

THE ROLE OF DIGITAL TWIN ON INTEGRATED CIRCULAR STRATEGIES OF BROWNFIELD RENOVATION

Unveiling the challenges and opportunities

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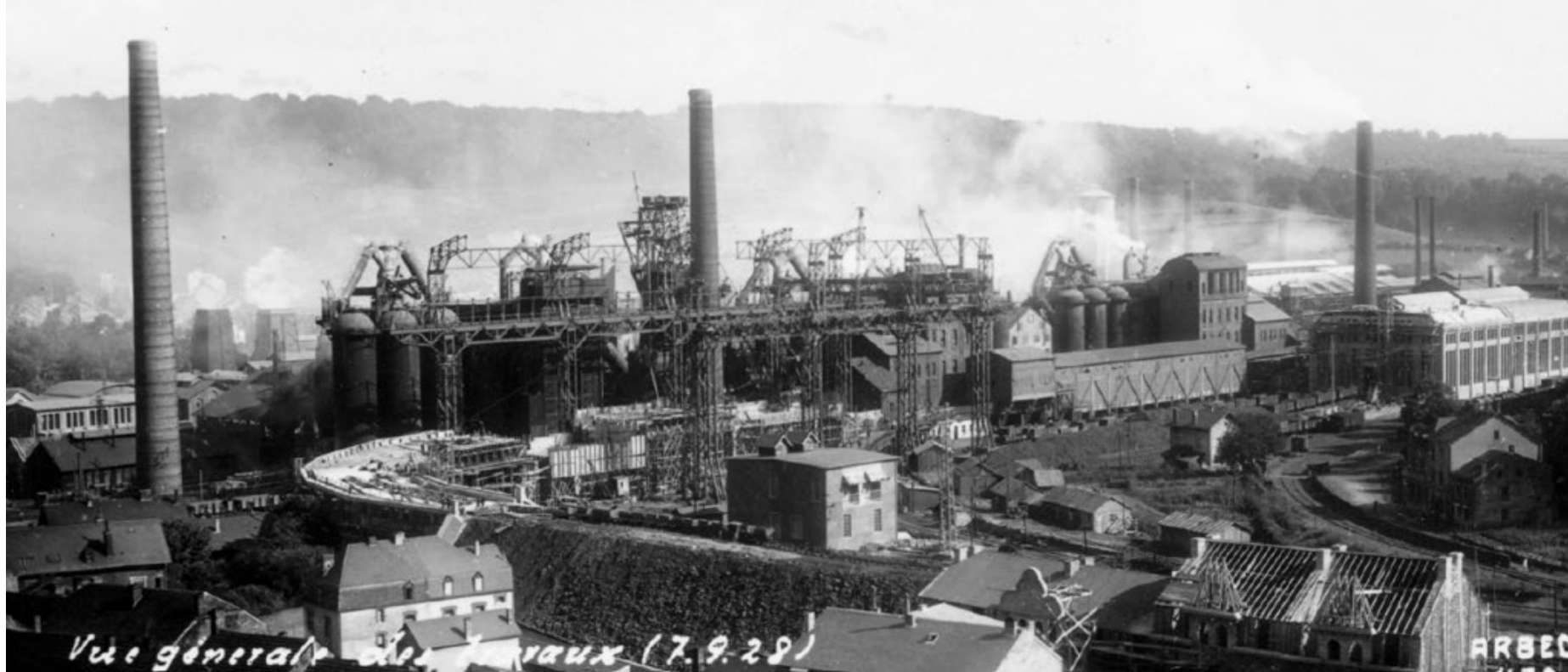
Architecture and Urban Planning
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Belgian Science for Climate Action conference 2026 on
'Achieving climate neutrality and just transition in Belgium'.



Brownfield definition and recognition (1)



View on the steel mill in 1928, that occupied the area of 'NeiSchmelz'. Source: City of Dudelange, 2017.

©Credits: <https://cipu.lu/tag/brownfield-development/>, Accessed on: 23/12/2025

... The concept of brownfield may vary from one European country to another, and in most EU countries, there is no exact definition of what it is....

Recognised as a problem in numerous European cities that require EU policy attention, resulting from structural changes such as the decline in traditional extractive manufacturing and mining industries.

Brownfields are sites that:

- Have been affected by the former uses of the site and the surrounding land.
- Are derelict or underused.
- May have real or perceived contamination problems.
- Are mainly in developed urban areas
- Require intervention to bring them back to beneficial use

Brownfield definition and recognition (2)

...Brownfields can have different forms, types, scales, levels of contamination,



INDUSTRIALIZED BROWNFIELD CONTAMINATED SITE [1]



FORMER COMMERCIALIZED USE OF BROWNFIELDS [2]



FORMER MILITARY USE OF BROWNFIELDS [3]

[1] ©Credits:

<https://theconversation.com/industrial-sites-of-old-can-be-the-cities-of-the-future-30050>,

Accessed on: 25/12/2025

[2] ©Credits:

<https://industrialenvironmental.com.au/project/brownfield-site-to-commercial-ready>,

Accessed on: 25/12/2025

[3] ©Credits: <https://le-pavillon-architectures.com/portfolio/mise-en-valeur-de-la-friche-caserne-espagne-auch-32/>

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Challenges and problem statement: Brownfields as a barrier or an opportunity? (1)

Urban Sprawl
Excessive land consumption



Aerial View Las Vegas

©Credits: <https://2-joe-fox.pixels.com/featured/aerial-view-of-las-vegas-urban-sprawl-nevada-usa-joe-fox.html>, Accessed on: 22/12/2025

Intensive Industrialized Activities



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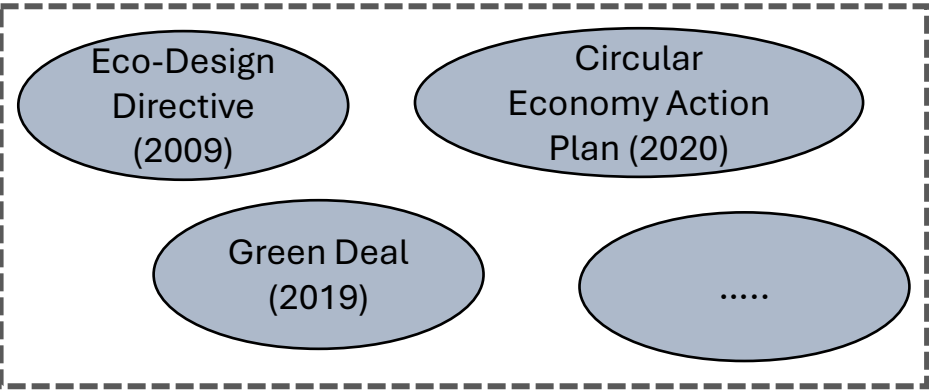
<https://community.naturephotographers.network/pub/image-critiques-join-npn>, Accessed on: 22/12/2025

Climate change pressures



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BROWNFIELD REGENERATION

Challenges and problem statement: Brownfields as a barrier or an opportunity? (2)

“Brownfields are sites that have been affected by the former human uses, derelict and underused, many of them perceived contamination problems mainly developed in urban areas requiring rehabilitation strategies for a second life”

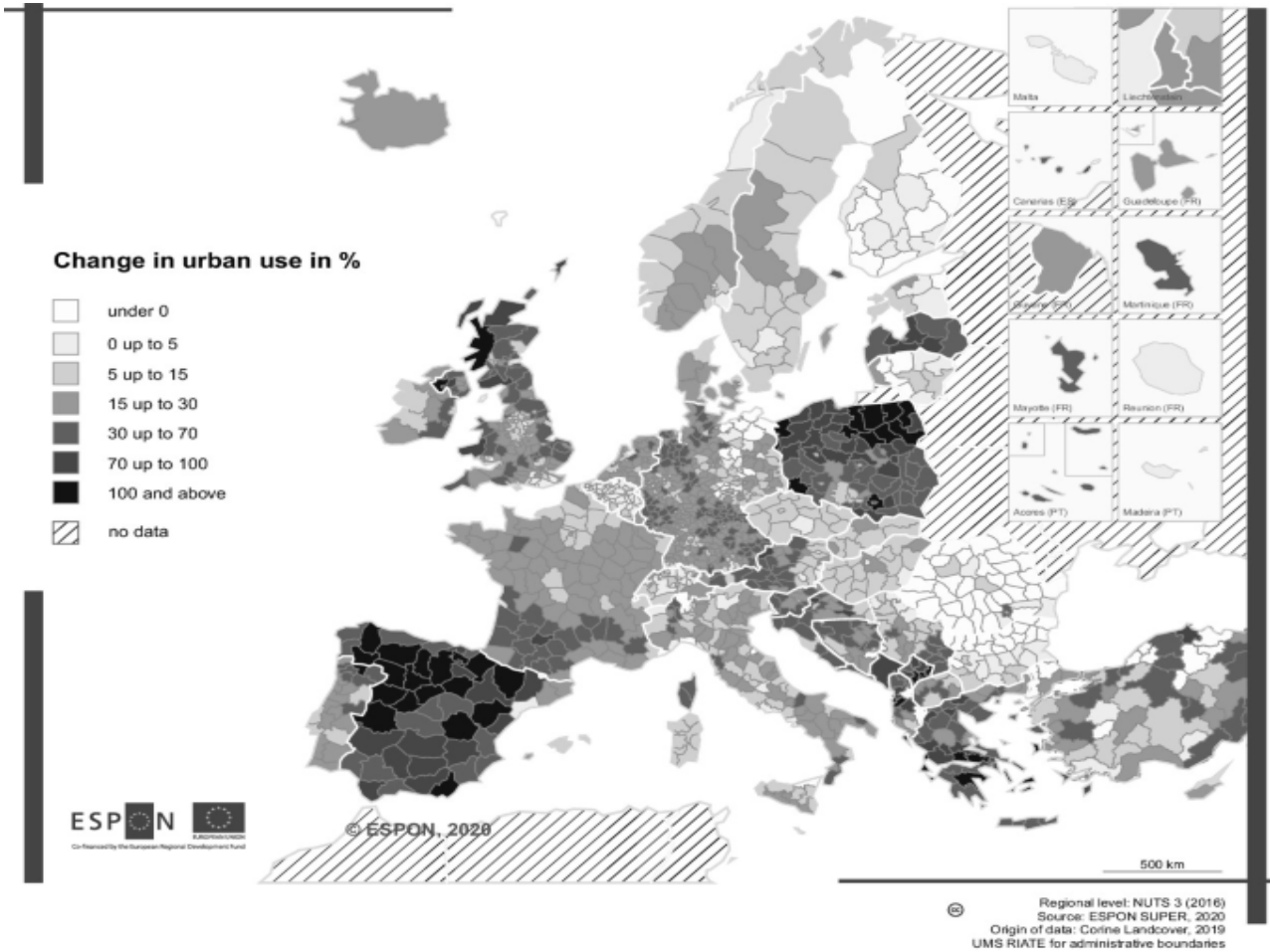


Charleroi Industrial Decline, ©Credits: <https://www.teunvoeten.com/photography/architecture-charleroi.html>,

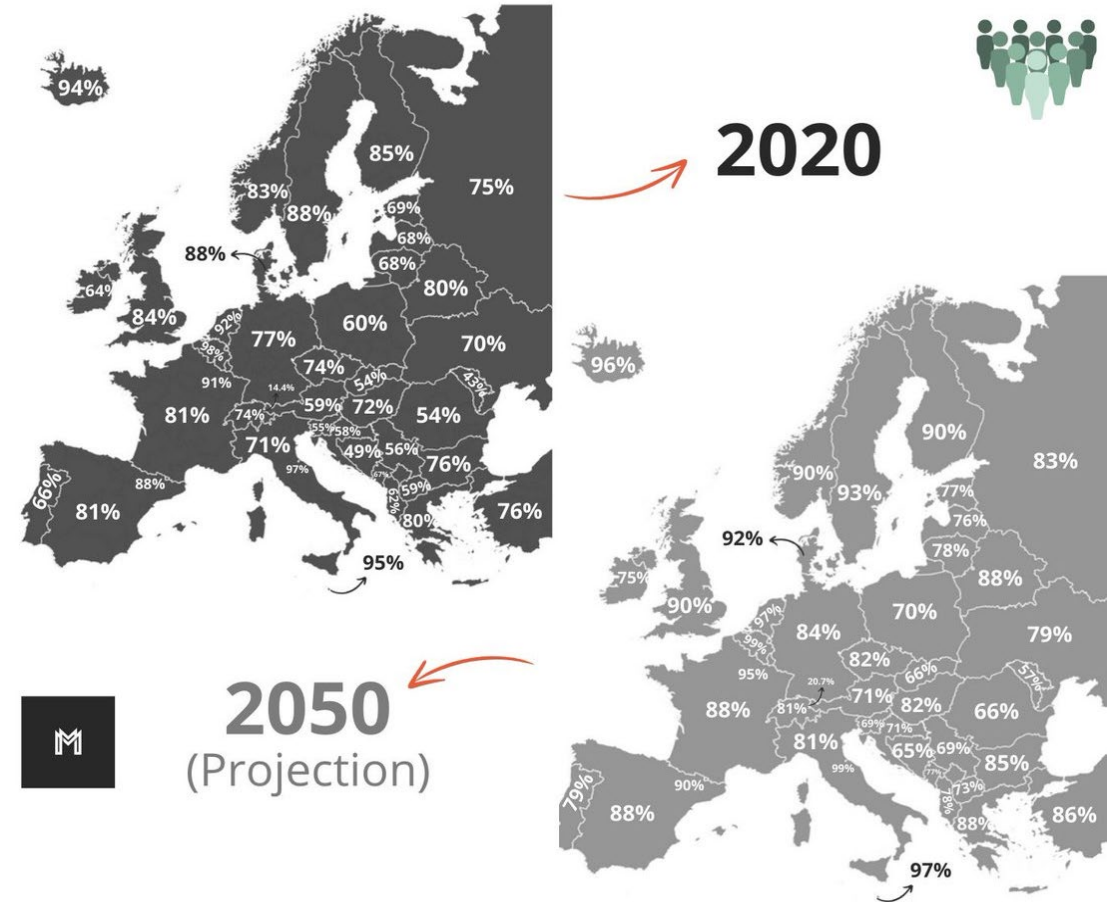
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Challenges and problem statement: Brownfields as a barrier or an opportunity? (3)

Zero Land Consumption (No Net Land Take) by 2050



Percentage of Urban Population in Europe, by country Difference between 2020 and 2050



Change in urban use (%), ©Credits: https://link.springer.com/chapter/10.1007/978-3-031-62261-8_2,
Accessed on: 22/12/2025

MAPS.INTERLUDE
Source: TheWorldbankgroup
©2024 Maps.interlude (<https://maps.interlude.wordpress.com>)

Challenges and problem statement: Brownfields as a barrier or an opportunity? (4)

1

Supporting development in the less prosperous regions

More than 20% of the European population receives financial support, including basic infrastructure, training and investments.

2

Revitalization of areas with structural difficulties

Examples: decline in industrial or other traditional activities, unemployment, etc.

3

Development of human resources

Promote active labor market policies to reduce unemployment, improve accessibility to the market, promote social inclusion, enhance employment opportunities, and promote gender equality.

EU Structural Funds are distributed to support brownfield redevelopment without necessarily considering either whether the development is sustainable, or whether the methods adopted to redevelop the project site are sustainable.

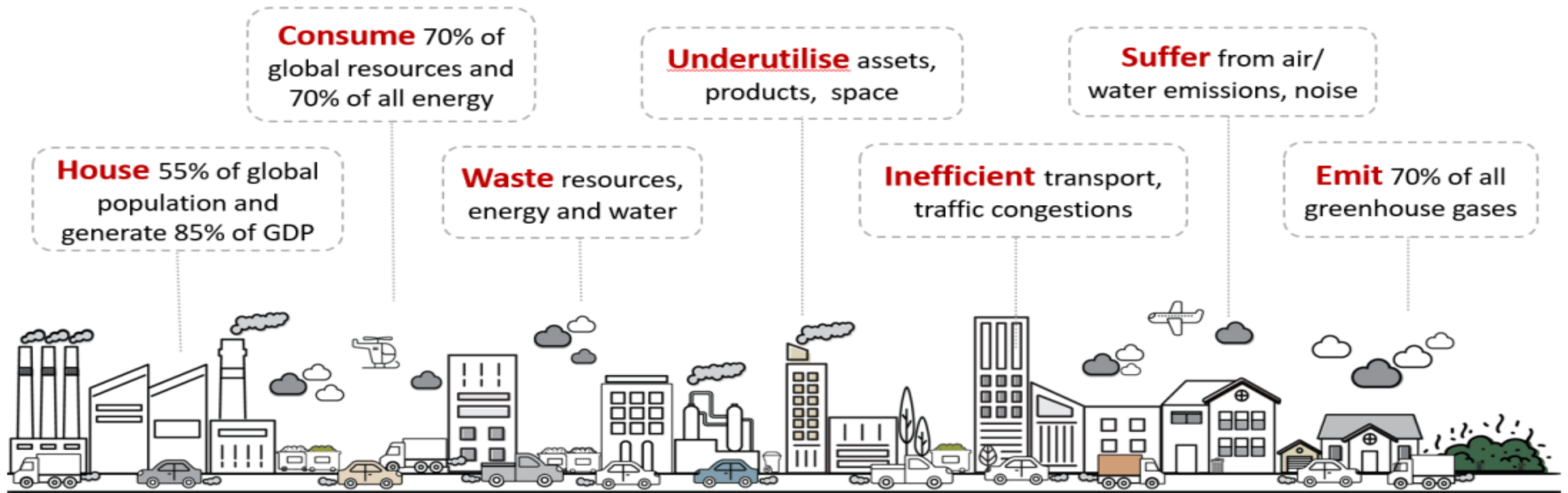
Thorton, G., Franz, M, Edwards, D.,
Pahlen, G., & Nathanail, P.

The challenge of sustainability: incentives for
brownfield regeneration in Europe
Environmental Science & Policy
Volume 10, Issue 2, April 2007

Circularity and Brownfield Redevelopment. A “key” or “buzz” word towards the transformation? (1)

“...Urban regeneration emerges as a critical challenge and opportunity for future urban development. This paradigm shift sees a reduction in new construction projects, which in turn, allocates more economic and spatial capital towards the revitalization of existing sites....”

Govindan, K., & Hasanagic, M., A systematic review on drivers, barriers, and practices towards circular economy: A supply chain perspective. International Journal of Production Research, 56(1–2), 278–311, 2018

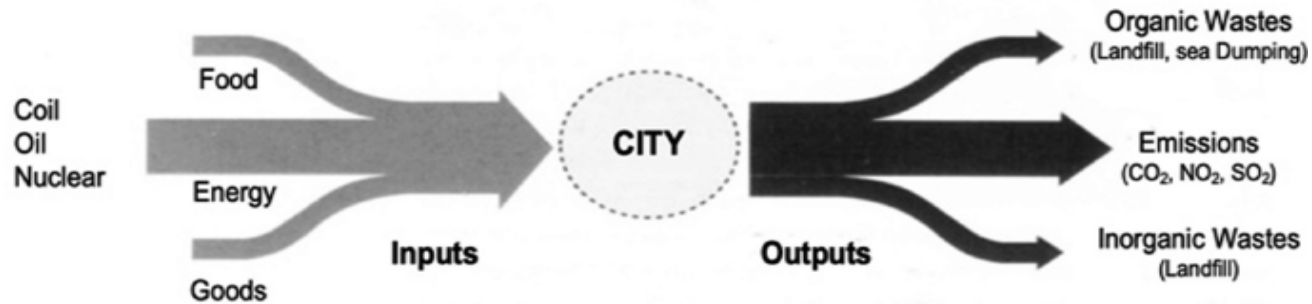


©Credits: https://www.eib.org/files/publications/thematic/circular_economy_15_steps_for_cities_en.pdf, Accessed on: 23/12/2025

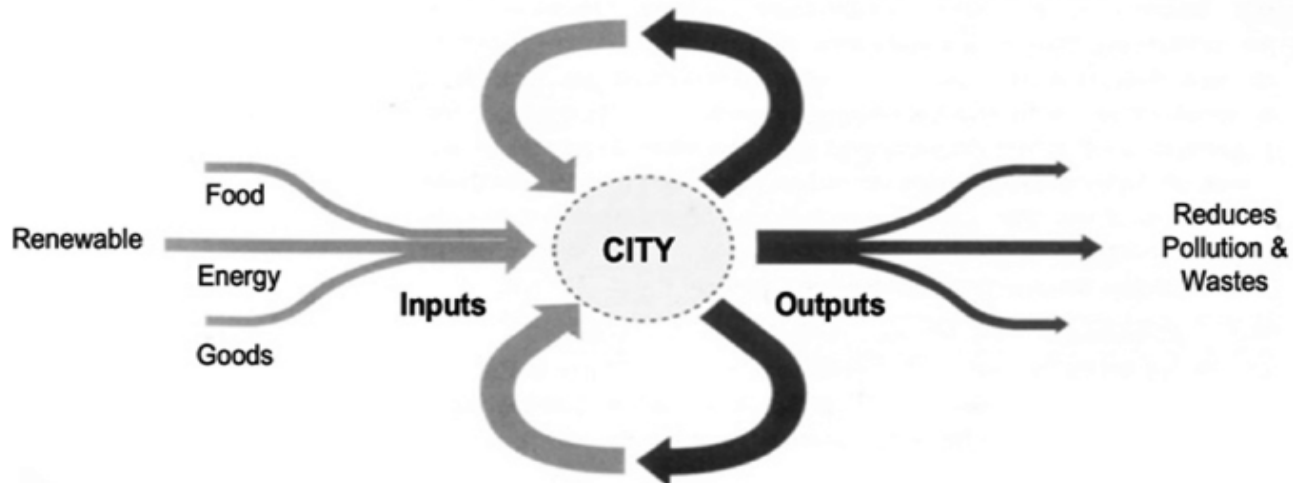
Circularity and Brownfield Redevelopment. A “key” or “buzz” word towards the transformation? (2)

Circular Urbanism

Linear metabolism cities consume and pollute at a high rate



Circular metabolism cities minimize new inputs and maximise recycling



From linear to circular metabolism of cities ©Credits: (Rogers, 1997),

https://link.springer.com/chapter/10.1007/978-3-030-41072-8_5, Accessed on: 22/12/2025

Richard Rogers, in his “Cities for a small planet” (1997), emphasizes that:

- ...Cities must be viewed as ecological systems and this assumption must provide information to our approach to designing cities and managing their use of resources...
- ...The transition from a linear metabolism to a circular metabolism, is necessary to obtain sustainable cities...
- The circular attitude must also concern land and buildings. “In cities, we cast off buildings, used land, industrial waste and millions of other damaged, used products directly into the urban environment and its wide hinterland....”

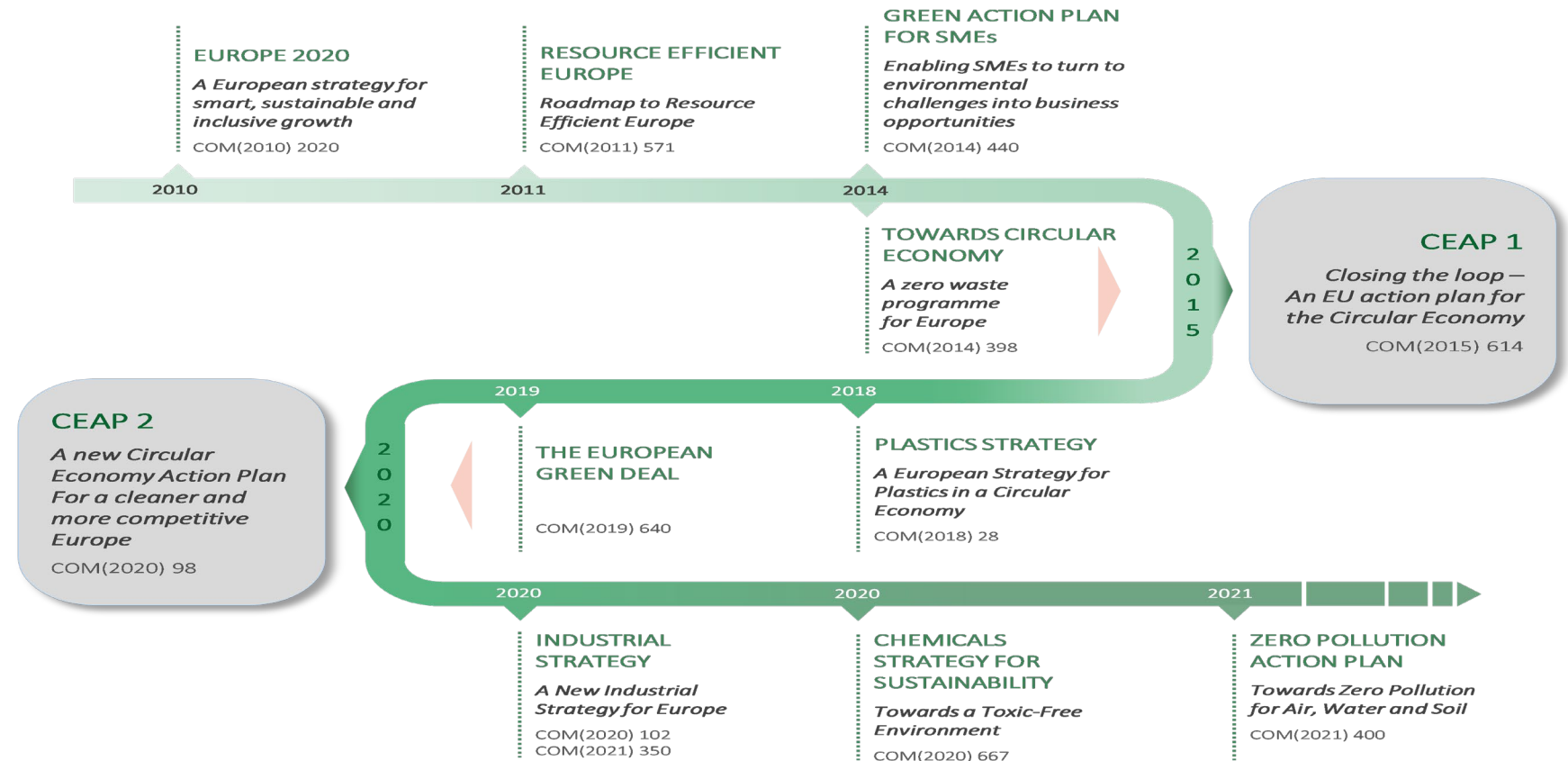
Rogers R (1997) Cities for a small planet.
In: Gumuchdjian P (ed) Faber and Faber, London

Circularity and Brownfield Redevelopment.

A “key” or “buzz” word towards the transformation? (3)

Conceptualized legal framework on circularity

The actions under the action plan accelerated Europe’s transition by helping "close the loop" of product lifecycles through greater recycling and reuse, bringing benefits for both the environment and the economy.



- 11 March 2020 ● Adoption of new circular economy plan
- December 2019 ● European Green Deal
- October 2019 ● Adoption of 10 Ecodesign implementing regulations
- December 2015 ● Adoption of first circular economy plan

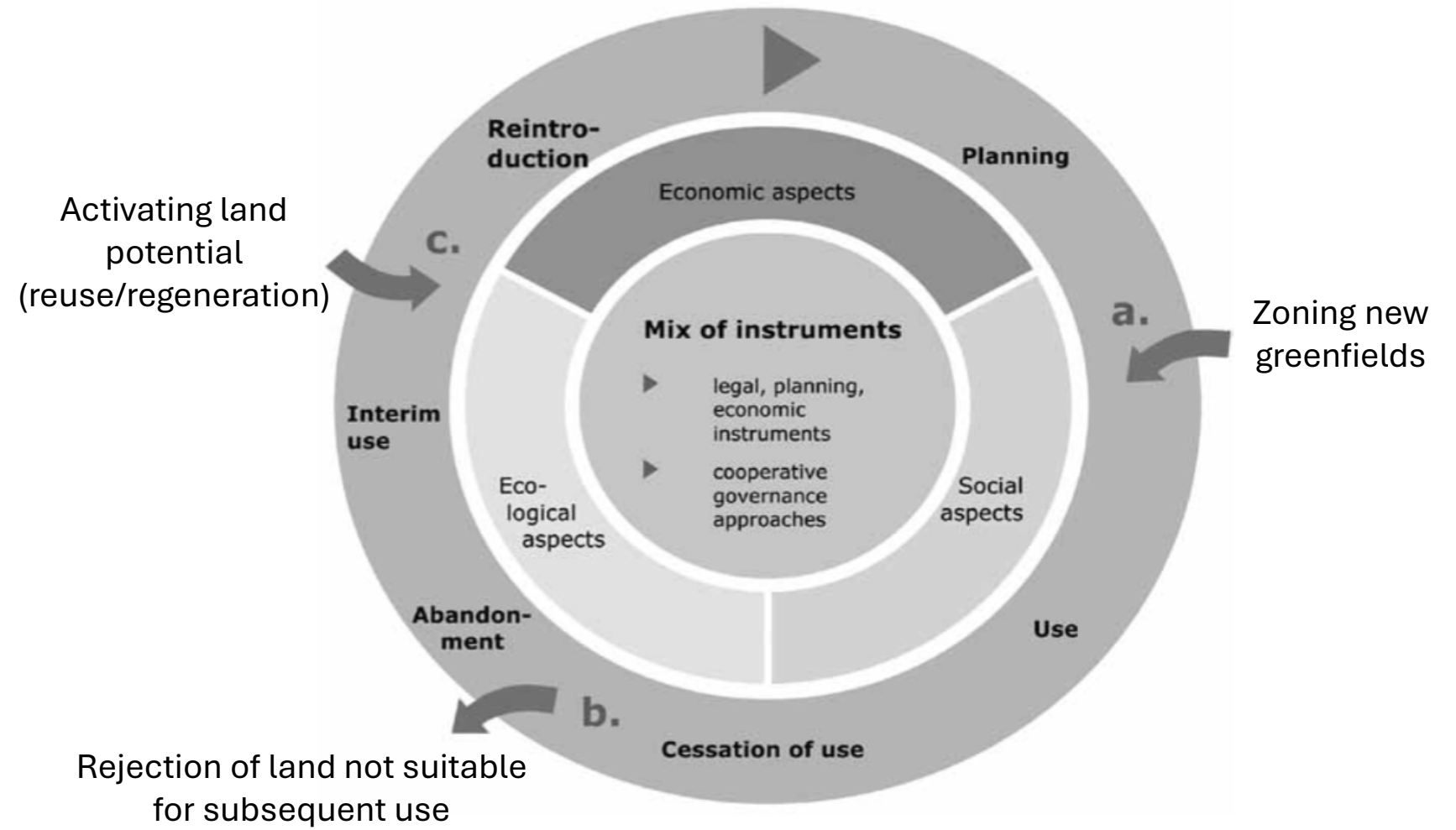
First circular economy action plan, https://environment.ec.europa.eu/strategy/circular-economy_en
 Accessed on: 23/12/2025

EU strategic framework on circular economy, Source: ECA.
 ©Credits: <https://www.eca.europa.eu/en/publications/SR-2023-17>, Accessed on: 22/12/2025

Circularity and Brownfield Redevelopment.

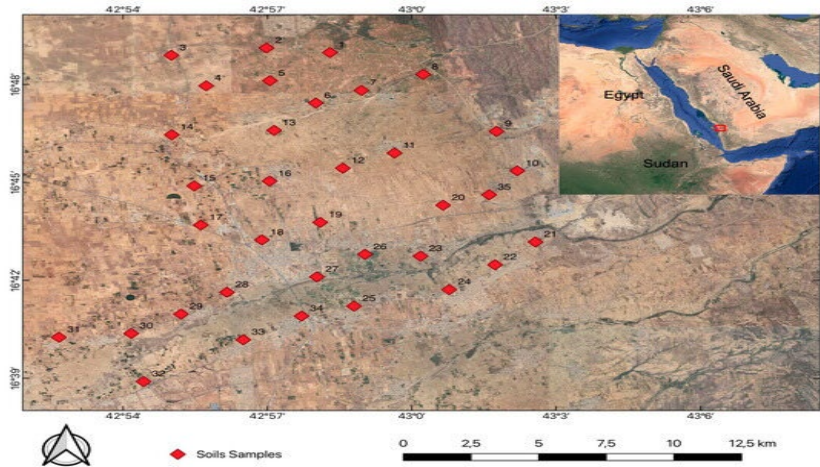
A “key” or “buzz” word towards the transformation? (4)

Circularity and Brownfield Regeneration

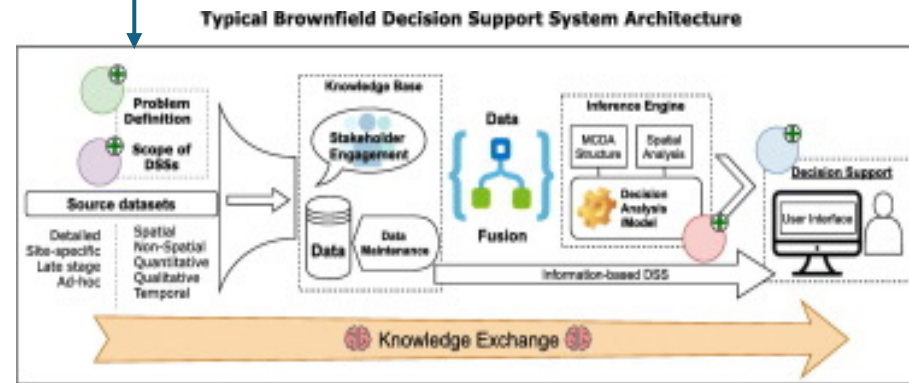


Tools, Methods, Scientific Approaches. Identifying the gaps

Brownfield regeneration tools are methodologies, and physical techniques helping redevelop former industrial sites, encompassing **GIS-based risk calculators**, **stakeholder-driven decision support systems (DSS)** for planning, remediation selection, and prioritization (e.g., **TIMBRE tools**), and **physical methods** like capping, soil removal, or creating "Technology Trains" for integrated resource reuse to transform challenging sites into valuable urban assets.



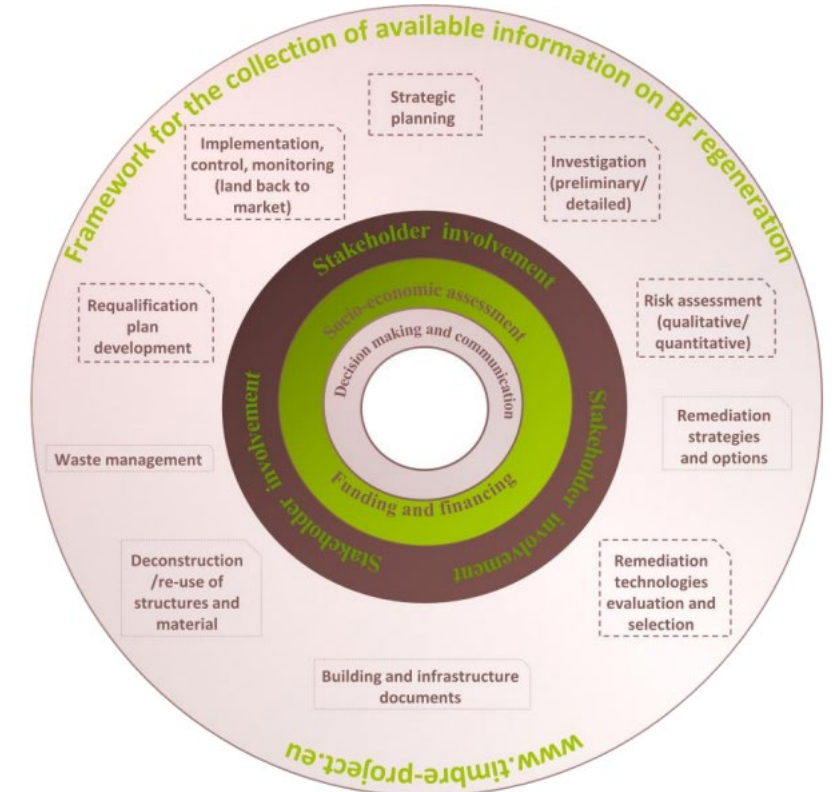
© (Kahal, A.Y., El-Sorogy, A.S., Meroño de Larriva, J.E., Shokr, M.S., Mapping Soil Contamination in Arid Regions: A GIS and Multivariate Analysis Approach, Minerals 2025, 15(2), 124



- Opportunities for Future Decision Support Systems**
- 1. Address early-stage brownfield issues
 - 2. Qualitative socioeconomic criteria
 - 3. Integration of predictive modelling
 - 4. Improved web-based, user experience

BGS © UKRI 2021 and Cranfield University © 2021

© (Hammond, E.B., Coulon, F., Hallett, S.H., Thomas, R., Hard, D., Kingdon, A., Beriro, D.J.), Science of the total environment (2021), 785(1)

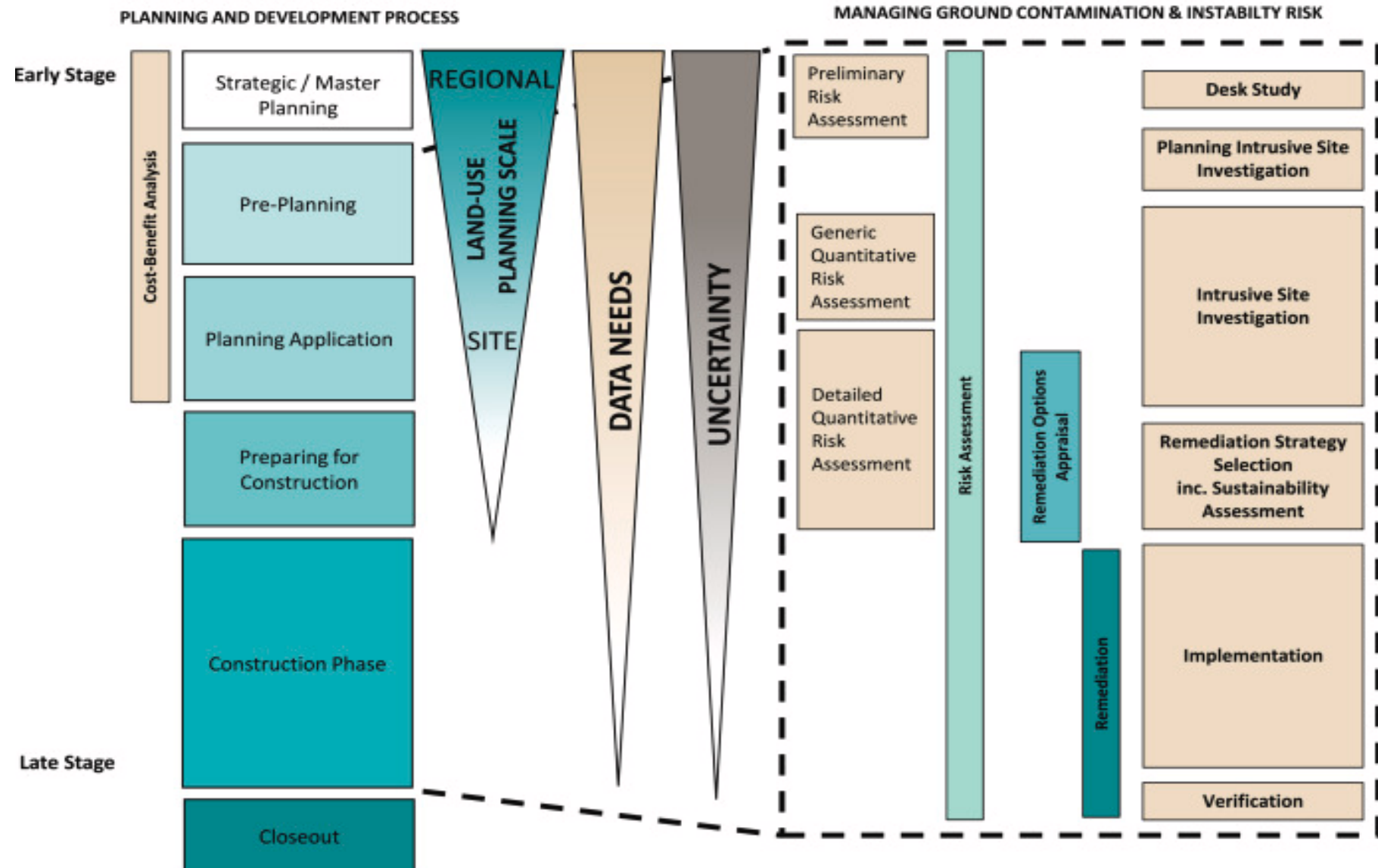


TIMBRE Project: Tailored Improvement of Brownfield Regeneration in Europe, Final Summary Report

© <https://cordis.europa.eu/docs/results/265/265364/final1-timbre-265364-final-report-publishable-summary.pdf>, Accessed on: 23/12/2025

Tools, Methods, Scientific Approaches. Identifying the gaps

Planning and land development process for brownfield sites



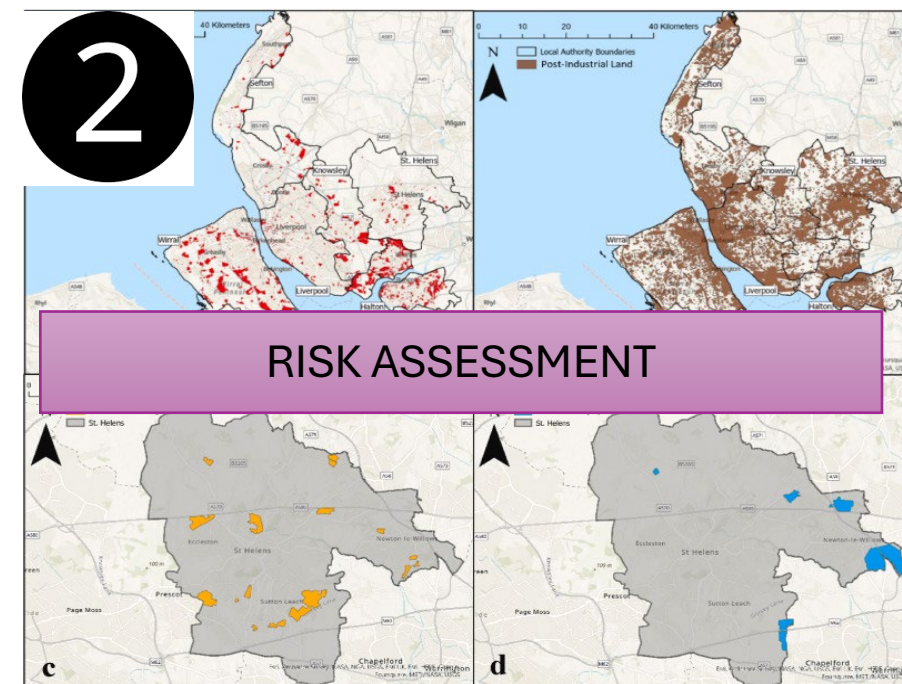
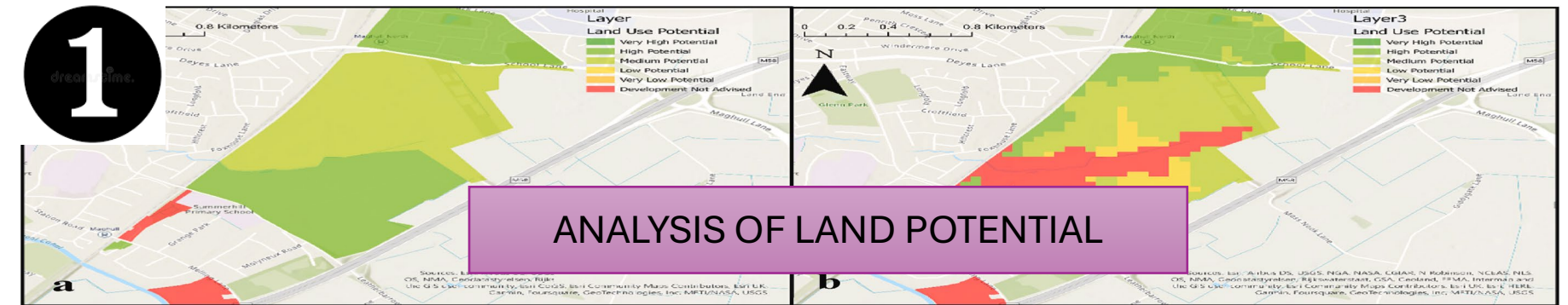
E.B. Hammond, F. Coulon, S.H. Hallett, R. Thomas, D. Hardy, A. Kingdon, D.J. Beriro
 A critical review of decision support systems for brownfield redevelopment
 Sci. Total Environ., 785 (2021)

Technological and urban innovations: The role of digital twins (1)

Across the urban planning and redevelopment sector, many **technologies and digital tools** are beginning to be adopted and used for a variety of tasks.

Within the brownfield redevelopment and land use planning literature, specialized digital tools called **Decision Support Systems (DSSs)** and **Planning Support Systems (PSSs)** have been developed to aid land use planners and decision makers.

Gap in the current literature for DSSs that address **early-stage, regional-scale, brownfield planning and redevelopment issues, and approach assessing post-industrial** land, considering environmental, social, and economic dimensions simultaneously



Hammond, E.B., Coulon, F., Hallett, S.H., Thomas, R., Dick, A., Hardy, D., Dickens, M., Washbourn, E., Beriro, D.,
From data to decisions: Empowering brownfield redevelopment with a novel decision support system, Journal of Environmental Management (2023), 347(1)

Technological and urban innovations: The role of digital twins (2)

Key innovation in urban regeneration, Digital Twins (DTs) have evolved from industrial applications to urban planning, infrastructure management, and energy systems, including methodologies for energy, material flows, waste, and data sharing.

DTs will **support brownfield decision-making** as collaborative and data-driven tools to support brownfield remediation and learning strategies

Although some practices exist to optimize rehabilitation benefits (e.g., use of eco-friendly materials, green infrastructure, stormwater management, sustainable transportation options, etc.), a lack of consistency in the applied approaches highlights the **need for further scope research and the development of customizable frameworks** with specific processes, while considering the insights from developed research to upscale circular-economy models and meet complex technological and social demands, as brownfields' regeneration.



A. Mehdipour and H. Rashidi Nia, 'The role of brownfield development in sustainable urban regeneration', *Journal of Sustainable Development Studies*, pp. 78–87, 2013.

E. Paull, 'The environmental and economic impact of brownfields redevelopment'. Northeast-Midwest Institute. Working Draft for Distribution, 2008.

Advantages of digital twin adoption for brownfield sites

SITE ASSESSMENT AND PLANNING

VISUALIZATION



Dynamic visualization of site, scenarios, and redevelopment

IMPACT AND RISK ANALYSIS

SIMULATIONS



Scenario analysis for the assessment of multiple impacts (e.g. environmental) of brownfield regeneration

ADAPTIVE PLANNING

CONSTRUCTION, RENOVATION, REHABILITATION



Construction and renovation optimization (resources, cost, time savings)

STAKEHOLDER COMMUNICATION

COMMUNICATION, ENGAGEMENT



Systems thinking, interactions, social innovation, citizen empowerment

/!\ If conditions are satisfied

Brownfield regeneration: Which impacts? (1)

From an environmental perspective: brownfield redevelopment **saves land** from the negative externalities associated with sprawl, **reduces air emissions and greenhouse gas levels**, improves **water quality** and balance by protecting natural lands and **maximizing vegetated areas**.

From an economic perspective: **creation of new job opportunities** and revenue gains, and the unlocking of hidden site development potential due to their strategic location in the vicinity of valuable areas.

From a social perspective: key to local human and environmental health through the implementation of decontamination strategies that offer multiple benefits for people's **well-being, including walkability and reconnection to natural green spaces after redevelopment**.



New EPA Grants Expand Brownfields Cleanup and Redevelopment in 2025

©Credits: <https://www.environmentenergyleader.com/stories/new-epa-grants-expand-brownfields-cleanup-and-redevelopment-in-2025,64811/>,

Accessed on: 25/12/2025

Brownfield regeneration: Which impacts? (2)

From an urban perspective: reduce **soil artificialization**, **construction intensification**, and **increase green spaces**. Genuine opportunities for urban development, leading to urban areas' densification and reinvigorating distressed sites by **reducing decarbonization threats** and **promoting green and social infrastructure** with **multiple benefits for human beings and biodiversity**.

From a technological perspective: **support decision makers** throughout redevelopment processes of site selection, planning, and development activities, linked to Open Government Data, and enhancing civic participation and **supporting monitoring of urban systems varying in complexity**.



Brownfield Regeneration - Delivering Homes, Growth and Nature

©Credits: https://www.berkeleygroup.co.uk/about-us/who-we-are/brownfield-regeneration?utm_source=google&utm_medium=organic&utm_campaign=019076_seo_sweepup, Accessed on: 25/12/2025

Conclusions

- Challenges in the comprehensive assessment and understanding of brownfield development.
- Recognized as a problem, but also as an opportunity worldwide, brownfields' challenge requires horizontal, cross-sectoral, and digital transformations for the development of structural changes.
- Multiple impacts (urban, economic, societal, environmental) from the brownfield regeneration and site renovation.
- Fragmented methodological tools on brownfield regeneration (e.g. cartographical analysis with static data).
- Digital twins become a promising conceptual framework for dynamic social, urban, and technological transformation and facilitate the decarbonization and clean energy transition processes.
- Need for dynamic settings for brownfield redevelopment strategies with real-time data and social innovation actions for stakeholders' engagement, citizen empowerment to activate bottom-up decision-making processes for rehabilitation and infrastructure renovation, and risk and impacts' assessment.
-

Discussion of future developments



Beyond Abandonment: 10 Realistic Ways to Breathe New Life Into Brownfield Sites

©Credits: <https://camoinassociates.com/resources/10-realistic-ways-to-breathe-new-life-into-brownfield-sites/>, Accessed on: 25/12/2025

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