece) shows that the cooling provided by the parks was varying between 3.3 and 3.8 K/h (Skoulika et al., 2014).
Supporting services	
Habitat and maintenance of species	A review covering 62 papers from 25 different countries shows that urban parks are consistently among the most species-rich types of urban green spaces and contain a large share of exotic species (Nielsen et al., 2014). Another study in Bangalore (India) shows that 77% of the vegetation in urban parks belongs to exotic species (Nagendra & Gopal, 2011).
Seed dispersion	A study conducted on the Stockholm National Urban Park (Sweden) that is home to one of the largest populations of giant oaks shows that the replacement cost (RC) of the seed dispersion services provided by a pair of Eurasian Jay (living in the urban park) is between SEK 35,000 – 160,000 (Hougner et al., 2006).
Cultural services	
Healthy living	Urban Park experience may reduce stress; provide a place to relax, enjoy peacefulness and tranquillity; and rejuvenate the city inhabitants (Chiesura, 2004; Gratani et al., 2016; Ulrich, 1981).
Overall wellbeing	A study covering 44 US cities shows that the quantity of parks (measured as the percentage of the city area covered by public parks) is among the strongest predictors of the overall wellbeing of the citizens, driven by parks' contribution to the physical and community wellbeing (Larson et al., 2016).
Neighbourhood greenspace/Allotment/Community Garden	
Provisioning services	
Food products	Gross benefit from food products per allotment plot in Manchester (UK) can be up to £698 in a year. Apart from plant produce, live stocks such as chickens are also kept in the allotment garden ((Speak et al., 2015). Community gardeners in New York City (USA) manage to supply a large share of their households' food product needs with the garden produce (Gregory et al., 2016).
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 (Barthel & Isendahl, 2013; Lwasa et al., 2014; Speak et al., 2015).
Medicinal herb and tea	Several allotments in Manchester are found to be cultivating medicinal herbs both for medicine and culinary purpose (Speak et al., 2015).
Regulating services	
Soil health	A study in the UK shows that soils in allotment gardens have 32% higher soil organic carbon (SOC) concentrations and 36% higher Carbon: Nitrogen ratios than pastures and arable fields (Edmondson et al., 2014).
Stormwater retention	The community gardens of New York City, USA are expected to be retaining 45 million litres of stormwater due to their raised beds (Gittleman et al., 2017).
Supporting services	
Habitat and maintenance of species	A study found that the parks in Manchester (UK) to have about 65% of the species richness of Manchester allotment gardens (Speak et al., 2015). Allotment gardens in Poznan (Poland) also show to have more native varieties of flora (Borysiak et al., 2017). A study in Stockholm (Sweden) found the variability of bumblebee visits in urban allotment gardens to be higher than in peri-urban ones (Ahrné et al., 2009).
Cultural services	
Nature education	Allotment and community gardens are prime spots for education on nature and sustainable food production techniques among community groups in cities (Breuste & Artmann, 2015; Chan et al., 2015; Middle et al., 2014; Speak et al., 2015).
Health benefits from physical activities	Allotment and community gardens provide alternative and more accessible physical activities, beneficiary especially for the elderly population (Middle et al., 2014; Speak et al., 2015).
Knowledge production	A study in Sub-Saharan Africa found community clinic gardens to be a place for co-production of knowledge on growing nutritious food by the involvement of multiple stakeholders (Cilliers et al., 2018).
Recreational benefits	The allotment gardens in Poznan (Poland) are treated like recreational retreats during the summer months (Speak et al., 2015). In Germany and Austria, allotment gardens are also considered as recreational areas in planning regulations (Breuste & Artmann, 2015).

Grassland/Shrubland	
Provisioning services	
Food, raw materials, medicinal plants	Grasslands are commonly used as grazing fields by many communities as well as providing games for hunting, thatching materials for roofs and walls, medicinal plants, and fruits (Dzerefos & Witkowski, 2001; Egoh, Reyers, Rouget, & Richardson, 2011; Friday, Drilling, & Garrity, 1999; Miller, 2005; Sala & Paruelo, 1997; Wen et al., 2013).
Regulating services	
Carbon sequestration and storage	Grasslands in various regions act as soil carbon storage, at the same time providing sites for tree plantation to sequester aboveground carbon (Farley et al., 2004, 2013; Hofstede et al., 2002; Paul et al., 2002). A study across six European shrublands shows that the net carbon storage in these systems ranged from 1,163 g C/m^2 to 18,546 g C m^{-2} (Beier et al., 2009).
Water supply and storage	Grasslands play an important role in water supply by mitigating and storing runoff waters (Egoh et al., 2011; Farley et al., 2013; Kotze & Morris, 2001).
Supporting services	
Habitat and maintenance of species	Grassland restorations in China show improved biodiversity by 32.44% (Egoh et al., 2011; White et al., 2000).
Cultural services	
Maintenance of culture and tradition	Alpine grasslands play an important role in Tibetan culture and the maintenance of tradition (Dong et al., 2010; Wen et al., 2013).
Meadow orchard	
Provisioning services	
Food provision	In Berlin, fruit trees are abundantly used for an ornamental reason but can potentially be used for consumption as the fruits are found to pose no additional risk from pollution if washed thoroughly and stored properly (von Hoffen & Säumel, 2014).
Supporting services	
Habitat support	A study suggests that with proper maintenance of living ground cover in almond orchards, these could provide habitats for pollinators like native bees (Saunders et al., 2013). Orchards, abandoned and functioning, are found to provide habitat and refuge to birds (Myczko et al., 2013).
Biofuel agroforestry	
Provisioning services	
Raw materials (Biofuel and biomass)	Jatropha plantation in a study shows to produce 230 kg biodiesel replacement in fossil fuel per hectare as well as producing 4000 kg of plant biomass per year (Wani et al., 2012). Agroforestry intercropping of woody and perennial bioenergy crops increases combined biomass yield and reduce the cost of production (Haile et al., 2016).
Regulating services	
Carbon sequestration and storage	In 4 years, Jatropha cultivation is showed to have increased the carbon content by 19% resulting in 25000 kg carbon sequestrated per hectare (Wani et al., 2012).
Nutrient cycling and climate change support	Strategically planted willow buffers can improve the net global warming potential (GWP) and eutrophication potential (EP) of the soil, as well as cut back nutrient loading to waters (Styles et al., 2016).
Water supply and storage	The water holding capacity of the soil under Jatropha plantations showed to increase by 35% compared to adjacent soils (Wani et al., 2012).
Supporting services	
Habitat and maintenance of species	Agroforestry with combining grass cover and perennial biofuel plantings is expected to support a larger and more diverse bee community, as well as many other beneficial insects (Gardiner et al., 2010).
Horticulture	
Provisioning services	
Food and raw materials	Horticulture contributes directly to urban economics through the production and sales of horticulture products (Lohr & Relf, 2014).
Spontaneous vegetation	
Cultural services	
Recreational purpose	Based on expert and resident interviews conducted in Berlin (Germany), (Hofmann et al., 2012) suggest that urban residents generally accept urban derelict land as recreational areas, if they are provided with minimum maintenance and accessibility.

2.4 Nature-based solutions as sustainable remediation technologies

One of the biggest challenges for retrofitting brownfields in green land uses is the probable soil contamination of urban soils. Previous, ongoing, or even adjacent uses can result in continuous accumulation of contaminants on urban soil (Debolini et al., 2015; Luo et al., 2012; Yousaf et al., 2017). Kennen & Kirkwood (2015) provide a classification of contaminants and the associated activities that can be a source of the pollution, summarised in Table 4. Contamination present in soil can be also transported to other environmental media (e.g. groundwater, surface water, air) and these contaminated sites pose a potential threat to human health and the environment (Luo et al., 2012; Öberg & Bergbäck, 2005; Scullion, 2006).

Table 4. Type of contaminants and typical source activities. Adapted from Kennen & Kirkwood Kirkwood (2015). *The same grouping of the contaminants and colour coding is maintained in Fig. 4.*

Organic pollutants	
Contaminant group	**Typical source activities**
Petroleum	Fuel spills, leaky storage tanks, railway corridors, industrial activities
Chlorinated solvents	Dry cleaners, military activities, industrial activities
Explosives	Military activities, munition manufacturing and storage
Pesticides	Agricultural and landscape applications, railway and transportation corridors, residential spraying for pests
Persistent Organic Pollutants	Agricultural and landscape applications, former industry, atmospheric deposition
Other organic pollutants of concern (Glycols, pharmaceuticals, etc.)	Wastewater, embalming fluids, aircraft de-icing fluids
Inorganic pollutants	
Contaminant group	**Typical source activities**
Plant macronutrients	Wastewater, stormwater, agriculture and landscape application, landfill leachate
Metals	Industrial uses, mining, agricultural applications, roadways, landfill leachate, piments, lead paint, emissions
Salt	Agricultural activities, roadways, mining, industrial uses
Radioactive isotopes	Military activities, energy production

Humans might be risking exposure to contamination through various pathways such as dermal contact with contaminated media, ingestion of contaminated soil, consumption of food grown on contaminated soil, and inhalation of dust or vapours, etc. (Scullion, 2006; SEPA, 1996). To ensure the safety of human health and ecosystems, 'critical soil contamination' or 'guideline value' are developed by national or international environment protection agencies to indicate contamination levels that do not pose an unacceptable risk to humans or ecosystems (SEPA, 2016a; Swartjes, 2015; US EPA, 2011a). The Swedish Environment Protection Agency (SEPA), for example, provides generic soil guideline values and a calculation sheet to develop site-specific contaminated site remediation goals (SEPA, 1996, 2016b).

The management and decisions concerning retrofitting brownfields would require an in-depth assessment of the risk posed by the contamination present at the site (Enell et al., 2016; Öberg & Bergbäck, 2005). Risk assessments on brownfields essentially evaluate the risk of adverse effects on receptors, humans or ecosystems, as a result of exposure to the contamination present on the soil (Carlon et al., 2009; Swartjes, 2015). The Source-Pathway-Receptor (SPR) model is fundamental in describing the flow of contaminants from a source, through different exposure pathways to potential receptors such as humans or living organisms in the soil ecosystem, ground water and surface water (Swartjes, 2015; Waldschläger et al., 2020). Humans might be exposed to contamination through various pathways, for example, ingestion of contaminated soil, consumption of plants grown on contaminated soil, inhalation of vapours or dust, and dermal contact with contaminated media (Scullion, 2006; SEPA, 2016a; Swartjes, 2015). Risk assessment can be generalised in two tiers:

- *Tier 1 risk assessments*: SGV is typically compared to measured total contaminant concentrations in the soil which provides an initial, but oversimplified, estimation of the risks based on generic conservative assumptions (Swartjes, 2015; Swartjes et al., 2013).
- *Higher tier risk assessments:* These type of assessments uses detailed site-specific information to provide a more in-depth, realistic estimation of the risks at a contaminated site (Swartjes, 2015; Swartjes et al., 2013).

Conventional soil remediation techniques use physical, chemical, biological or a combination of methods and can occur both in-situ (e.g. degradation, transformation, extraction or stabilisation of (in)organic contaminants or using barriers to isolate the contaminants) or ex-situ (e.g. soil excavation and subsequent treatment on- or off-site via soil washing, thermal treatment) (Kuppusamy et al., 2016b, 2016a; Swartjes, 2015). The remediation technologies themselves, however, can have considerable environmental impact (e.g. CO2 emissions resulting from the use of fossil fuel-derived energy employed throughout the remediation process) (e.g. Cappuyns, 2013). In addition, Volchko et al. (2014) highlights that the remedial action can lead to soil structure disturbances, decline in organic matter and nutrient deficiencies, and in turn affect a soil's capacity to carry out its ecological soil functions. Such impacts on environments push forward the need to have evaluation of remediation technologies and derive more sustainable remediation options (Bardos, 2014; Cappuyns, 2016; NICOLE, 2010; Rizzo et al., 2016; Smith et al., 2010; US EPA, 2008). Sustainable remediation is defined as 'remediation that eliminates and/or controls unacceptable risks in a safe and timely manner whilst optimising the environmental, social and economic value of the work' (ISO 19204:2017). Green remediation narrows the focus a bit with the following definition 'the practice of considering all environmental effects of remedy implementation and incorporating options to maximise net environmental benefit of clean-up actions' (US EPA, 2008, p. 1).

Apart from the widely discussed necessities and benefits of UGS, vegetation on brownfields may also be a low-cost and effective solution to bring derelict lands back in use (French, Dickinson, & Putwain, 2006). But most importantly, vegetation can also potentially provide effective remediation strategies for reducing the ecological and human health risks potentially posed by a contaminated brownfield (Kennen & Kirkwood, 2015). Plant-based remediation options are discussed as sustainable alternatives (Carlon et al., 2009). The use of plants to manage the risk for human health and environment (i.e. phytoremediation) is part of the broader category 'Gentle Remediation Options' (GROs) that also includes remediation technologies using fungi and/or bacteria and soil additives (Bardos et al., 2008; Onwubuya et al., 2009). Cundy et al. (2013) 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. Some common examples of GROs based on phytotechnologies are briefly presented in Table 3. Plant-based remediation technologies are proven to be efficient for both contaminated soil and water, under specific circumstances, and at the same time helps to maintain the ecological functions (Cundy et al., 2013; Juwarkar et al., 2010).

Table 5. Examples of Gentle Remediation Options (GROs). Adapted from Cundy et al. (2016).

GROs	Descriptions
Phytodegradation/ phytotransformation	Use of plants (and associated microorganisms) to uptake, store and degrade or transform organic pollutants.
Phytovolatilisation	Use of plants to remove pollutants from the growth matrix, transform them and disperse them (or their derived products) into the atmosphere.
Phytoextraction	The removal of metal(loid)s or organics from soils by accumulation in the harvestable biomass of plants. When aided by the use of soil amendments (e.g. EDTA or other mobilising agents), this is termed 'aided phytoextraction'.
Phytostabilisation	Reduction in the bioavailability of pollutants by immobilisation in root systems and/or living or dead biomass in the rhizosphere soil.
Rhizodegradation	The use of plant roots and rhizosphere microorganisms to degrade organic pollutants.
Rhizofiltration	The removal of metal(loid)s or organics from aqueous sources (including groundwater) by plant roots and associated microorganisms
In-situ immobilisation/phytoexclusion	Reduction in the bioavailability of pollutants by immobilising or binding them to the soil matrix through the incorporation into the soil of organic or inorganic compounds, singly or in combination, to prevent the excessive uptake of essential elements and non-essential contaminants into the food chain. Phytoexclusion, the implementation of a stable vegetation cover using so-called excluder plants which do not accumulate contaminants in the harvestable plant biomass, can be combined within situ immobilisation
Phytodegradation/ phytotransformation	Use of plants (and associated microorganisms) to uptake, store and degrade or transform organic pollutants.
Phytovolatilisation	Use of plants to remove pollutants from the growth matrix, transform them and disperse them (or their derived products) into the atmosphere.
Phytoextraction	The removal of metal(loid)s or organics from soils by accumulation in the harvestable biomass of plants. When aided by the use of soil amendments (e.g. EDTA or other mobilising agents), this is termed 'aided phytoextraction'.
Phytostabilisation	Reduction in the bioavailability of pollutants by immobilisation in root systems and/or living or dead biomass in the rhizosphere soil.
Rhizodegradation	The use of plant roots and rhizosphere microorganisms to degrade organic pollutants.

GRO technologies are best applicable for 'green' or bio-based reuse of a site, such as parks, biofuel production, and potentially even urban agriculture (Cundy et al., 2016; Erdem & Nassauer, 2013; Evangelou et al., 2012, 2015; Fässler et al., 2010; HOMBRE, 2014a; Huang et al., 2011; Tripathi et al., 2016). The remediation potential of GRO, however, varies greatly based on the type of contaminant and GRO technology used across different time scales. Considering time constraints, promising phytoremediation applications are phytostabilisation, degradation of chlorinated solvents and petroleum products and evapotranspiration by phytovolatilisation (Fig. 4) (Kennen & Kirkwood, 2015; OVAM, 2019). GROs, if properly implemented, can have a significantly lower deployment cost than conventional remediation techniques. Brownfields that are deemed unfit for development can thus still be beneficial, e.g. by harvesting the vegetation while simultaneously managing the risks posed to human health and the ecosystem.

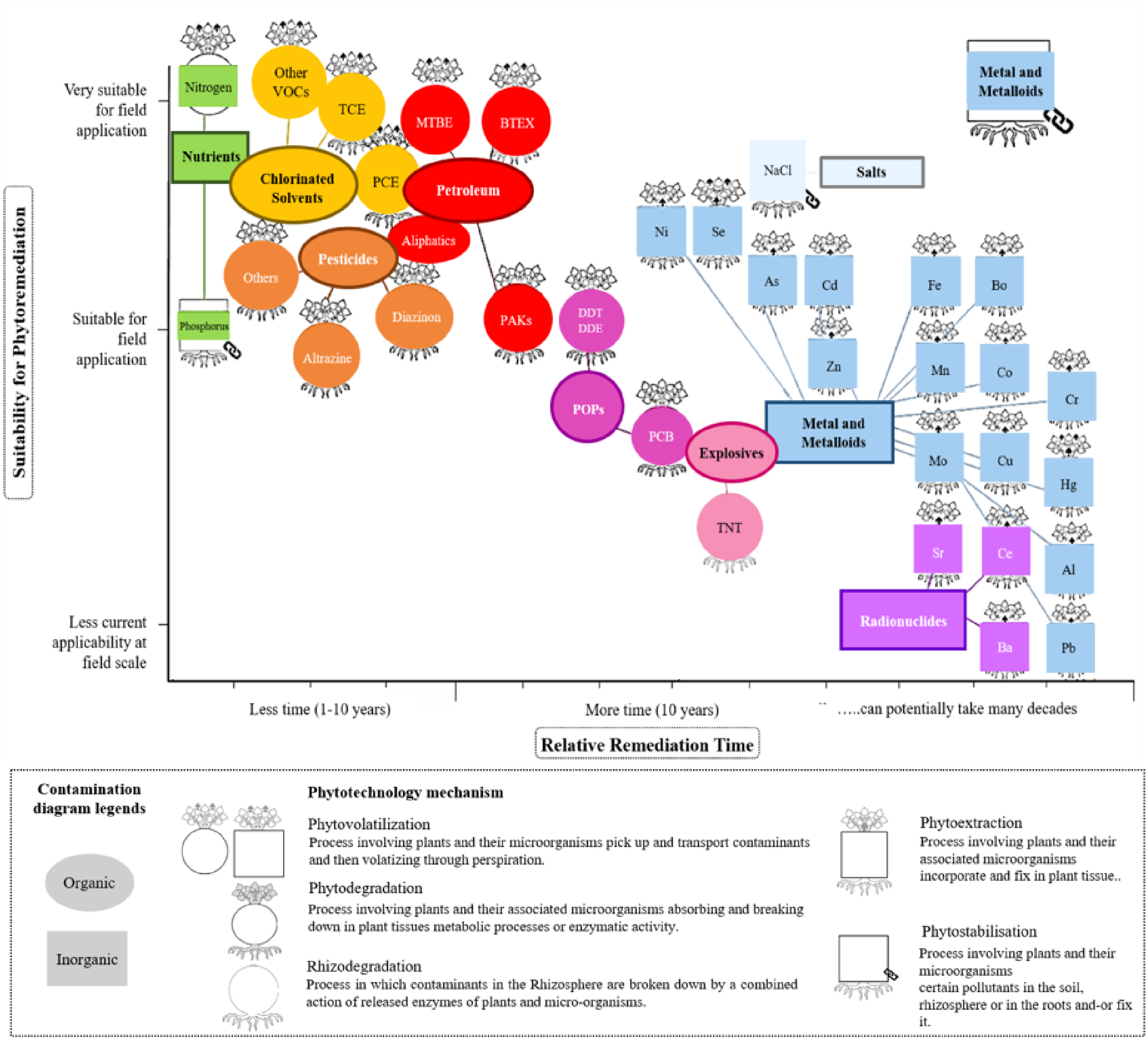


Figure 4. Overview of the phytoremediation potential of some contaminants and associated phytoremediation mechanism. From OVAM (2019) *and Kennen & Kirkwood* (2015) *with a slightly adapted legend.Stakeholders involved in realising UGS on brownfields*

As greenspaces provide an array of services that are essential for city dwellers and the urban environment, a wide range of stakeholders are involved in greening the brownfields. Immediate financial incentives often motivate the redevelopment of brownfields by turning them into residential, commercial, or industrial land use, but the recognition of green land use as an alternative end-use is growing (De Sousa, 2003; De Sousa, 2006). For example, over 19% of brownfields were retrofitted as greenspaces in the UK in the years between 1988 to 1993 (De Sousa, 2003). Here, stakeholders can simply be defined as 'any individual or group of individuals who may have influence, or be influenced, on the realisation of the purpose of an organisation' (Freeman & McVea, 2005). Azadi et al. (2011) classify the relevant stakeholders for urban greenspace development and performance in three groups namely: state-all types of government from local to national level; private – includes banks, enterprise, manufacturers contributing to greenspace development; and society – ranging from an individual (e.g. philanthropists, residents) to groups (non-governmental organisations, community-based organisations, academic institutions). After investigating 42 urban greenspaces across the globe, Azadi et al. (2011) identify ‘society’ and ‘state’ to be of particular importance in urban greenspace performance as many get realised as public greenspaces.

Government, municipal or state, plays an important role in the realisation and later, the performance of the brownfields retrofitted as greenspace (Azadi et al., 2011; Doick et al., 2006). In a study analysing 12 examples of turning brownfields into greenspace in Toronto (CA), De Sousa (2003) found all redevelopment projects to be carried out by the public sector, with the majority being attended by the parks department of the municipal government. Involvement of the stakeholder group, ‘society’, is also key in realising urban greenspaces as they are designed to serve the public (Azadi et al., 2011). The increased involvement of NGOs in public place development across Europe and the USA can be attributed to the dissatisfaction with regulatory planning failures (Azadi et al., 2011). Public participation in the planning process can stabilise future use by creating collective awareness (Azadi et al., 2011; Erickson, 2006). It can be also argued that increased public involvement in urban greenspace development and management can increase the sense of ownership, sense of belonging, and willingness to maintain urban greenspaces among the public (Azadi et al., 2011; Erickson, 2006).

Considering the potential of using greening as a medium for managing the risks posed to human health and the environment by the contamination of the brownfields, the involvement of additional groups of stakeholders becomes necessary. For instance, regulatory authorities monitoring the safety of the brownfield site and experts in the phytoremediation technologies are needed if bio-based remediation is to be considered in the brownfield redevelopment process (Cundy et al., 2013).

3 METHODOLOGY

This chapter provides an overview of the methodologies adopted to achieve the research objectives, and a description of the case study used for demonstration.

3.1 Objective 1 – Support identification of different UGS on brownfields

To facilitate selection of appropriate UGS at brownfields, the bio-based land use framework was conceptualised. The framework was developed in two steps:

i. *Framework support:* The conceptual development of the framework is supported by a literature study conducted to identify relevant UGS, as well as the benefits of these greenspaces in terms of ecosystem services. From the 44-item categorisation proposed by the Green Surge project (Haase et al., 2015) (Section 2.4.1), a tentative selection of 15 UGS elements were identified to examine as potential future bio-based land uses on brownfields. The 15 UGS selected from the Green Surge inventory were further investigated in terms of provision of ES. A literature survey was performed to present an inexhaustive list of ES that can be derived from the list of the UGS potentially relevant for brownfields. The literature review was carried out using the Scopus database and was extensive but limited to the 15 specified UGS, using the combination of search word "ecosystem services" and the labels of the final set of 15 UGS. The literature output used for supporting the framework is summarised in Chapter 2, Section 2.3.

ii. *Framework realisation:* The second step of the methodology aimed at conceptualising the bio-based land use framework by providing a set of practical tools. The basis of the framework was the literature explored in the previous steps and builds upon, but is not limited to, phytoremediation potential mapping (Kennen & Kirkwood, 2015), the Greenland decision support framework (Cundy et al., 2015), the urban vacant land typology (Kim et al., 2018), models developed by Sustainable Brownfield Regeneration project (Ferber et al., 2006), the stages of brownfield redevelopment (Loures & Vaz, 2018), and the system of information categories for brownfield development (Rizzo et al., 2018). The following three tools and methods were developed:
   - a conceptualisation of linkages between land use, soil contaminants and time - The resulting first tool of the framework is a conceptual diagram illustrating these linkages;
   - UGS across different time frames and degrees of required interventions - The second tool of the framework is a scatter diagram to provide a graphical representation of 15 UGS opportunities on brownfields taking into consideration the required intervention level, realisation time, and permanency;
   - a decision matrix for the potential future green land uses on urban brownfield - The third tool of the proposed framework is a decision matrix aimed to support an assessment of the potential for the different UGSs at a specific brownfield, by analysing whether the site fulfils a number of conditions.

A more elaborate description of the supporting literature and tools along arguments with reference used for support can be found in Paper I and Chowdhury (2020)

3.2 Objective 2 – Support identification of potential GRO strategies

The GRO framework for risk management was developed to support identification and communication of potential GRO strategies for risk mitigation. The development of the risk management framework for GRO was done in two steps:

i. *Generic framework conceptualisation:* Linkages between GRO, risk mitigation mechanisms and their impact on ecological and human health risks were to be conceptualised and illustrated in a conceptual diagram and forms the basis for the GRO framework. The expected timeframes for risk reduction of different GROs and contaminant groups were added to this visualisation, based on existing literature. An extensive literature review was done to provide evidence for the risk reducing mechanism in literature. The main author for Paper II did the investigation, so not covered in this thesis.

ii. *Site-specific application:* The following selections were made for site-specific application of the GRO framework. To calculate safe concentration targets (soil guideline value, SGV, i.e. contaminant concentration targets or soil quality standards) for a certain UGS, the Swedish Environmental Protection Agency (SEPA) soil guideline value model (SEPA, 2016b) was used. The soil guideline value model can be downloaded as an Excel worksheet at the Swedish EPA website (SEPA, 2022). It has become a standard tool, accepted by regulatory authorities, and is commonly used for deriving site-specific SGV in risk assessment for contaminated sites in Sweden. The Swedish soil guideline value model (SEPA, 2009) is based on the source-pathway-receptor concept and takes four main receptors into account: human health, the soil ecosystem, nearby surface water ecosystems and groundwater as a resource. Generic soil guideline values (SGV) are developed for two generic land uses: land with sensitive use (KM) (e.g. residence, agriculture, kindergarten, etc.) and land with less sensitive use (MKM) (e.g. office, industry, roads, etc.), aiming to protect all four receptors. Humans as receptors are assessed assuming four exposure pathways for less sensitive use (ingestion of soil, inhalation of dust and vapours, and dermal contact) and two additional exposure pathways for sensitive land use (intake of vegetables, and groundwater as drinking water source). The exposure scenario for a specific UGS could be outlined and adjusted in the SEPA model. For site-specific application, the contaminants present at the case study site were selected. second, to measure the relative risk by comparing the contamination concentration at site with the SGV. Depending on which contaminants that were present and the expected UGS scenario, different environmental receptors and human health exposure pathways would dominate the risk situation. The most important receptors and human health exposure pathways could be identified for each contaminant and each UGS, and the generic framework could be expanded with site-specific information to identify the potential GRO to manage the risk present at a site.

A more elaborate description of the supporting literature and tools along arguments with reference used for support can be found in Paper II.

3.3 Objective 3 – Support the identification and categorisation of stakeholders and their interests, resources, and challenges

To achieve the third research objective which aims to identify and categorise relevant stakeholders and their interests, resources, and challenges when it comes to regenerating brownfields to UGS, the following steps were taken:

i. *Methods for stakeholder analysis:* The stakeholder analysis was divided in three parts; identifying, and categorising relevant stakeholders, mapping the interests and resources of these stakeholders, and mapping the various challenges associated with realising UGS on urban brownfields. A scoping review was done to select three suitable methods from the literature (see Supplementary material 1 of Paper III). For stakeholder identification and categorisation, the categorisation by Rizzo et al. (2015) was selected. For analysing stakeholders' interest and resources, the Crosby method (Crosby, 1991) was selected. To identify and analyse challenges, the challenge categorisation proposed by Fernandes et al. (2020) was selected. A new method was developed to match the identified challenges with the mapped resources over the timeline of UGS development.
ii. *Method for data collection:* A digital questionnaire survey in combination with an in-person survey version was undertaken during spring and early summer 2021. The three selected methods for stakeholder analyses of the previous step helped to formulate the questions, to collect appropriate site-specific data, and to understand the applicability of the methods. The questionnaire was available in both Swedish and English. In total, 31 survey responses were collected. Twenty-six of these were responses on the digital platform (Momentive) and five were responses collected in person near the site. Both online and offline survey participants could choose to stay anonymous. The English version of the questionnaire is provided as supplementary material in Paper III.
iii. *Gigamapping* (Davidová & Zímová, 2021; Sevaldsen, 2012) was used for assessing, adapting, and applying the selected methods for stakeholder analyses, and also for structuring and analysing the collected data. Gigamaps were produced using Miro (miro.com), an online platform for visual mapping and collaboration. Miro's web platform was used by the first author to process the data and to document the analyses of multiple processes with the aim of co-discussing them with the other authors using the interlinked diagrams and visualisations. The final Gigamap is attached as supplementary material for Paper III.

A more elaborate description of the supporting literature and tools along arguments with reference used for support can be found in the Paper III (submitted and revised manuscript).

3.4 Objective 4 – Support an exploration for combining UGS with GRO on brownfields by suggesting and challenging a framework

The methodology adopted to achieve the fourth research objective which aims to propose a framework to support an exploration of the potential to combine UGS and GROs on brownfields was divided in three steps:

i. *Framework development:* The framework was motivated by existing literature and is supported by tools developed as part of the previous research. A conceptualisation of the framework was first developed and illustrated which forms the basis for a more detailed schematic diagram outlining the phases of transition and the tools and methods and the benefits.
ii. *Framework application and demonstration*: The framework including the tools and methods was demonstrated on a case study.
iii. *Stakeholder interaction*: A workshop was conducted with selected stakeholders with the following objectives: i) to investigate challenges with and possibilities for implementing the suggested framework, and ii) to discuss how the framework could be improved to facilitate its practical application. The Strength, Weakness, Opportunity, and Threat (SWOT) analysis method (Ansoff, 1980) was used to facilitate stakeholder consultation during the workshop. Stakeholders were selected based on the outcome of the questionnaire survey carried out in the previous objective (Paper III) where relevant stakeholders were identified. Representatives were contacted through a formal personalised e-mail invitation and six out of eleven contacted organisations got back with positive responses and participated in the workshop. The persons accepting the invitation represented the following organisations and roles: two representatives from the Real Estate Office (Göteborg stad), one representative from the Environmental Department (Göteborg stad), one representative from the Recycling and Water Office (Göteborg stad), one representative from Älvstranden Utveckling AB, and one landscape architect, with a special interest in phytoremediation technologies. A three-hour workshop was held on June 2022 in Gothenburg at Chalmers University of Technology. The workshop was bilingual (Swedish and English) where everyone spoke the language with which they were most comfortable, and participants helped to translate when needed. The workshop agenda included the following main parts: 1) a short background to the research work and the purpose of the workshop, 2) a time slot for presentation of the proposed framework using the Polstjärnegatan site for demonstration of its application, 3) two time slots for discussion in groups followed by reporting back the main discussion points to the whole group. The participants were informed about how the results were going to be used and that their names would not be revealed in any publication, but that their roles would be described. The workshop participants had the possibility to ask questions during the presentation which was actively used by them and perceived as helpful for better understanding of the presented material. Workshop participants were divided into two groups for the discussion part. The authors of this paper and a PhD student who was involved in the development of one of the tools that is included in the suggested framework had the roles of facilitators during the group discussions.

A more elaborate description of the methodology as well as the supporting literature and tools along arguments with reference used for support can be found in the Paper IV (manuscript).

3.5 Case study description

The case study used for demonstrating the tools and methods in this study is located along the Polstjärnegatan street within the Lindholmen district which is a rapidly developing harbour area in Gothenburg (Sweden). The site is part of a large development project of mixed housing and commercial facilities, Karlastaden. According to the detailed area plan of Karlastaden (Fig. 5), the redevelopment consists of eight building quarters spanning across three hectares and consists of five high rises (>60 m, with the tallest being Karlatornet rising 245 meter) (Göteborg stad, 2017). The development is projected to finish by 2026 and will add 2,000 more apartments to the Lindholmen area which currently has around 4,000 residents.

Figure 5: Top. Location map integrated with the concept plan of the Karlastaden development project with the site area highlighted (Karlastaden plan redrawn from Göteborg stad (2017)*; base map and orthophoto ©Lantmäteriet (https://www.lantmateriet.se/en/maps-and-geographic-information/maps/), used under Creative Commons License CC BY 4.0), bottom left: Physical conditions of the site as of June, 2022 (source: author), bottom right: axonometric sketch of the site to project the future look after the development of the Karlastaden produced by author.*

The site for this study is about 14,800 m^2 and the planned future use is a park area, specially designed to manage surface water runoff and with new roads being constructed around its perimeter. This site is currently surrounded by roads and a railway on all sides: Polstjärnegatan to the south, Karlavagnsgatan to the east, a petrol station and a fast-food restaurant to the west, and a railway (Hamnbanan) as well as a motorway (Lundbyleden) to the north (see Fig. 5). Due to the presence of the Hamnbanan, the north part of the site is in the risk zone associated with traffic with dangerous goods (Göteborgs Stad, 2017). As well as providing infrastructue to reduce the risk (i.e. a three meter high earthen wall with a 2 meter high flameproof plank along Hamnbanan) The park area in the northern part is planned to be designed without facilities that can encourage crowds to stay for a longer period of time (e.g. large playgrounds, sports fields or similar activities) (Göteborgs Stad, 2017).

Historically, most of the site has previously been used as a railyard with loading and unloading operations for coal products, forming part of the Sannegårdshamnen harbour and its shipyard (Kaltin and Almqvist, 2016). The shipyard was in operation from the early 1900s to 1980-90s. After the shipyard was closed, the site was turned into a golf course, demolishing the yard structures and the rail cross-ties and replacing them with sludge brought in from Ryaverket (a sewage treatment plant) to model the surface. The golf course was closed in the early 2000s and since then the site has remained unused. As the access to this abandoned site has not in any way been restricted, it has been subject to unauthorised use for illegal cable burning and metal reclamation at several places.

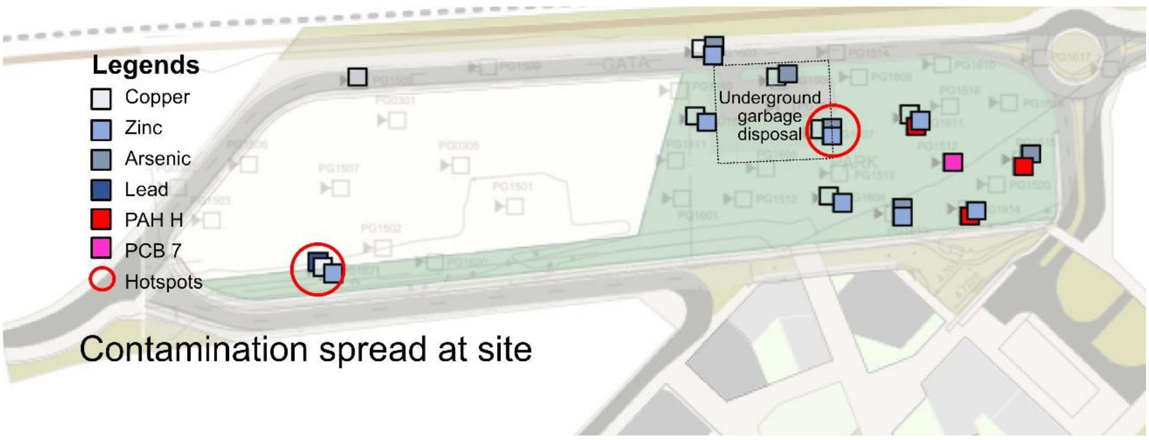


Figure 6: Spread of contamination across the site based on the SWECO report (Kaltin and Almqvist, 2016), the hotspots are circled red.

The site use history has resulted in soil pollution. The risk assessment results indicate that there are several small hotspots from illegal cable burning with high contamination levels, whereas lower but nevertheless elevated levels of contamination are detected in the rest of the area, primarily in the upper soil layer of 0 - 0.7 m (Kaltin and Almqvist, 2016). The primary contaminants are metal(loid)s (As, Cu, Pb, and Zn), petroleum products (primarily PAHs with high molecular weight) and persistent organic pollutants (PCBs) (see Fig. 6). The contaminant concentrations levels at hotspots correspond to Swedish criteria for hazardous waste (SEPA, 2009). Such severely contaminated hotspots are relevant to locate, excavate the soil and remove from the site. However, the rest of the site has slightly elevated levels of soil contamination which presents the opportunity for remediation solutions alternative to soil excavation and disposal.

4 RESULTS

This chapter summarises the outputs of the research in four sections. The output of the fourth objective (Section 4.4) is the only output exemplified using a case study (Section 4.5) in this chapter, as it includes tools and methods presented in the previous three sections (Section 4.1 – 4.3).

4.1 A framework for assessing the bio-based land use potential of brownfields

The bio-based land use framework, consisting of three tools, is the output of objective 1 and is presented in the following sub-sections. A more elaborate description of the bio-base land use framework can be found in Paper I, appended in this thesis, and in the licentiate thesis (Chowdhury, 2020).

4.1.1 A conceptualisation of linkages between land use, soil contaminants and time

The first tool is a conceptualisation of the relationship between prospective bio-based land uses and their gentle remediation potential over time for different types of soil contaminants (Fig. 7). A specific UGS will interplay with a set of GROs which will improve the soil condition, making room for new types of UGS to take place. The new UGS, in turn, will facilitate the possibility of adopting new types of GROs that, subsequently, will make another UGS possible, and so on.

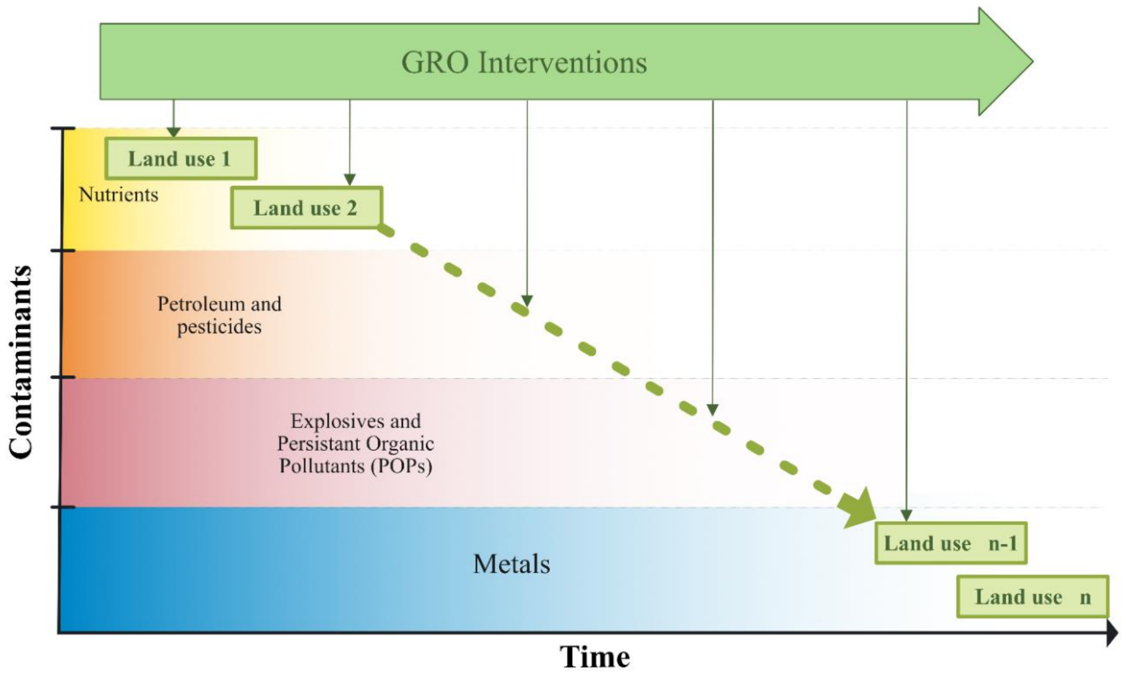


Figure 7. Conceptual framework showing how different types of gentle remediation options (GRO) relate to prospective UGS land uses, taking soil contaminants and time frames into account. From Paper I (Chowdhury et al., 2020).

4.1.2 UGS across different time frames and degrees of required interventions

The second tool of the framework is a scatter diagram to provide a graphical representation of UGS opportunities on brownfields taking into consideration the required intervention level, realisation time, and permanency (Fig. 8). The various UGS are consequently arranged along a diagonal line, depending on where they fit best. This tool introduces the temporal aspect in the planning by sorting the UGS based on the time required for their realisation.

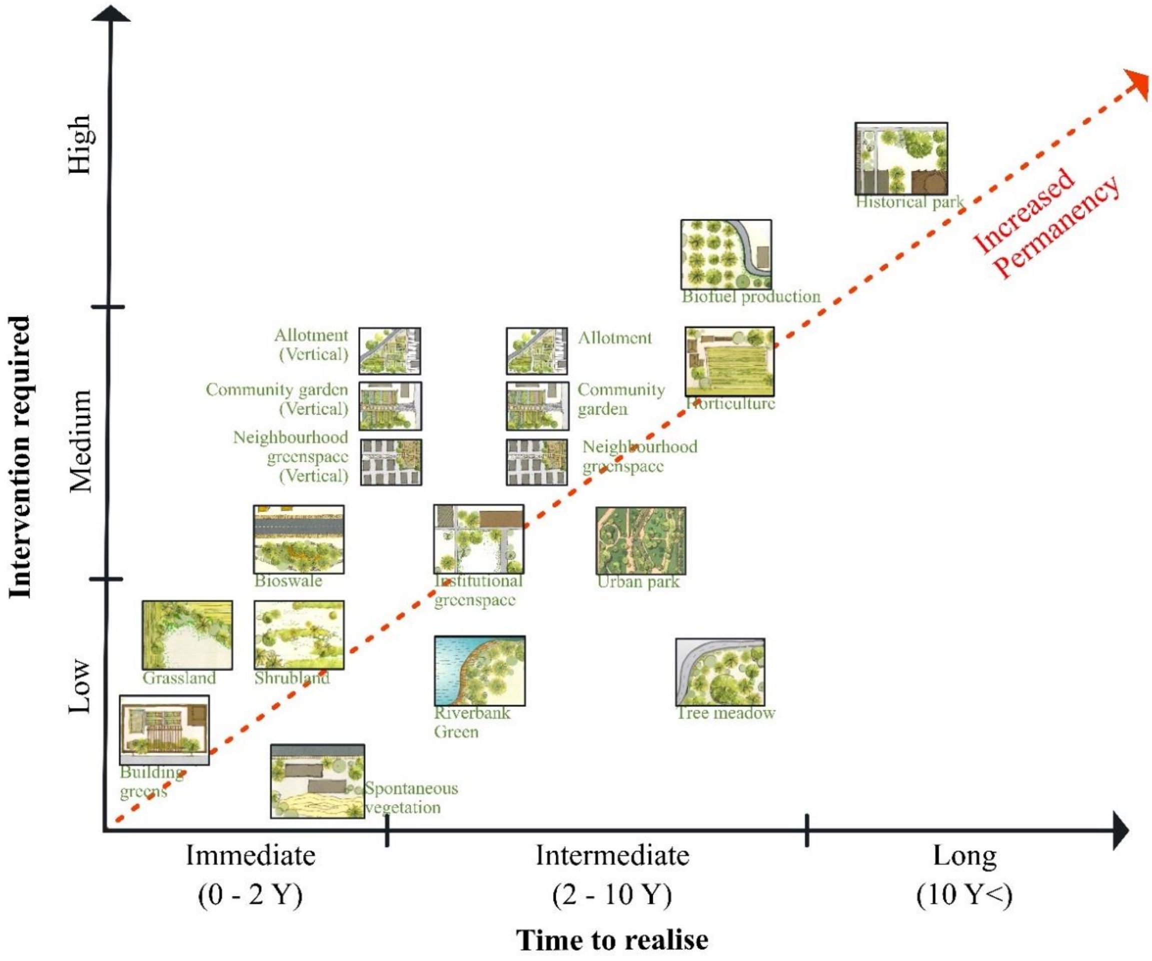


Figure 8. The scatter diagram of future bio-based land use on urban brownfields with provisional positioning of the icons. From Licentiate thesis (Chowdhury, 2020).

Potential future green land uses (the identified UGS elements in Table 2) are analysed in the context of two basic requirements: interventions and time needed to realise them. The Y-axis of the diagram represents the required intervention which can be understood as resource intensity requirements of e.g. information, stakeholder commitment and capital. This acts as a general understanding of the bulk of work entailed by an upcoming development The vertical position of each land use in the diagram depicts the relative scale of intervention required – low, medium, or high – for a UGS to be realised. The X-axis of the diagram indicates the relative time frame in years (Y) estimated for realising the future green land use. This axis is scaled in three parts: immediate (<2 Y), intermediate (2-10 Y) and long term (>10Y). 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 not least concentrations and types of contaminants. The diagram finally incorporates the permanency, i.e. the likely longevity, of the green land uses based on their position in the diagram. The more time and resources required, the more likely it is for the UGS to be more long-lasting. Vice versa, land uses with low time and resource requirements can be considered as more temporal interventions.

4.1.3 A decision matrix for the potential future green land uses on urban brownfield

The final tool is a decision matrix that filters out potential UGS for specific a brownfield based on the fulfilment of a set of basic conditions. Based on these previous studies, a suggested shortlist of basic conditions including the pre-conditions required for UGS is presented in Table 6. This shortlist is not intended as a complete set but rather as a starting point to trigger the process of greening by indicating the potential of a brownfield.

Table 6. The suggested list of basic conditions affecting the potential of bio-based 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 an either 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 planting
Size	The size of the land parcel available for development further categorised 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 bio-based land use.
Profit	The need for profit generation linked to the biological resources to be produced on the site.
GROs potential	The possibility of green land use to facilitate soil remediation through GROs. This always implies that a risk assessment is needed to ensure that the risks are not too high (for humans or ecosystems) to be handled with GRO.
Regulations	The regulations and policies by authorities (local, national, or global), that need to be adhered to when realising a new land use.

Next, the different types of UGS (Table 2) are connected to the basic conditions using a screening matrix (Table 7). The degree of fulfilment of basic conditions for a particular brownfield site can be marked using green (fulfilled), brown (not fulfilled), grey (unsure), yellow (can be changed if needed) or blue (not applicable).

Future UGS on brownfields depends on the *density* of the urban area. In densely built-up neighbourhoods, building greens and bioswales should be manageable within a tightly weaved urban fabric. Also, agricultural UGS that traditionally take place in sparsely built parts of cities can be done vertically in dense neighbourhoods *Sealing* is important since most greenspaces (e.g. grassland) require open soil, but some UGS can be practiced vertically such as building greens and allotments and community gardens on sealed surfaces. This can help to meet the safety precautions needed for contaminated soil exposure. Though the *size* is somewhat subjective, natural UGSs, such as riverbank green, should require rather large parcels of land. 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 the floor or wall area of the built infrastructure. *Access* to a site will also have an impact on the viability of the future UGS. UGS such as riverbank greens and shrubland, and possibly also grassland and meadow orchards, are expected to have public *access*. 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 UGS also depend on how the *management* is carried out for the type of activity. Horticulture is commonly practised as a private business, while neighbourhood greenspaces, community gardens and allotments, typically are for communal usage. Meadow orchards can be managed during harvesting seasons both privately and communally. For some of the agricultural UGS such as horticulture and biofuel production, *profit* requirements may play a critical role. Environmental improvements through e.g. building greens can also bring commercial benefits. In contrast, food produced from communal agricultural practices are for personal or shared use. Different types of local, national, and transnational *regulations* strongly affect what can and cannot be done on brownfields. Site specifics such as contaminant condition can have an impact on what sort of regulations would apply on a specific site. The *GRO potential* is explored in more detail in the GRO framework in the following section.

Table 7. 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.

Basic Conditions \ UGS		Building green	Bioswale	Riverbank green	Urban park	Historical park	Neighbourhood 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	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 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, but unsealed is possible	Unsealed, but sealed is possible	Unsealed	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 possible	Medium or large	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	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	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	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	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														

4.2 The GRO risk management framework

The risk management framework for Gentle Remediation Options (GRO framework) was developed for identifying feasible GRO strategies for managing contamination risks of brownfields as a tool to support better communication to decision-makers and relevant stakeholder A more elaborate description of the framework can be found in Paper II attached with this thesis. The generic GRO framework is presented in Fig. 9 while the site-specific application of the framework is presented in the case study demonstration (Section 4.5.2). The risk objects (column 1) – human health (including various exposure pathways) and the environment –is connected to risk mitigation mechanisms supported by GRO (column 2). The framework lists different GRO strategies (column 3) and connects them to their risk mitigation mechanism (column 2). It also provides the relative time required for reducing the risks posed by different groups of soil contaminants (column 4) to human health and the environment with help of different GRO strategies. Adaptive GRO management is important part of the framework for all GRO strategies during their implementation, and includes long-term monitoring, watering, etc. for upkeep and to ensure the risk reduction is maintained over time. The literature review to support the connections is summarised in detail in Paper II (see Table 2 in Paper II).

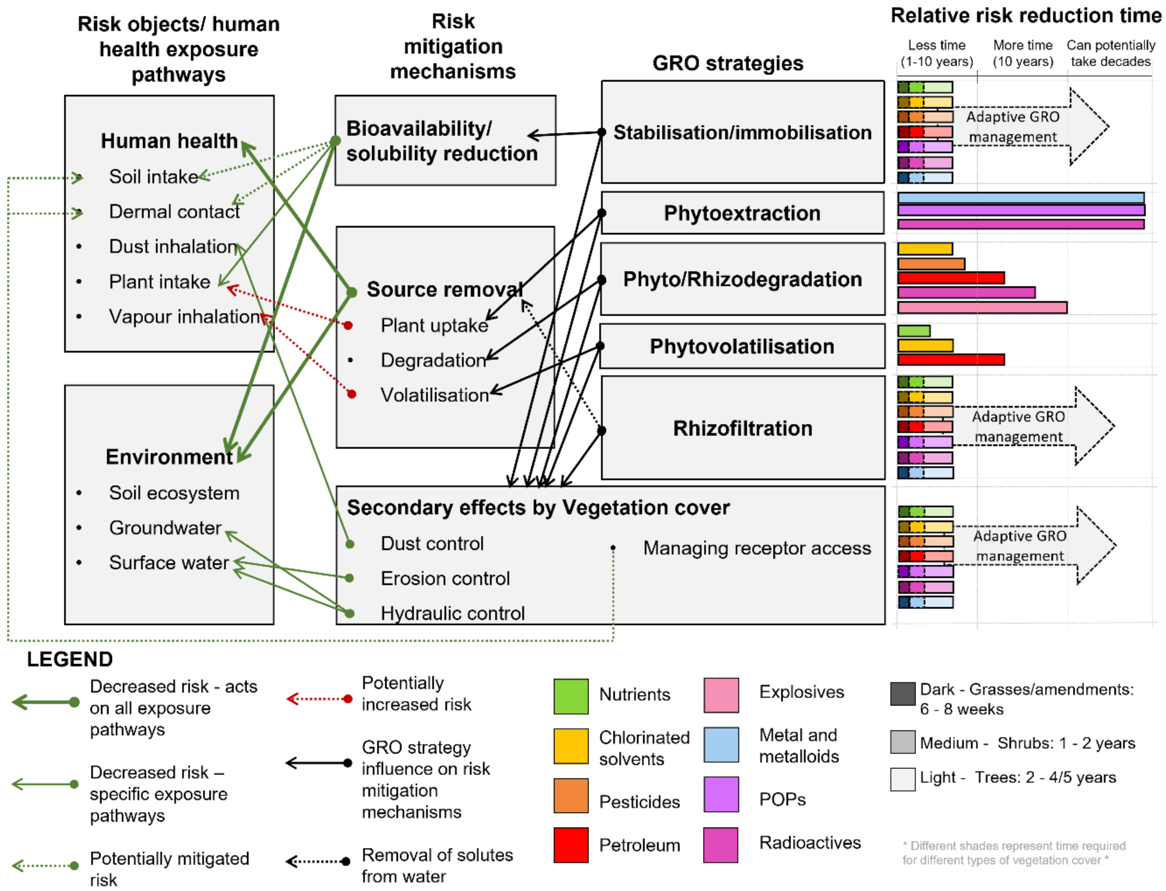


Figure 9. The generic risk management and communication framework for GRO with columns for Risk objects, Risk mitigation mechanisms, GRO strategies and a bar chart depicting relative risk reduction time for each GRO strategy. Relative risk reduction times are based on those shown in Fig. 4. Relative times for stabilisation/immobilisation, rhizofiltration and vegetation cover are based on literature. Adaptive GRO management is needed for all GRO strategies during their implementation, and includes long-term monitoring, watering, etc. for upkeep and to ensure the risk reduction is maintained over time.

4.3 Methods for stakeholder analysis

This chapter provides the methodology adopted to achieve the third research objective and presents methods for stakeholder analysis. A more elaborate description of the framework can be found in Paper III.

4.3.1 Identification and categorisation of stakeholders

Stakeholder categorisation for brownfield development proposed by Rizzo et al. (2015) was initially used for identifying all the stakeholders relevant for UGS realisation identified in the Polstjärnegatan. But the categorisation could not fully capture the role of the relevant stakeholders relating to the realisation of UGS. Following the responses from the questionnaire survey, an interconnected and flexible stakeholder categorisation was proposed, where the diverse roles of some stakeholders were recognised by allowing them to be represented in more than one stakeholder group. The categorisation was visualised using a Venn diagram which can accommodate the interconnections and overlaps of different stakeholder roles.

The proposed categorisation has one main category (*everyone*) which then includes three cluster categories (*government*, *local community*, *non-local community/visitors*), where stakeholders can appear in more than one group. All stakeholders relevant for UGS realisation have been further categorised into groups or sub-groups within the main cluster categories. The developed stakeholder categorisation is demonstrated in the case study (Fig. 12) and discussed in Section 4.5.1.

4.3.2 Mapping of stakeholders' interests and resources

The Crosby method uses a matrix that lists the stakeholder characteristics as a necessary first step for the mapping, but the matrix itself does not provide any comparison between different stakeholders based on their interests or resources. Instead, the graphical Gigamapping approach was used to analyse and present stakeholders' interests and resources which otherwise could not be easily visualised by using the Crosby matrix. In particular, the adapted approach focused on visualising which stakeholders, and how many of them, express similar interests, and resources. As a result, it became possible to differentiate between stakeholders' interests and resources, and their preferences could be highlighted and interpreted in various ways, such as number of mentions, type of mentions, or mentions by whom.

The interest was expressed in terms of respondents' interest in the UGS options. The potential resources were what the respondents could contribute as stakeholders to develop the study site as UGS and are categorised as *time*, *knowledge*, *money*, and combinations thereof. The suggested method for identifying and visualising stakeholders' interest is demonstrated in the case study (Fig. 13) and discussed in detail in Section 4.5.1. The visualisation for method for resource identification and description can be found in Paper III.

4.3.3 Identifying and categorising challenges

The challenge categorisation proposed by Fernandes et al. (2020) to map stakeholders' perception on challenges on brownfield redeployment is adjusted to address the specific challenges identified by the respondents. The suggested adjusted set of categories for categorising challenges for realising greenspaces on brownfields were:

- *Governance* – includes issues that fall under the domain of government agencies, both municipal and regional, and also political visions;
- *Land* – includes challenges regarding the location and size of the site, its accessibility, existing and planned physical facilities, restrictions such as urban zone mapping;
- *Finance* – covers challenges involving solvency, and availability as well as access to financial resources, both public and private;
- *Design* – includes challenges concerning the design of any future greenspaces at the site and ensuring the realised UGS is both aesthetic and functional;
- *Sustainability* – includes a broad range of environmental and socio-economical concerns that can challenge the realisation of UGS and the access to the long-term benefits they provide.

The challenge categorisation is demonstrated in the case study (Fig. 14) and discussed in Section 4.5.1.

4.3.4 Matching challenges with resources

A method was developed to how the challenges identified by the stakeholders could be matched with the resources available and to see how that could be engaged in the realisation of the UGS. The developed method consists of three steps:

- A timeline for UGS development is established, consisting of four consecutive phases: (i) *planning* phase, (ii) *design* phase, (iii) *building* phase, and (iv) *use and maintenance* phase.
- The identified challenges are regrouped according to the phases of the timeline.
- The stakeholders, and the resources they can contribute, are placed in the timeline. Stakeholders' engagement in each phase of the timeline is based on the relevance of their resources to address the challenges associated with that phase.

The final output of this method is a timeline showing the stakeholders' involvement in each phase of an UGS development. The method was applied and visualised in the case study (Fig. 15) and discussed in Section 4.5.1.

4.4 A framework exploring possibilities of combining UGS with GRO on brownfields

The suggested framework is presented in two ways: as a conceptualisation (Fig. 10) and as a schematic diagram (Fig. 11). Conceptually, the suggested framework proposes a redevelopment of brownfields based on two main principles: *space*– on the surface level, the site is repurposed for use as greenspace, while at the subsurface level, the contamination risk is managed, and soil health is improved; and *time* – the changes at the surface and subsurface levels occur gradually over time (Fig 10). The transition of a brownfield is conceptualised to take place in three consecutive stages: 1) abandonment and underuse, i.e. brownfield, 2) temporal use as greenspace, and 3) long-term use as greenspace. The temporal use combines UGS and GRO to simultaneously remediate the site, improve soil functioning and increase the provision of ecosystem services. The remedial action itself does not only reduce human health and ecological risks but also increases the land value on site and in surroundings. Gradually, the risk reduction over time allows for more user-intensive and more sensitive UGS are associated with stricter safety requirements.

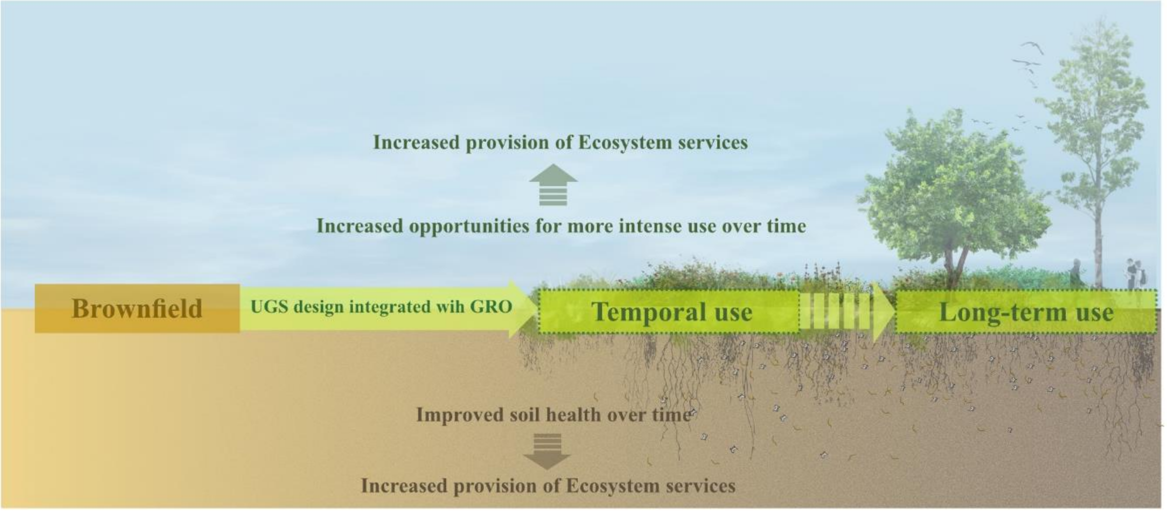


Figure 10: Conceptualisation of a temporal regeneration of brownfield. From Paper IV.

The schematic diagram (Fig 11) outlines the types of assessments that are suggested and some tools and methods that can support an exploration of the site potential. There are tools and methods that are suggested to be used for investigating the UGS potential at the site, and a number of tools and methods for investigating the GRO potential at the site. Combined, they can support the process of exploring the possibilities for creating a GRO-integrated UGS design at a site for one or several temporary land uses towards a more long-term land use. The selected tools and methods are listed below:

- The bio-based land use matrix (for detail, section 4.1.3)
- UGS across different timeframes and degrees of required interventions (for detail, section 4.1.2)
- Methods for stakeholder analysis (for detail, section 4.3)
- The Swedish Environmental Protection Agency (SEPA) soil guideline value model (SEPA, 2016b)
- GRO framework (for detail, section 4.2)
- A conceptualisation of linkages between land use, soil contaminants and time (for detail, section 4.1.

During the site's temporary use phases, monitoring is suggested: the soil should be monitored for the performance of the GRO for risk reduction as well as improvement of the soil health, and the provision of ecosystem services and site users' preferences should be monitored to detect if new needs arise. Should monitoring indicate that changes are needed to reach the long-term strategy, or that a new land use is considered more suitable or preferred by the stakeholders, this information feeds into the creation of a new design to better reflect the users' needs and to reduce risks effectively.

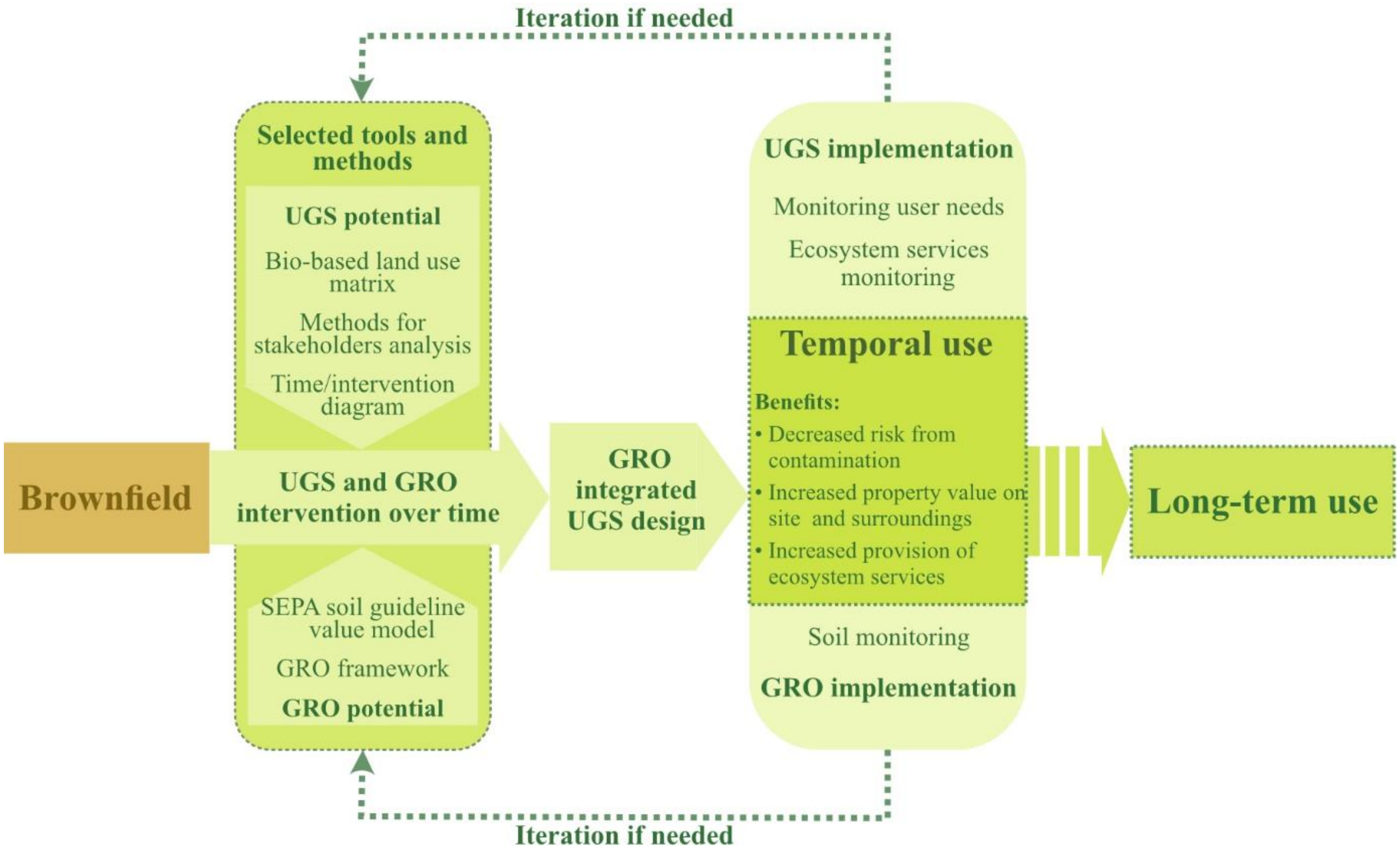


Figure 11: Schematic diagram of the suggested framework. Suggested tools and methods for the exploration of the site potential are listed. The implementation of a UGS combined with GRO suggests monitoring to follow up on progress and potential changes. Dotted arrows indicate the possibility for iterations if needed, should conditions or user needs change over time. From Paper IV.

4.5 Case study demonstration

4.5.1 Exploring the UGS potential

Bio-based land use matrix

The bio-based land use matrix is developed for screening and selection of the feasible UGS at the site. The matrix includes a total of 15 different UGS that can potentially be developed at Polstjärnegatan if the basic conditions are fulfilled. Description of these basic conditions and their fulfilment for the study site is presented in Table 8. Bio-based land use matrix application based on the fulfilment of the basic conditions for this site is presented in Table 9.

Table 8. The fulfilment of the list of basic conditions for the case study Polstjärnegatan.

Basic conditions	Description	Polstjärnegatan
Pre-conditions	Building greens - Presence of built infrastructures	Not present but can be changed if needed
	Institutional greenspace- Institutional ownership or interest	Not present but can be changed if needed
	Riverbank greens - Presence of a waterway	Not present
	Historical park- Historical relevance	Not present
	Neighbourhood greenspace-Adjacent neighbourhood	Present, adjacent housing facilities
	Spontaneous vegetation- Derelict site conditions	Present
Density	Site (Dense or sparse)	Sparse
	Surroundings (Dense or sparse)	Dense
Sealing	Sealed or unsealed	Unsealed
Size	Large (>1 ha), medium (0.1-1 ha), small (<0.1 ha)	Large (14,800 m^2 ~1.48 ha)
Access	Public, semi-public, or private	Semi-public or public
Management	Individual, communal, private or public	Undecided, possibly public
Profit	Needed or not needed	Undecided, but can be both
GRO potential	The possibility of green land use to facilitate soil remediation with GROs. This always implies that a risk assessment is needed to ensure that the risks are not too high (for humans or ecosystems) to be handled with GRO.	Not investigated yet
Regulations	The regulations and policies by authorities (local, national or global), that need to be adhered to when realising a new land use.	Not investigated yet

The site fulfils the criteria of eleven UGS and they are 1) bioswale; 2) urban park, 3) neighbourhood greenspace, 4) allotments, 5) community gardens, 6) grassland, 7) meadow orchard, 8) biofuel production, 9) horticulture, 10) shrubland, and 11) spontaneous vegetation (Table 9)

Table 9. Decision matrix application on the case study site, Polstjärnegatan. 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

Basic Conditions \ UGS		Building green	Bioswale	Riverbank green	Urban Park	Historical Park	Neighbour-hood 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	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 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, but unsealed is possible	Unsealed, but sealed is possible	Unsealed	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 possible	Medium or large	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	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	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	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	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														

Spontaneous vegetation is the present use of the site because the site is presently covered with naturally occurring vegetation. Similarly, other types of natural vegetation cover, such as *grassland* and *shrubland*, are also possible on site. *Urban Park* is both a possible and likely the future UGS of the site (Göteborgs Stad, 2017). The future park area on the site is planned to be specially designed to help with the surface water runoff (Göteborgs Stad, 2017) which makes *Bioswale* (i.e. UGS that are specially designed to treat and capture stormwater runoff) a potential future land use as well. The site is potentially too large to plan only for such functions but integrated with *Urban Park* as planned in accordance to the detail plan, this UGS is a good fit for the site not least since the site is surrounded by heavily trafficked roads. Given the contamination conditions of the site, UGSs that can potentially produce edible products such as *Meadow orchard*, *Horticulture*, *Allotment*, *Neighbourhood greenspace* and *Community Garden* would most likely need handling of the contamination situation before unrestricted use. The site is potentially 'too large' for *Neighbourhood greenspace* and *Community Garden* but like bioswale, they can also be combined with other UGS types at the site. *Horticulture* and *Biofuel production* are both fundamentally private practices, whereas the site is currently of public ownership.

Methods for stakeholder categorising and identifying interests, resources, and challenges

The stakeholder analysis methods described in Section 4.3 were applied next. These methods were designed for identifying and categorising relevant stakeholders and highlighting their preferences of UGS, but also mapping their resources, the challenges associated with the site and matching those challenges with mapped resources over the timeline of a UGS site development. A questionnaire survey had been performed (detailed in section 3.3).

Stakeholder identification and categorisation

An interconnected and flexible stakeholder categorisation (Fig 12) was proposed, where the diverse roles of some stakeholders were recognised by allowing them to be represented in more than one stakeholder group. The proposed categorisation has one main category (everyone) which then includes three cluster categories (government, local community, non-local community/visitors), where stakeholders could appear in more than one group. All stakeholders relevant for UGS realisation had been further categorised into groups or sub-groups within the main cluster categories.

Government consists of two stakeholder groups, municipal/local government, and regional government. The municipal government is perceived to have a stronger role to play. Several departments within the municipality that can play specific roles in UGS realisation are identified by the survey respondents: the Parks and Nature Administration (Park och Naturförvaltningen), the Recycling and Water Office (Kretslopp och vatten), the Environmental Administration (Miljöförvaltningen), the City Planning Authority, (Stadsbyggnadskontoret), the Real Estate Office (Fastighetskontoret), and the municipal urban development company Älvstranden Utveckling AB. Some departments of the regional government, along with some branches of the local government, form the controlling authority group are likely to play a role in, for example, managing local and regional land use and implementing safety regulations.

The Local community cluster category consists of six stakeholder groups: landowner (of the site), property owners and managers of the surroundings, civil society/NGOs, local residents, schools and research institutes, and local business. These groups often overlap and are interlinked with stakeholders that belong to more than one group or category. As the study site is located near a university campus with several student housing blocks nearby, students living in these housing facilities a could benefit from the established UGS. The Lindholmen Science Park was mentioned which is a collaborative platform between the business community, university, and the municipality. Real estate developers were often mentioned as a relevant local business, and they overlap with property owners and managers of the surroundings. Few other local businesses were mentioned as potential stakeholders such as event organisers, cafés and restaurants, and local gyms.

Figure 12: Mapping of identified and categorised stakeholders at Polstjärngatan. From Paper III.

Stakeholders representing civil society/NGOs were identified for specific UGS: the association Voluntary Nature Conservation (Ideell naturvård) for grassland or shrubland; Färjenäs Forest Garden (Färjenäs skogsträdgård) for meadow orchard; the association Urban Agriculture (Stadsnära odling) for allotments and a community garden. The School Food Academy (Skolmatskadamien) is a regional network in the Västra Götaland region promoting good meals and good eating habits in schools and was mentioned as a potential stakeholder by a respondent if the site is designed with an UGS that works or integrates collaborative school garden for nearby schools and kindergartens.

Non-local residents and visitors is the last cluster category. Passers-by, visitors, office workers, and youth are all part of this group and are mentioned occasionally as relevant stakeholders, however, people working in the area are regularly mentioned as an important stakeholder group.

Stakeholders' interests at Polstjärnegatan

To analyse stakeholders' preferences for the UGS (identified by applying the bio-based land use matrix), the conducted questionnaire survey asked the respondents to select three UGS each and explain their choices. Urban Park is the most popular choice of greenspace among the stakeholders, where 26 out of the 31 respondents selected this as a potential future use for the site with bioswale being the second (selected by 19 respondents). Community garden is selected by 12 respondents and meadow orchard is selected by 10. The detailed preferences of UGS are presented in Fig. 13 below. A more elaborate exploration of stakeholder preference can be found in Paper III.

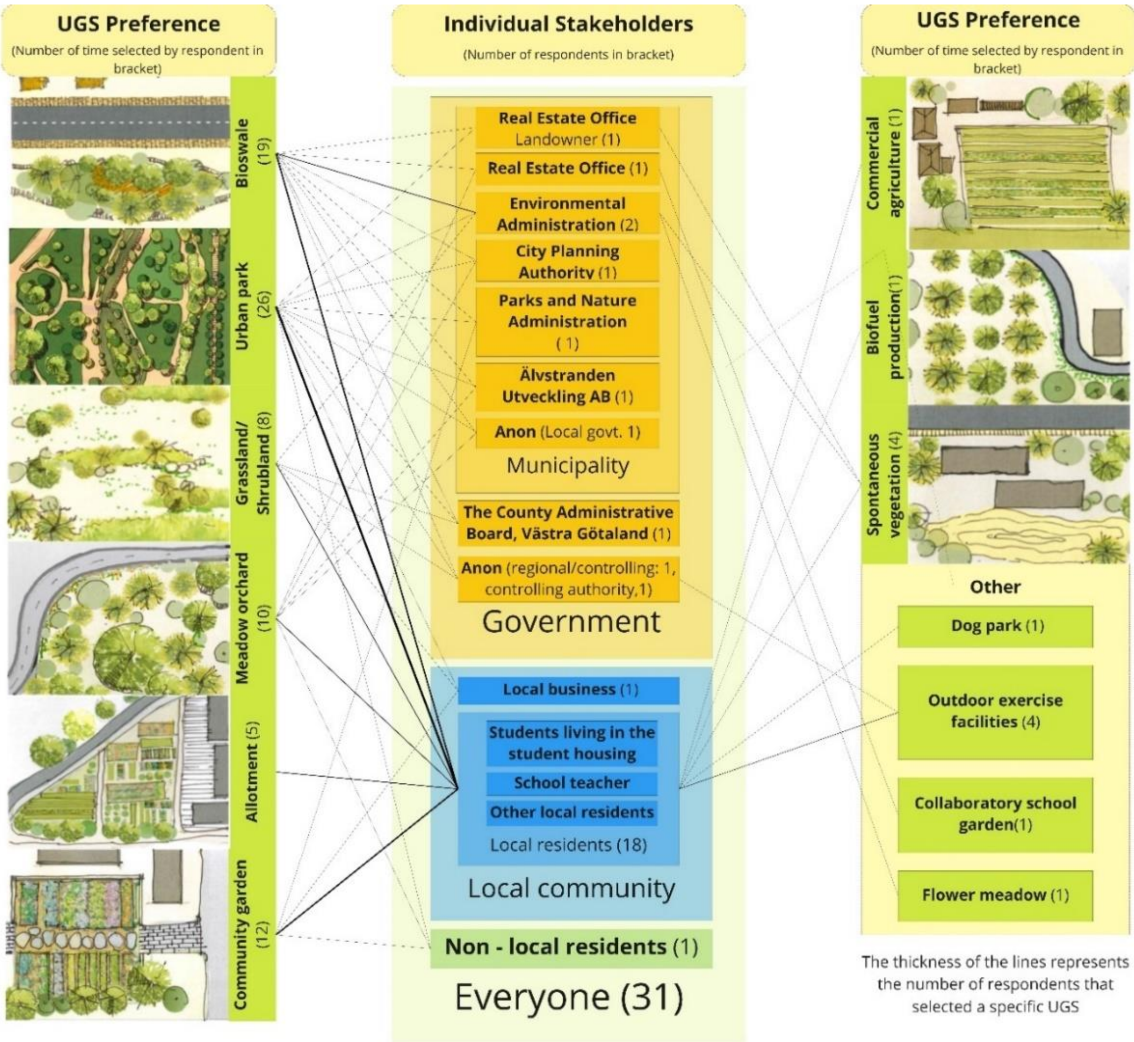


Figure 13: Site-specific UGS preferences. From Paper III.

Identifying challenges and resources at Polstjärnegatan

The respondents were asked to identify challenges with realising UGS at the site and the modified categorisation of challenges (Section 3.2) was applied to categorise and visualise the identified challenges (see Fig.14). The 'governance' issues identified by the respondents were: co-ordinating the planning process between the different departments of the municipal and regional governments, the speed of development, and ensuring maintenance of the greenspace (e.g. coping with a large number of visitors, damage over time, littering etc.). Multiple issues associated with 'land' have been identified by the survey respondents. They were current derelict condition of the site., ongoing infrastructure projects around the site and the projected dense population neighbourhood of the site's location. The 'finance' challenge was mainly related to the lack of resources for developing a greenspace. Several 'design' challenges were recognised by the survey respondents: ensuring that the realised UGS is both aesthetic and functional, proportionate design of the UGS to fit the seventy-three storey Karlatornet, and the shadow cast by the high-rises. Identified challenges for ensuring 'sustainability' were related to strict competition over urban land might favour other more immediately profitable, alternatives to greenspaces, and the present soil contamination.
However, the most prominent issue of concern for the study site is the road and railway (Lundbyleden and Hamnbanan respectively, see Fig. 5) that border the north of the site. Various challenges were identified due to their presence adjacent to the site, with these issues spanning all categories: environmental concerns, such as noise and air pollution (sustainability), low connectivity to smaller roads and walkway (land) and negatively affecting the design of a pleasant green area (design). The proximity to the railway means a higher risk of traffic accidents (land) with dangerous goods which puts the site into a high-risk zone. The current detailed plan therefore restricts future uses of the site for 'extended stay' (governance). This implies that future UGS should not be planned to allow people to stay there, but only to pass through, if no measures are implemented to lower the risk. These complications could potentially lead to policy conflicts that could entail significant cost to resolve in future (finance).

Governance	Land	Finance	Design	Sustainability
G1 Co-ordinated planning between administrations	**L1** Present derelict condition of the site	**F1** Economic/financing difficulties	**D1** Proportionate design of the site to fit the scale of the surroundings	**S1** Ensuring sustainability in exploitation economics • Preferring alternative more income generating land use
G2 Lack of speed in development due to logistical complicacy and delays	**L2** Ownership of the land	**F2** Lack of resources for site development	**D2** Lack of knowledge and acceptance	**S2** Strict competition over land with other plausible land use • Green land use vs other more economically viable alternative such as residence or parking
G3 Ensuring maintenance (e.g. withstanding large number of visitor, damage with time, littering, etc.)	**L3** High density of the locality		**D3** Achieving both functionality and aesthetics	**S3** Present soil contamination • affecting the possibility of designing the green area for cultivation and residence
	L4 Ongoing infrastructure projects around the site		**D4** Stormwater management with regard to the correct dimensioning	
Proximity to a highway and a railroad (Hamnbanan and Lundbyleden)				
G4 Planning restriction on land use	**L5** Higher risk of accidents connected to transportation of dangerous goods	**F3** Potential policy conflict that can lead to large cost in future	**D5** Negatively affecting the possibility of designing a pleasant green area	**S4** Noise pollution
	L6 Low connectivity to smaller roads and walkways			**S5** Air pollution

Figure 14. Identified challenges in realising UGS at the study site. From Paper III.

Matching challenges with resources at Polstjärnegatan

The developed method consists of three steps: firstly, establishing a timeline for UGS realisation consisting of four consecutive phases: (i) *planning* phase, (ii) *design* phase, (iii) *building* phase, and (iv) *use and maintenance* phase; secondly, regrouping the identified challenges according to the phases of the timeline; and finally, placing the stakeholders, and the resources they could contribute with in the timeline. The final output of this method is a timeline (Fig. 15) showing the stakeholders' involvement in each phase of an UGS development.
Eight challenges with a broader scope need to be addressed in the planning phase, where the conceptualisation of the UGS takes place. The design phase includes eleven challenges that are more specific and relevant when a specific UGS has been decided on. The third phase of UGS development, the building phase, includes three challenges. In the final maintenance phase; there is only one challenge from the governance category related to ensuring the maintenance of the realised UGS.

The stakeholders and the resources they could contribute with were included in the timeline visualisation, based on their ability to address the identified challenges in the various development phases. As the landowner and the primary financier of the site development, the Real Estate Office should be preferably engaged in all four phases of the timeline. The Parks and Nature Administration should also be involved throughout the timeline as the responsible authority of greenspaces in the city and be engaged in the realisation and maintenance of any UGS realised in the study area. The other municipal departments, such as the City Planning Authority and the Environmental Administration, are expected to be engaged sporadically throughout the UGS development phases as they are not directly involved in developing UGS. The municipal company Älvstranden Utveckling AB should also be engaged initially as they have experience of developing parks in the neighbourhood. The involvement of Water and Waste Recycling Department is necessary if the planned UGS has features to handle stormwater runoff (i.e. bioswale). Local community stakeholders were very well informed about local context and local needs, and they could provide valuable inputs during the planning phase of the UGS development. If allotments or community garden are chosen to be developed, local residents with experience in such activities can prove to be useful. The local community mainly represents the users of the realised UGS, and are essential in the final phase of use and maintenance.

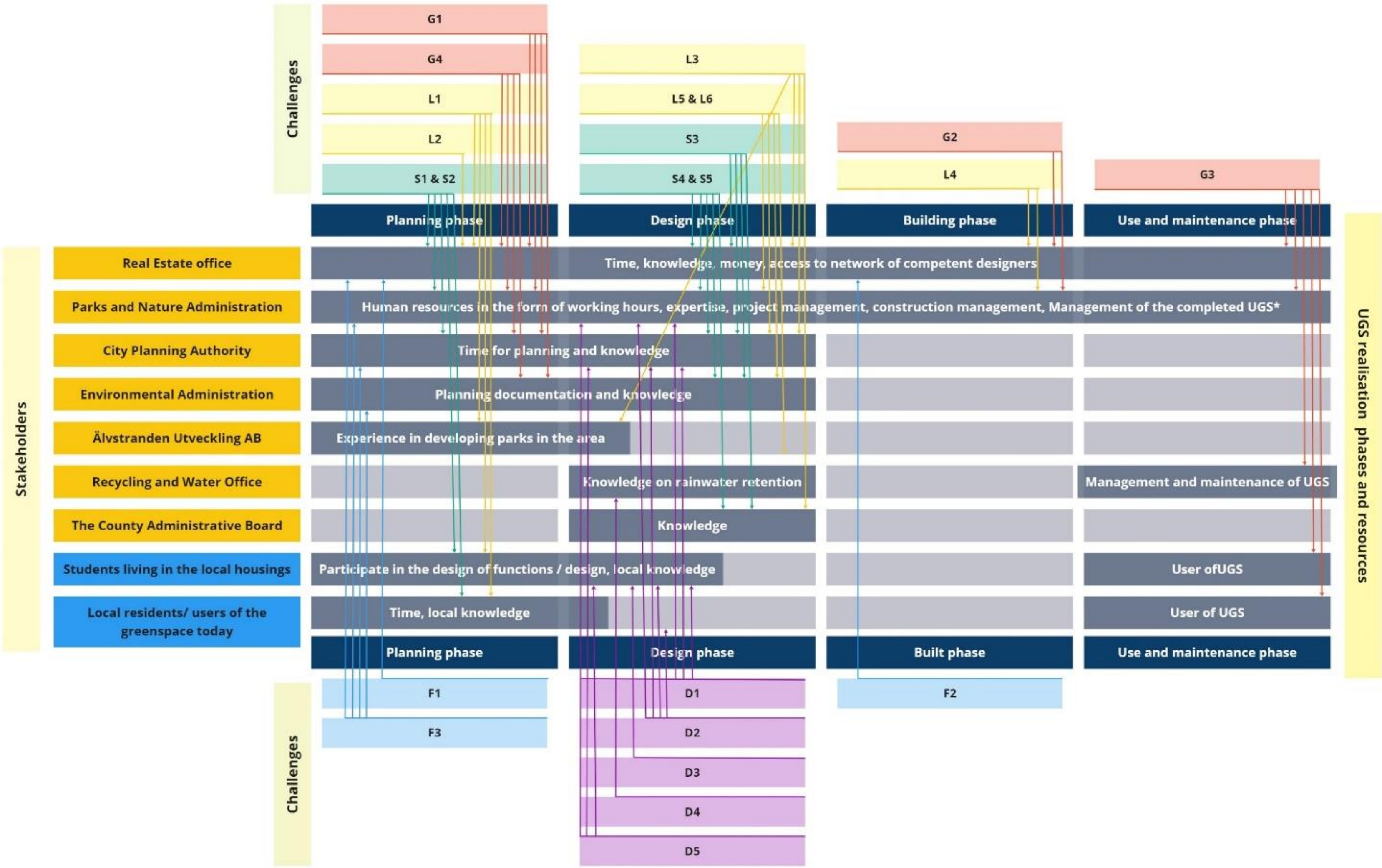


Figure 15. Identified resources (in grey) hold by stakeholders (in orange and blue) that can be used to address the identified challenges in realising UGS at the study site. G, L, F and S: challenge categories related to respectively Governance, Land, Finance and Sustainability. See details on each challenge in each category in Fig. 14. From Paper III.

UGS across different timeframes and degrees of required interventions

The scatter diagram to provide a graphical representation of UGS opportunities on the site is developed next (for details on this tool, see Section 4.1.2). The site is currently sparsely, and spontaneously vegetated, the UGS Spontaneous vegetation is therefore representing the present land use and does not require any intervention as such. Other UGS that are possible with low intervention for almost immediate realisation are grassland and shrubland (immediate, low). Tree meadows are considered to require low intervention but would take longer (i.e. intermediate) to be realised. The planned future UGS on the site which is a park area with bioswale properties requires medium intervention. While bioswales can be realised immediately, urban park can take up to 2 to 10 years (intermediate). Allotment gardens is another possible UGS at the site that can be realised on an intermediate timeframe with medium intervention. Neighbourhood greenspace and community garden are also in this category, but the site is potentially too large for these uses and may require being divided up into different functions. Horticulture is also in the same category but as a private use, it would require managing privacy as the site is to be developed as public area. Biofuel production would require high intervention and can be realised intermediately but it also assumes private use.

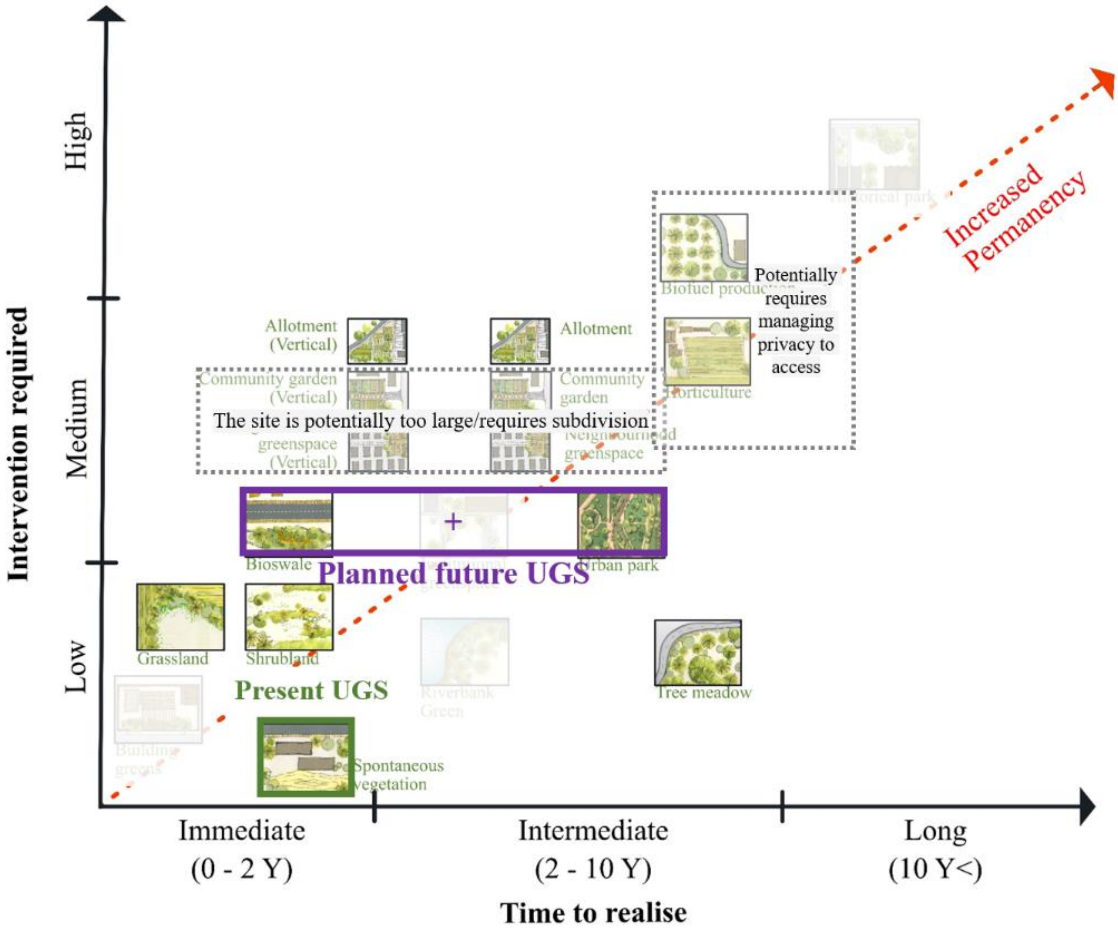


Figure 16: The scatter diagram of future UGS on the case study site. From Paper IV.

The four UGS are selected as potential future land use at Polstjärnegatan after exploring the UGS potential and they are: ***Spontaneous vegetation, Urban Park, Bioswale,*** and ***Community Garden.***

4.5.2 Exploring the GRO potential

The Swedish guideline value model

The SEPA model (SEPA, 2016b) was used to determine soil guideline values which represents the safe limit of contaminants on the site, as well as the dominating risk and exposure pathways for the different UGS scenarios. The UGS scenarios that were examined here were spontaneous vegetation, which was divided in two scenarios, with or without users' opportunity to pick berries, urban park, and community garden. Bioswale was however not considered in this step because it can be considered a GRO itself and is constructed by tilling to establish the infiltration capability and manage quantity and quality of stormwater. For the three potential UGS uses at Polstjärnegatan, the parameters in the SEPA model were adjusted to better reflect these exposure scenarios (Table 10). For all scenarios, the acceptable risk level for the soil ecosystem was set to sensitive land use (KM), and intake of drinking water was not included in any of these scenarios.

Table 10: Exposure parameters used in the SEPA model for calculation of soil guideline values for different UGS. KM and MKM represents generic scenarios in the SEPA model (KM – sensitive land use, MKM – less sensitive land use).

Exposure Scenarios – UGS Polstjärnegatan (all other parameters in the model corresponding to sensitive land use, KM)						
Human health exposure pathways	Exposure parameters	MKM	KM	Spontaneous vegetation (with berries)	Urban park	Community garden
Intake of soil	Exposure time - child (day/yr)	60	365	60	200	365
	Exposure time - adult (day/yr)	200	365	200	200	365
Dermal contact	Exposure time - child (day/yr)	60	120	60	120	120
	Exposure time - adult (day/yr)	90	120	90	120	120
Inhalation of dust	Exposure time - child (day/yr)	60	365	60	200	365
	Exposure time - adult (day/yr)	200	365	200	200	365
	Proportion of time indoors	1	1	0	0	0
Inhalation of vapor	Exposure time - child (day/yr)	60	365	60	200	365
	Exposure time - adult (day/yr)	200	365	200	200	365
	Proportion of time indoors	1	1	0	0	0
Intake of plants	Consumption - child (kg/day)	Not included	0.25	0.25	Not included	0.25
	Consumption - adult (kg/day)		0.4	0.4		0.4
	Proportion of food grown on site		0.1	0.025		0.1
Intake of drinking water		Not included	Included	Not included	Not included	Not included

Output from the Swedish guideline value model for three UGS was the final SGV as a result of calculations for exposure to human health and ecological receptors (See Paper IV supplementary materials Table S3.2 – S3.4). For Arsenic, the final SGV is automatically adjusted upwards to 10 mg/kg in all three UGS scenarios in the model, as Arsenic is a naturally abundant metal in Swedish soils, and guideline values cannot indicate the need of remediation for concentrations below naturally occurring concentrations. These SGV for different UGS compared with the contaminant concentration at the to calculate the risk. Table 11 presents the soil data at the Polstjärnegatan site, together with the calculated risk quotients for the most sensitive receptors (human health and the soil ecosystem in the case of Polstjärnegatan). The risk quotient (RQ) is calculated using the following equation:

$$RQ = \frac{Shallow\ soil\ concentration}{Soil\ guideline\ value}$$

An RQ > 1, indicates that there is a potential risk (marked grey in table 11) at the site.

Table 11. Mean contamination concentrations [mg/kg] detected at Polstjärnegatan, UGS specific SGV for each contaminant [mg/kg] according to the various land use scenarios calculated with the SEPA model, and Risk Quotient (RQ) calculations.

Contamination levels (arithmetic mean)	**As**	**Cu**	**Pb**	**Zn**	**PAH-H**	**PCB-7 (n = 2)**
Unit:	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Mean value (shallow soil)	10	118	57	264	1.2	0.025
Mean value (deep soil)	8	70	35	192	1.1	-
Mean value (all soil layers)	8	88	44	188	1	0.025
UGS specific SGVs*	**As**	**Cu**	**Pb**	**Zn**	**PAH-H**	**PCB-7**
Spontaneous vegetation (Human health)	10*	8 200	320	12 000	3.4	0.036
Spontaneous vegetation (Soil ecosystem)	20	80	200	250	2.5	0.1
Urban park (Human health)	10*	22 000	150	33 000	4.9	0.054
Urban park (Soil ecosystem)	20	80	200	250	2.5	0.1
Community garden (Human health)	10*	2 300	64	2 900	1.1	0.009
Community garden (Soil ecosystem)	20	80	200	250	2.5	0.1
Risk Quotients	**As**	**Cu**	**Pb**	**Zn**	**PAH-H**	**PCB-7**
Spontaneous vegetation (Human health)	1.0	0.0	0.2	0.0	0.4	0.7
Spontaneous vegetation (Soil ecosystem)	0.5	1.5	0.3	1.1	0.5	0.3
Urban park (Human health)	1.0	0.0	0.4	0.0	0.2	0.5
Urban park (Soil ecosystem)	0.5	1.5	0.3	1.1	0.5	0.3
Community garden (Human health)	1.0	0.1	0.9	0.1	1.1	2.8
Community garden (Soil ecosystem)	0.5	1.5	0.3	1.1	0.5	0.3

* The SGV for each of the most sensitive receptors is presented OR the adjusted final guideline value, where this is relevant (As).

The GRO framework

The GRO framework was applied based on the SEPA model output to identify potential GRO strategies to manage the risk for the three UGS, Spontaneous vegetation with berries, Urban Parks, and Community Garden (Fig. 17). The calculated RQ for each soil contaminant (Table 11) was used to identify soil contaminants that pose the risks to human health and the soil environment in each UGS scenario.

The concentration of Cu and Zn present at the site pose a potential risk to the soil ecosystem in all three UGS scenarios. Although the RQ for Pb is acceptable (RQ < 1) for human health in all UGS scenarios, the mean concentration of Pb in the shallow soil is close to the SGV for the community garden scenario (RQ = 0.9) which requires caution when planning this UGS. PAH-H and PCB pose risks to human health in the Community Garden scenario, with Intake of plants as the dominating exposure pathways, and Intake of soil as the secondary human exposure pathway. The concentration of As at the site is in line with naturally occurring concentrations in Swedish soils, and thus the risk quotient (RQ) is equal to 1 in all UGS scenarios. The dominating exposure pathway for As is Intake of berries (or plants) for Spontaneous vegetation and Community garden, and Intake of soil for Urban park where no edible plants are assumed (Fig 17, for details see Paper IV supplementary materials Table S3.2 – S3.4). Even if the human health risk posed by As is acceptable (RQ = 1.0), it may be beneficial to reduce this risk if possible for Urban Park scenario and the risk potentially needs to be managed for Spontaneous vegetation and Community Garden.

To lower the risk of Cu and Zn to the soil ecosystem, GRO strategies involving stabilising agents is of interest. Using this strategy implies that the contaminants remain in the soil but becomes less bioavailable. This can reduce the human health risk posed by Intake of plants, and potentially also the risk posed by Soil intake, as well as the risk to the soil ecosystem. Stabilisation can also be considered viable options for As and PAH-H. However, an important aspect is that As typically behave different than many other metals and other substances, and agents that may stabilise Cu, Zn and PAH-H can potentially mobilise As, and thus need to be carefully selected. Phytoextraction of As, Cu and Zn is a potential option to achieve risk mitigation by source removal. Phytoextraction is likely to take long (More than 10 years) for Cu and As. Another drawback with phytoextraction is the handling of the biomass afterwards.

Regarding PCB, only relying on stabilising strategies for mitigating risks is probably not a good option, since the risk is significant for the Community Garden scenario (concentration of PCB is almost 3 times higher than the SGV). Instead, source removal is most likely needed. PCB can potentially be phytoextracted but since the biomass needs handling, rhizodegradation may be more interesting to investigate further. If starting up a GRO strategy to phyto/rhizodegrade PCB in an early phase of the development of the site, the source could potentially be decreased enough to allow for more sensitive use such as Community Garden later in the site development process. However, continuous monitoring and adaptive management of this, and any other, GRO-strategy is needed to make sure that targets are reached over time.

Human exposure due to soil intake is expected to be lowered with a vegetation cover, thus all GROs involving plants i generate risk mitigation by these secondary effects. However, in the Community Garden scenario, involving growing of edible crops, this risk mitigation is not likely to be very effective since users are expected to engage in gardening and be in direct contact with the soil despite a vegetation cover.

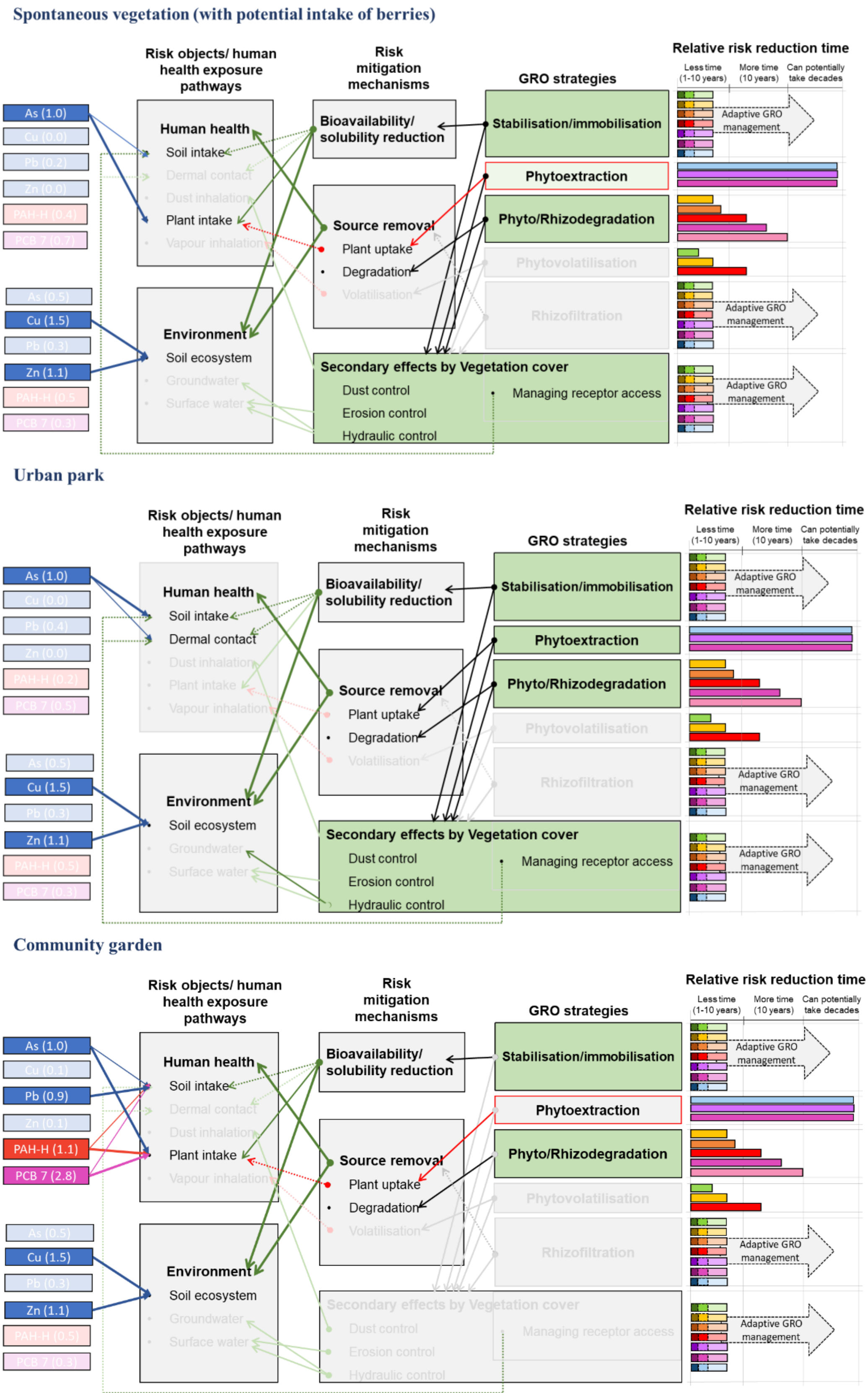


Figure 17. GRO-framework application for the top three preferred UGS. The decreased intensity of lines from the soil contaminants indicates secondary exposure pathways. See also legend in Fig. 9. From Paper IV.

4.5.3 UGS and GRO intervention overtime – Site-specific design consideration

The tool for conceptualising linkages developed as part of bio-based land use framework between GRO and UGS can be applied next (Fig. 18). Based on the UGS potential exploration, the potential UGS on site can start with the current Spontaneous vegetation. Bioswales can be added in parts next. Both of these UGS can be integrated to the next UGS to be realised, Urban Park. Urban Park use is potentially of less risk than spontaneous vegetation for users, as plants that are grown are managed, and edible plants can be avoided. Community garden can potentially be implemented over time when the concentrations of PCB and PAH-H are decreased enough to allow for a more sensitive land use. To achieve this, methods for stimulation of rhizo- and phytodegradation of PCB and PAH-H should be investigated further for immediate implementation. As the RQ of PCB is high (2.8) and PCB is difficult to degrade, the time required may be (potentially very) long but should continue until the more sensitive land use is safe. An alternative way to manage risks for a Community Garden scenario, if concentration levels are not low enough, is to implement vertical practices (i.e. bring in clean soil and place in boxes on top of the current soil), or to implement restrictions on the type of crops that are allowed (i.e. avoid edible plants altogether or such edible plants that are likely to take up existing contaminants, instruction on wearing protection gear and careful washing of body parts and crops, so called Best Management Practice, (US EPA, 2011a)

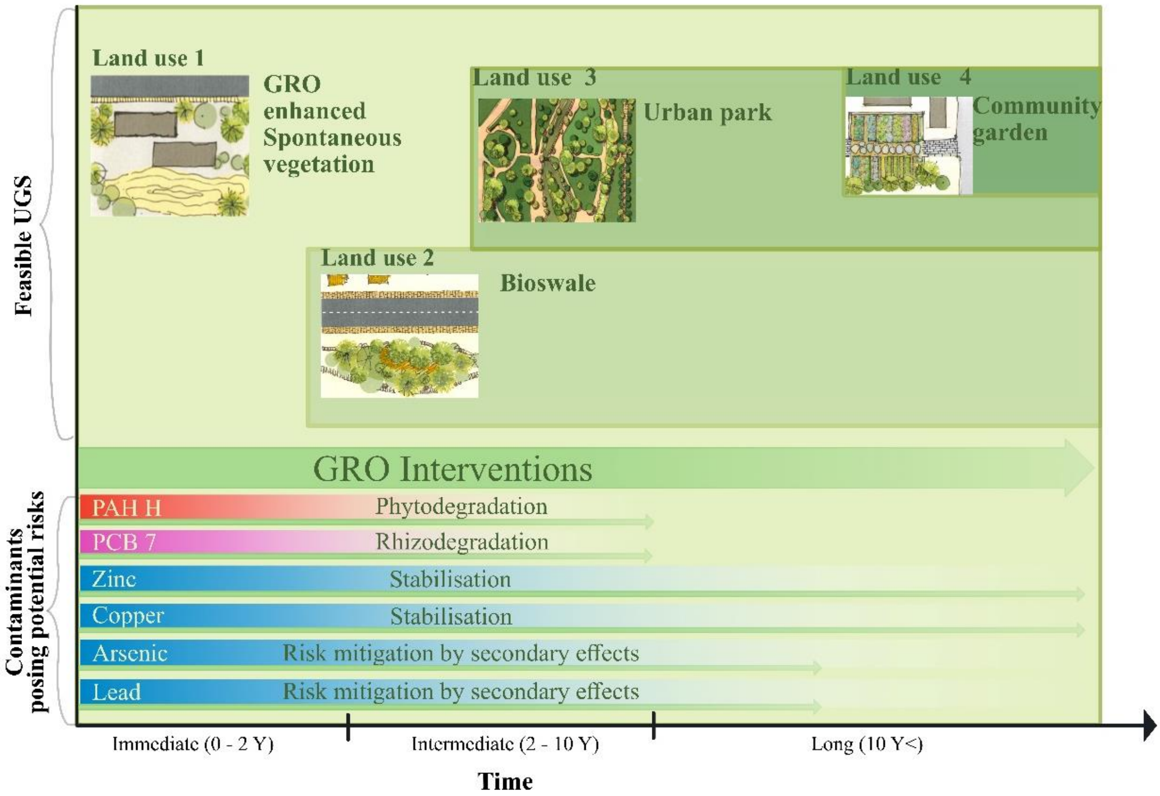


Figure 18: Possible UGS transition on the case study site. From Paper IV.

Risks to the soil ecosystem are suggested to be investigated further to better understand the current bioavailability, and if needed, implement stabilising measures with plants and/or amendments to reduce the risk. Stabilisation strategies can apart from protecting the soil ecosystem, also prevent uptake of contaminants in edible plants at the site. Special care should be taken regarding As, levels are in line with natural background levels, but may respond the opposite way than Cu and Zn (and Pb, PCB and PAH-H) to amendments in soil, and become more mobile (Beesley et al., 2013, 2014). Monitoring of the soil, as indicated in the framework, is needed to ensure that GROs are effective and to ensure safe soil conditions for a more sensitive use in the future. The suggested timeline with combinations of UGS and GRO is illustrated and visualised in Fig. 17. The illustration is a further development of the suggested graph in Section 4.1.1 to more clearly indicate i) the preferred UGS over time and ii) how risks potentially posed by the different contaminants are suggested to be managed with GROs at the study site.

To further increase the possibility to reach acceptable contaminant concentrations in the soil over time, the design of the site should also consider the contamination situation. The detailed plan indicates construction of an underground waste storage facility (see Fig. 5 and Fig. 6), which requires excavation of soil. Such facility, as well as bioswales should ideally be located where soil contamination is most complex and/or at its highest levels since these constructions require excavation and off-site handling of the excavated masses. For example, the underground waste storage facility, could potentially be located in the south-eastern part of the area, where observations exceed generic soil guideline values for PAH-H and PCB, as well as for metals, to excavate and handle this soil off site. Such placement could also potentially elongate the green axis implied in the detailed plan, suggested to connect the existing greenspaces on the other side of Karlastaden with this green area. GROs on the other hand, should be applied at parts of the site where soil contaminant concentrations are at low or medium levels. A more detailed soil investigation to map contamination can support such detailed planning and decrease the need for GROs and decrease the time needed for implementing more sensitive land uses.

4.5.4 Possibilities and challenges of the framework for exploring possibilities of combining UGS with GRO on brownfields

The relevant stakeholders associated with Polstjärnegatan were invited to participate in a workshop to discuss the suggested framework where they were presented with a demonstration of the framework on the case study site (see Section 3.4). The stakeholders considered the suggested framework to support the formulation of long-term goals for a brownfield and shows the potential of a brownfield to be brought back into beneficial use instead of sitting idle awaiting redevelopment. The suggested framework brings forward the increased market value of the brownfield over time by combining its remediation with temporal use and provides a better understanding of the opportunities of integrating UGS and GRO. The stakeholders found the framework efficient for supporting planning of larger brownfields where the site can be sectioned and developed. A summary of the stakeholders' feedback during the SWOT analysis of the suggested framework at the workshop can be found in the appendix of the Paper IV. The workshop output has been analysed to identify the possibilities and the challenges with the framework and they are presented below.

Possibilities

The workshop participants suggested several strategies for further actions and studies that can support the practical implementation of the framework and they are described below.

- *Integrating financial and economic analysis methods:* It is essential to include financial and economic calculation methods to estimate costs and benefits of the suggested frameworks which may i) help to better relate to practice of how current investment plans are made, and ii) show the generation of benefits from the site over time in monetary terms.
- *Investigating the benefits on a city scale:* To better understand the scope, it would be beneficial to investigate the framework on a larger scale, e.g city scale. Examining all the underused in the municipality and their potential to provide UGS benefits would provide a clearer extent of the framework.
- *Development of tools:* Several practical tools and methods were identified that could facilitate the framework even further such as (i) estimating time requirements of GROs, and (ii) selecting relevant plants and amendments for potential GROs and specific contaminants in a Swedish context (e.g. climate).
- *Relating the framework to local sustainability goals:* The framework relates well to EU strategies regarding CE, but these strategies often have little local impact unless they are legally binding. Relating the framework to and clarifying how it contributes to local sustainability goals or other relevant strategies will increase its relevance and accessibility.
- *Municipal reorganisation*: The upcoming large reorganisation of the municipality has been identified as a more specific opportunity for implementing the framework in the City of Gothenburg. The new organisation is intended to get experts from different sectors to work together in different phases of development and thus facilitate better collaboration. The long-term strategic planning carried out at the municipal level is also in line with the long-term planning suggested by the framework.
- *Facilitating knowledge building and sharing:* International (and national) reference projects should be compiled and be made more known using various dissemination channels. Examples of similar concepts and their implementation such as in Germany and the Netherlands (Bergman, 2019; Latz et al., 2016) may inspire the local implementation initiatives and start local small-scale GRO applications as prototypes that can demonstrate and make the benefits more visible.

Challenges

The workshop participants agreed that despite its strength, the suggested framework identified several challenges which need to be dealt with for the framework to be used in practice and they are detailed below.

- *Economy and finance:* The main identified challenge with the suggested framework is its lack of compatibility with the present economic and financing strategies used for brownfield redevelopment. For municipal landowners, long-term economic planning which is required for the framework is limited or even not possible since budget expenditures are usually time limited (e.g. 1 year). Private landowners tend to have more flexible financing strategies, but these strategies are difficult to motivate with long-term and non-monetary benefits such as ecosystem services.
- *Politicians and the political system:* Workshop participants were sceptical about how the framework would be received by the politicians. They commented that some politicians consider the concept of ecosystem services to be 'fuzzy' i.e, that the benefits of combining UGS and GRO are not clear or are not perceived as real (financial) benefits. Furthermore, repurposing brownfields with UGS and GRO is a long-term process which may take a decade and within that time, the government may change as well as the political visions and budget priorities. This challenge is a threat, but it can also present an opportunity if the political vision favouring implementation of the framework does not change over time. For example, there is today a municipal intention to increase the share of greenspaces and green infrastructure in the city, although there are no legal requirements to demand this on private developments.
- *Preference for 'business as usual':* There is today a low level of knowledge about GROs among landowners and a strong preference to do remediation "as usual", which is perceived as a safe and quick practice. There is also a practice today not to carry out early detailed soil investigations on future green spaces, a practice which would need to change. Such practices in place may resist the changes required for the framework implementation.

5 DISCUSSION

This chapter discusses the result from a more localised research context and a more general context to capture a broader perspective. This chapter is expected to undergo some transformation, some work left to be done.

5.1 Lessons learned from the results

This research presents several tools and methods developed to support a circular use of both land in soil in brownfield regeneration as UGS using GRO. Targeted users of the tools and methods are primarily practitioners in the field of urban planning and remediation, and potentially policy makers, for better understanding the challenges of remediating brownfields with GRO and transforming the contaminated sites into greenspaces. Needs for better integration of soil contamination issues and accommodating GRO as part of nature-based solutions (NBS) for brownfield remediation in urban land use planning and design are similarly identified by Song et al. (2019) and Norrman et al. (2016) and this study responses to such needs. Song et al. (2019) also states how GROs for brownfield remediation can be effective if combined with landscape architecture. However, to understand the GRO potential, analysis of several site-specific elements, such as bioavailability of contaminants (Kennen & Kirkwood, 2015), climate conditions, site topography (Andersson-Sköld et al., 2014) and soil quality aspects other than contaminant total concentrations, need to be assessed for an effective UGS and GRO integration. The need for strong and reliable engineering approaches for designing NBS is also pointed out by Fernandes & Guiomar (2018). To avoid fragmented governance and implementation, holistic and participatory planning approaches needs to combine NBS realisation with Green Infrastructure and Ecosystem Based Adaptation as “all three approaches aim at delivering social, environmental and economic benefits simultaneously” (Dorst et al., 2019, p. 6). Lessons learned from the case study application of the tools and methods and the knowledge gap identified are discussed below.

5.1.1 Insights from the case study application

The framework application at the case study site, Polstjärnegatan in Gothenburg, shows the potential of the developed tools and methods. The bio-based land use matrix applied to the case helps to filter out UGS that are preferable considering the basic conditions of the study site. The potential for future land uses on brownfields can be attributed to many site-specific conditions (Kim et al., 2018; U.S. EPA, 2011) and the bio-based land use matrix consists of a limited set of conditions. Thus, even with just elementary insights on a brownfield’s contextual properties, the list of potential greenspaces can be shortened even further. Applying the bio-based land use matrix can also help to support the presently planned future land use at Polstjärnegatan. The site is expected to be developed aspark area specifically designed to help with the surface water runoff (Göteborg stad, 2017)and both ‘urban park’ and ‘bioswales’ are filtered out as appropriate future green land use on the site. Methods for stakeholder analysis helped to identify the interests on UGS among the stakeholders. The case study demonstration of the GRO framework application helped to identify relevant GRO strategies associated with potential UGS-specific risks and provided preliminary timeframes for risk reduction. The case study application also helped to identify several challenges associated with UGS transition and GRO integration. The case study site is in a rapidly developing and densifying urban district and is part of a development project, Karlastaden, that consists of eight urban blocks of mixed commercial and residential development (Göteborgs Stad, 2017, 2022). Haaland & van den Bosch (2015) states that densification processes such as infill development and consolidation can pose a threat to UGS. Even though the site is designated to be designed as a greenspace, it can be considered as part of a larger urban densification project. With the speed of urbanisation in the area, the concern of the local stakeholders that greenspaces in the area can come under more pressure to be repurposed for more economically beneficial (e.g. housing or commercial) land use. Such rapid transition at the site can also pose challenges to remediate the site with GRO as it may require time to achieve safety targets. On a more positive note, the respondents in the questionnaire survey conducted as part of this study showed high awareness of the green benefits associated with UGS, even among non-professionals. The respondents also emphasised the importance of UGS by reasoning about how stakeholders across all domains potentially benefit from them. The challenges identified for UGS realisation by the respondents as well as the resources they bring to tackle the challenges can help to support UGS realisation and maintenance in cities.

The final framework that combines all the tools and methods was not only applied on the case study, but it was also tested with the relevant stakeholders in a workshop. The suggested framework builds on several years of research done to support the UGS and GRO integration, but the workshop helped to identify many more practical opportunities and challenges for further improvement (see Section 4.5.4). The stakeholders identified the financial aspects (e.g. estimation of costs and benefits over time, monetisation of ecosystem services, etc.) as the main challenge for practical implementation of the framework and suggested several strategies (e.g. methods for monetising the benefits) to tackle them. Implementing the proposed methods on more brownfields would enable practitioners to map the awareness and acceptance of different greenspaces and GROs by the public at large. If the municipality or local government in question has appropriate practice in place, or has enough autonomy and interest in UGS development, then the methods developed in this study can facilitate their needs.

5.1.2 Addressing the knowledge gap

There is a lack of knowledge regarding GRO amongst stakeholders. Many other studies regarding development of decision support tools for brownfield redevelopment and GRO application have also similarly identified knowledge gap(Bert et al., 2014; Cundy et al., 2015; Cundy et al., 2015, 2016; Gerhardt et al., 2017; Onwubuya et al., 2009). Consequently, contamination risk communication in itself would benefit from a clear, transparent framework, in line with existing regulations, to use in the early stages of planning for brownfield redevelopment (Cundy et al., 2016; Onwubuya et al., 2009). The GRO framework can be considered as a first step in an attempt to bridge the knowledge gap as a risk communication tool. The other developed tools and methods along with GRO framework helps to develop holistic reuse of brownfields so the target users can potentially also be architects, planners, land developers, or landscapers. Such users are not necessarily trained in GRO and risk assessment, so the GRO framework targets to educate them on the connections between risk mitigation mechanisms, risk objects, and GRO strategies.

Urban agriculture (UA) practices as UGS are more sensitive to the potential contamination of brownfields than others (US EPA, 2011b) since the consumption of fresh produce grown on contaminated soil can be an important exposure pathway for the urban population (Säumel et al., 2012). These concerns have led many countries to follow strict regulations for gardening in urban areas, considering the use as sensitive to contamination exposure as residential use (US EPA, 2011b). But there are many different types of UA practices with varying degrees of user involvement and management. Although there are some studies published on human health risks associated with UA (Entwistle et al., 2019; Margenat et al., 2019; Sharma, Cheng, & Grewal, 2015; Weber, Mawodza, Sarkar, & Menon, 2019), there exist neither a definitive model by city authorities that refers to different UA practices nor studies on UA scenarios that would help modify the exposure parameters to facilitate creating of such models. There is room for further development on risk management on contaminated sites, especially regarding UA practices that would benefit from more insights on the risk associated with such land uses.

Another well-established deficit is the measures regarding planning to maximise ecosystem service. Although awareness of green benefits has been increased, Kabisch (2015) states that the level is still low across different stakeholders and there are very few existing informal strategies that explicitly identify such ecosystem services. In the workshop, the stakeholders also showed awareness about the benefits but pointed out that it will be difficult to implement developed tools and methods without proper measures to estimate the economic benefits. Ecosystem Services Valuation Database (ESVD, https://www.esvd.net/) has long been established to produce estimates on values based on the TEEB database (van der Ploeg et al., 2010) but the database lacks indicators for urban areas (only 4 out of 1310) to support valuation of ecosystem services provided by UGS. There are examples of monetising such ecosystem services provided by UGS such as hedonistic valuation of ES provided by the New York central park by approximating it to the estimated real estate value of the covered area (Sutton & Anderson, 2016) and contingent valuation for urban forests in Puerto Rico by willingness to pay (WTP) for their preservation. The suggested framework combines GRO implementation with greenspaces for regenerating brownfields and such combined ecosystem-based adaptations helps to capture the provided benefits more efficiently (Dorst et al., 2019). Valuation of soil ecosystem services (Jónsson & Davídsdóttir, 2016) can be potentially appropriated to capture the benefits GROs can provide by restoring soil health. The Brownfield opportunity matrix (BOM) (HOMBRE, 2014b) is built around similar principles as the suggested framework but focuses on remediation strategies. The BOM matrix helps to explore the benefits that can result from these remediation technologies (Bardos et al., 2017), and can thus support the suggested framework in communicating these benefits to stakeholders. These strategies of valuation can be used to generate estimates on benefits that can be achieved by combining UGS and GRO for brownfield regeneration.

5.2 Greening the browns – an iterative process

The research presented in this thesis has been an iterative and explorative process. The work starts off with a surface level exploration of how CE values can be incorporated in the renewal process of brownfields as UGS (Chapter 4, Paper I). The tools developed as part of the bio-based land use framework requires minimal initial information. The research then forks, and Chapter 5 and Chapter 6 summarises the results of simultaneous but separate deep dives that took place into GRO strategies and stakeholder analysis. The outputs of these two investigations, the GRO framework (Paper II) and the working process for stakeholder analysis (Paper III) are two sets of standalone tools and methods that facilitates brownfield regeneration from two different perspectives, remediation and stakeholder integration in decision making. The final framework presented in Chapter 7 then connects all the previous works under one umbrella to propose a way forward for 'greening the browns'.

There was an initial plan to map out how the research work will progress, but the scope has constantly been revised to address the issues brought forward as the research progressed and the developed tools and methods reflect that. The interplay between the tools and methods was an interactive process that made the outputs of the tools crisper and better. The bio-based land use framework was developed first and followed by the stakeholder analysis and GRO framework. The stakeholder analysis methods when used after the bio-based land use matrix can act as an added layer of filtration of potential UGS uses. This in turn, provides feedback to the time-intervention diagram limiting the possible UGS and making the process of forming a connection between the possible UGS a simpler process. The feedback from the GRO framework improves the first tool of the bio-based land use framework, conceptualisation of the linkages and adds information that is generically handled in GRO framework. The feedback from the stakeholder analysis and the bio-based land use matrix simultaneously helps the GRO framework. The final framework provides a platform to connect such the feedback loop for all the developed tools and methods and helps to create an overall process of brownfield regeneration as UGS with GRO.

5.3 A prediction on the relevance - Comparing the findings with contemporary concepts, research, and practices

Concerns regarding brownfields and their management started to become part of the mainstream policy derivative at the European Union at the turn of the 21st century. The EU soil thematic strategy (COM(2006) 232 Final) proposed a framework to protect soil across Europe from degradation which unfortunately was withdrawn in 2014 after a long pending period. Among highlighting the wider sets of benefits and importance of soil, EU soil strategy was the first to propose an EU wide 'polluters pay' principle and creating an inventory of the contaminated sites by the member states. NICOLE (Network for Industrially Contaminated Land in Europe, established in 1996) outlined the points in the EU soil strategy directly and indirectly addressing contaminated land and their management, and provided their opinions and concerns regarding the policy outlook (NICOLE, 2007). The 7th Framework Programme (FP7), the EU's research funding programme between 2007 and 2013, had pioneered in-depth research on brownfields, such as HOMBRE (Holistic `1management of brownfield regeneration) and TIMBRE (Tailored improvement of brownfield regeneration in Europe).

Hombre proposed a 'Zero brownfields framework' where land use and management shifts in cycles and early signs of abandonment are monitored to anticipate and prevent formation of brownfields (HOMBRE, 2014, p. 8, Fig. 1). This circular thinking in brownfield management was developed around the same time when the Circular Economy was just taking shape from theory to be a practical model for sustainable transition of production and consumption patterns. The Ellen McArthur Foundation report, 'Towards a Circular Economy', that would come to revolutionise sustainability discourse, just came out a year earlier (Ellen MacArthur Foundation, 2013). The European Union was swift with their transition from waste hierarchy (COM(2011) 571) to Circular Economy and put together the action plan in 2015 (COM(2015) 614 Final) to facilitate Circular processes. 'Closing the loop' was focused mostly on the industrial growth and rebranding the industrial waste to growth management and producing more jobs. The same year, a more impactful set of strategies were put forward by the UN. The 2030 Agenda for Sustainable development proposed the 17 sustainable development goals (United Nations, 2020) with multitude of indicators to monitor the achievement of the set targets. The goals became, and still is, the prominent discourse to discuss sustainability. In recent times, circular thinking is not being limited to waste management and product or process management but is being transpired to tackle different issues. As part of the European Green Deal that came out in 2020, the new circular economy action plan (European Commission, 2020) is more encompassing in the topics it covers, from diversification of individual sectors (from IT to food) to providing a more holistic outlook for cities and regions as well as nontoxic environment. Circular thinking more clearly is being incorporated in the new EU soil strategy (COM(2021) 699). The strategy elaborates on the use of soil, including the excavated soil, as a circular resource, and outlines steps to ensure circular use of both soil and land.

At the time of starting this thesis research in 2018 August, and the only policy directive which could be used to cover (loosely) circular thinking when it comes to soil and land was the No Net Land Take by 2050 (European Commission, 2016). But since then, the Circular Economy integration to discuss issues regarding soil and land, specifically contaminated ones, have been constantly growing. The initial part of the research depended on a very small array of research (mainly Breure et al (2018)) to support the discussion of soil and land from a CE perspective., Now policy directives such as the EU soil deal (as part of the EU soil strategy) are ready at hand to strengthen the reasoning for retrofitting brownfields and ensuring the sustainable use of the soil resources. This research goes on to connect these two aspects and takes it a step further by presenting a way to combine realising land use on brownfields with sustainable gentle remediation to ensure both circular use of land and soil as resource. The progress in policy development so far, seem to have supported the circular thinking presented in this thesis when it comes to soil and land reuse. Hopefully future policy briefs would make the same connections and would use circular thinking to promote GRO techniques for sustainable remediation alongside UGS for brownfield regeneration. The thesis provides tools and methods for facilitating circular use of land as well as soil, and this exploration could potentiallyplay a role in supporting more research regarding similar discourse which would in return, would help the transition of policy development and potentially practice, in the same course.

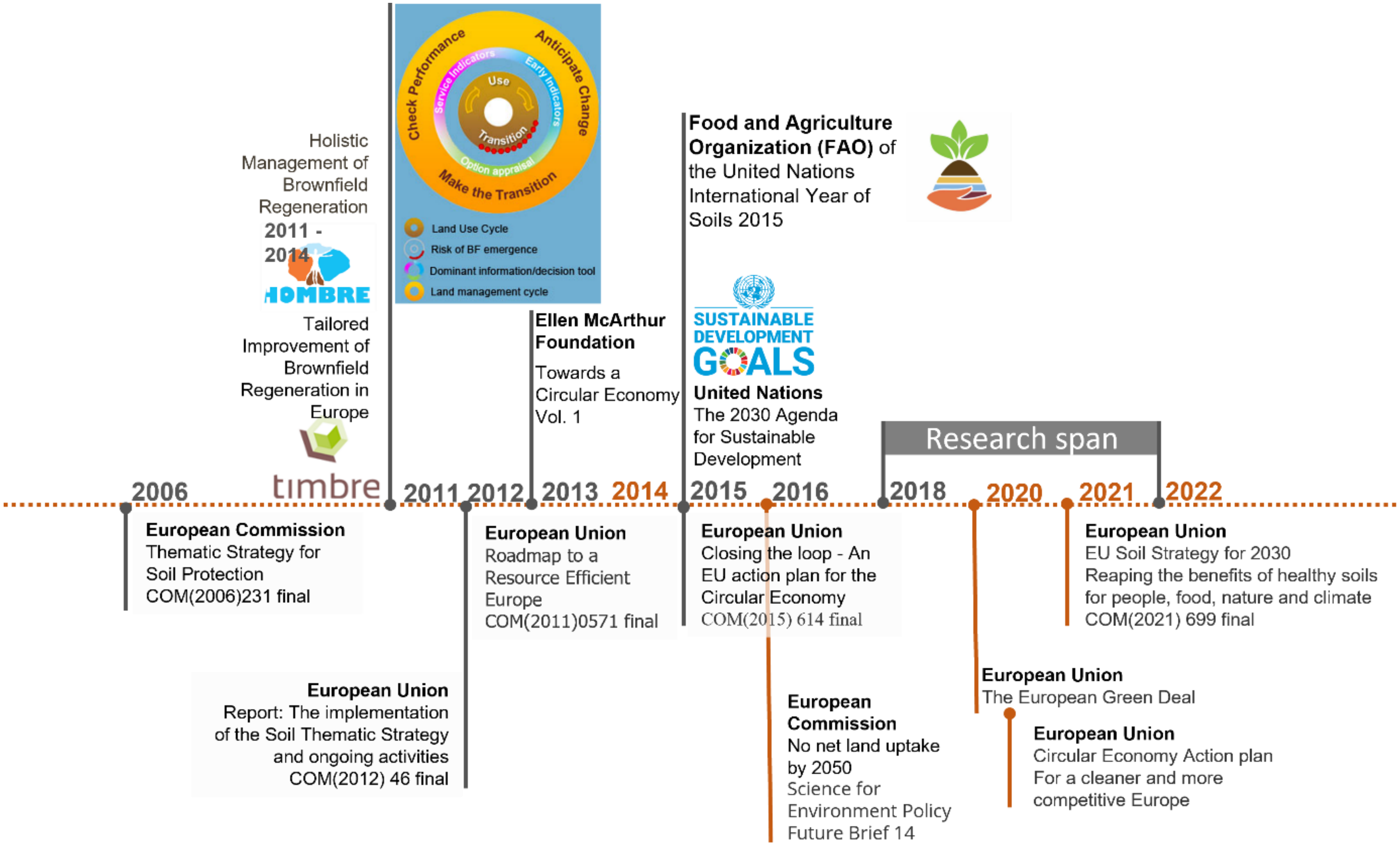


Figure 19: Timeline of the policy discourse and research development regarding Circular Economy (CE), and brownfields alongside the research span

5.4 Addressing the context – The implications of doing case-study research

This thesis presents case study research. Apart from the meta-analysis done to identify the greenspaces and the associated ecosystem services for brownfields in general, the rest of the input data is contextual of the site at the Poltjärnegatan in Gothenburg, SE. As case study research, this research consists of the characteristics common in such and some of the implications are discussed in this section.

As Flyvbjerg (2006) states, there are two main benefits of doing case study research. The first one is that it helps in developing a nuanced view of the reality. For this study, this turned out to be particularly true. There were certain general assumptions made throughout the research span that turned out not to be aligned with the reality. The first realisation of the reality was when the first reference group presentation was made in February 2019. No Net Land Take by 2050 (European Commission, 2016) was part of the presentation, as explained in the previous section, to support the circular land use argument. As the reference group for this study consists of members of different departments of the city council, the assumption was that there would be awareness about such an EU wide policy which turned out to be wrong. This in turn, begs the question of how well the EU non-legally binding goals and policies are dispersed across the member states. Looking at Sweden's milestone targets (link), it is not surprising to see that 'No net land take by 2050' is not present in the list though Sweden specific targets are set to meet legally binding EU directives such as (EU) 2016/2284 is mentioned to set. Sweden may not be alone in not having clearly set goals to meet the no net land take targets. Observing European Environmental Agency's (EEA) metrics on land take across Europe (link), although the general trend of land take is decreasing since 2000, most member states are far below the level necessary to reach the no net land take target.

The last workshop with the stakeholders (including Gothenburg city representatives) as part of the investigation of the working process applicability (Paper IV) taken place in June 2022 (see Chapter 7) also resulted in a surprising outcome. The work process to accommodate GRO in retrofitting brownfields as UGS depends on the flexibility to plan across a long timeline. The assumption was that the government possesses the ability to provide for such flexible planning processes while the private sector might be too goal oriented to suit the purpose. In contrast, the workshop results, as presented in section 7.2, shows how it is the government that might be limited (e.g due to the fixed budget window) but the industry might be more interested in supporting such innovative process while also possessing more control over their own finance. Unfortunately, no industry representative related to land development was present at the workshop to verify such perspective. Their absence can be blamed on the short-sightedness of not inviting them in the first place. In defence, the assumption made seems to be widely prevalent. While presenting the basics of the process at the World Soil Congress held in Glasgow, UK (July 31st – August 5, 2022), the panel host raised the same concern that the target audience of the research must be the government as the industry might find this hard to accommodate. This finding provides a new lens to see the reality and implications of such in practice and further research is discussed in Chapter 9.

The second benefit of case study exploration identified by Flyvbjerg (2006) is that it's necessary for the researchers' own learning processes to facilitate the development of the necessary skills. Polstjärnegatan is fundamental in this research and helped both actively and passively at the development and formulation of most of the research output and the skill needed to produce them. This was evident in the stakeholder analysis done in Chapter 6 (Paper 3). The study was explorative, and the case provided the context necessary to understand the stakeholder dynamics. There was some reference researches used to formulate the base of the stakeholder analysis but the questionnaire data helped to rethink, learn, and then analyse to formulate results that more closely represents the context as well as what was aimed to achieve in the study, ‘was to support effective and realistic realisations of UGS in the context of urban brownfields’ regeneration and stakeholder engagement’.

6 CONCLUSION

The final chapter of the thesis presents a summary of the main conclusions of the thesis. It further outlines possible implications for practice and for relevant future research.

The main contributions from this study are:

- Urban brownfields provide a unique opportunity to incorporate Circular Economy (CE) values in cities and can be identified as valuable land wastes of a linear land use system. In the circular land use system, brownfields are not considered as a waste but as a valuable resource in the transition from abandonment to redevelopment and reuse. Recent CE policies and action plans acknowledge soil as a finite resource and set out clear directives for circular management of both soil and land.
- Brownfields provide opportunities to integrate urban greenspaces (UGS) which are fundamental for urban wellbeing by providing the citizens with numerous ecosystem services (ES). Greenspaces can be combined with GRO which include plant-based remediation strategies for managing the risks posed by the contaminants present at brownfields.
- The study presents tools and methods namely: a bio-based land use framework for identification of different UGS on brownfields (section 4.1), the GRO framework for identification of potential GRO strategies (Section 4.2), and a working process for stakeholder analysis for understanding stakeholder preferences, resources and challenges (Section 4.3). Finally, a framework (Section 4.4) integrating the aforementioned tools and methods is suggested for exploring the potential of combining UGS with GRO on brownfields for managing risks and provision of urban green spaces that in turn can provide ecosystem services to urban inhabitants.
- The case study demonstration of the final framework (Section 4.5) filters out the possible UGS on the site and the associated GRO strategies and conceptualises a plan over time, tailored for the site for realisation of UGS enhanced with GRO strategies. The suggested framework facilitated a multifaceted investigation of opportunities for combining UGS and GRO at the Polstjärnegatan site. The four preferred UGS – spontaneous vegetation, bioswale, urban park, community garden – were placed in a timeline. This timeline indicates the progression over time when a certain UGS fits best given changes in risks to human health and the environment. Community garden may be established in the end whereas spontaneous vegetation may be enhanced with amendments and intercropping in the early stage of brownfield transition to long-term land use as UGS. Design consideration to develop the UGS on sites have also been provided based on the output of the tools and method application.
- The application of the framework is challenged in a workshop with the relevant stakeholders which indicates that there is a need for more exact estimates of time required for risk reduction with GRO as it is essential for the cost estimates required for site development.

6.1 Implications for practice

This thesis presents tools and methods that are intended for practical application. Conclusions that contain implications for practice include:

- The research work in this thesis has led to a better understanding of the benefits and the potential of UGS on brownfields. The tools developed as part of the bio-based land use framework offer different ways of assessing the bio-based land use potential. This output specifically intends to integrate CE values to the urban land development and help to strengthen sustainable redevelopment of brownfields. The bio-based land use framework is designed to be used at the initial stage of an urban land redevelopment process but needs to be supported with flexible policies promoting nature-based solutions.
- The GRO framework was developed to facilitate better understanding and communication of contamination risk, different risk mitigating mechanisms associated with, and required timeframes of various GRO. By doing so, it aims to support a much needed early communication between remediation contractors, decision-makers, regulatory bodies, and other stakeholders related to contaminated sites for acceptance of such strategies. Long-term monitoring is essential for evaluation of the effectiveness of GRO for regulatory purpose (i.e. ensuring that an acceptable risk level is maintained) and ensuring that the soil quality is improving by monitoring important soil parameters linked to key soil functions or ecosystem services. Adaptive maintenance and monitoring and the inclusion of iterative decision points in GRO application would help to reduce uncertainty regarding remediation effectiveness and response.
- The methods developed as part of the working process for stakeholder analysis aim to facilitate citizen participation on developing UGS in cities. Citizen engagement is essential in UGS to reflect the need of the public. As the results from the questionnaire survey in Paper III suggests, local stakeholders are also apt at identifying the challenges present at a site and can contribute with valuable resources to mitigate the challenges in the UGS development. A positive outlook of stakeholder engagement on the case study is that the stakeholders showed high awareness of the green benefits, even among non-professionals. Such local awareness can be exploited by practitioners and the municipality to push forward for more green solutions and greenspace integration.
- The potential of the final framework for exploring UGS with GRO to lead to practical implementation was discussed with selected stakeholders in a workshop and the need for such an approach was verified, although several challenges were acknowledged. For practical application, a financial analysis is needed to be able to compare such approach with the existing remediation and land development practice. Monetisation of the ecosystem services provided by the UGS, and the GRO, would make it possible to also make a cost-benefit analysis to show societal benefits, which is also deemed necessary to motivate decision makers.

6.3 Implications for further research

The following areas for further research have been also identified, listed below.

- The set of tools and methods presented with the framework should be complemented with methods, tools, or databases to:
  - make predictions of time requirements, and thus cost estimates, of GROs to reach acceptable risk levels;
  - make quantitative, preferably monetary, valuations of non-market benefits such as ecosystem services associated with urban UGS and GRO to communicate benefits to decision-makers; and
  - support the selection of plant, bacteria, fungi, and soil amendments for various GROs and contaminants in a Swedish setting.

- Evaluating contamination risks in different Urban Agriculture (UA) to provide knowledge and improve data for assessing human health risks associated with different UA scenarios, and better understanding the possibilities for transforming underused urban areas into UA sites. The scope of work could potentially include:
  - collect primary behavioural data on UA practices by means of a questionnaire complemented with individual interviews,
  - perform chemical analyses of different contaminants in soil and edible crops from selected locations, and review literature data on plant uptake of these contaminants,
  - conduct human health risk assessments for intake of crops grown on urban sites, based on the collected data, and
  - modify the Swedish health-based soil guideline value model for scenarios relevant for UA using a probabilistic approach and model UA scenarios using Monte Carlo simulations to calculate potential soil guideline values.

- Exploring the potential of the bio-based land use framework at the city scale and producing GIS-based analysis of:
  - Brownfield potential to support different UGS alternatives;
  - Possibilities for combining UGS with different GRO and their potential for delivering ecosystem service over time; and
  - stakeholder preferences/expectations linked to UGS in particular locations in the city.

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