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## Brownfields over the years: from definition to sustainable reuse

Guillaume Jacek, Anne Rozan, Maylis Desrousseaux, Isabelle Combroux

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1  
2 **Brownfields all over the years: an exploratory analysis of scientific**  
3 **literature (4530 mots)**

4  
5 JACEK Guillaume \*<sup>1;2;3</sup>; ROZAN Anne <sup>1;2</sup>; DESROUSSEAUX Maylis <sup>4</sup>; COMBROUX Isabelle <sup>3</sup>

6 <sup>(1)</sup> ENGEES, GESTE UMR MA8101, 1 quai Koch, F-67000 Strasbourg, France

7 <sup>(2)</sup> Université de Strasbourg, F-67000 Strasbourg, France

8 <sup>(3)</sup> Université de Strasbourg, UMR 7362 CNRS LIVE, Institut de botanique, 28 rue Goethe, F-67000 Strasbourg,  
9 France

10  
11 <sup>(4)</sup> CNAM-ESGT, Laboratory of Geomatics and Property, Le Mans, France

12  
13 \* Corresponding author: JACEK Guillaume, Institut de botanique ;28 rue Goethe, F67000, Strasbourg

14 [guillaume.jacek@engees.unistra.fr](mailto:guillaume.jacek@engees.unistra.fr)

15  
16 **Email addresses**

17 JACEK Guillaume : [guillaume.jacek@engees.unistra.fr](mailto:guillaume.jacek@engees.unistra.fr)

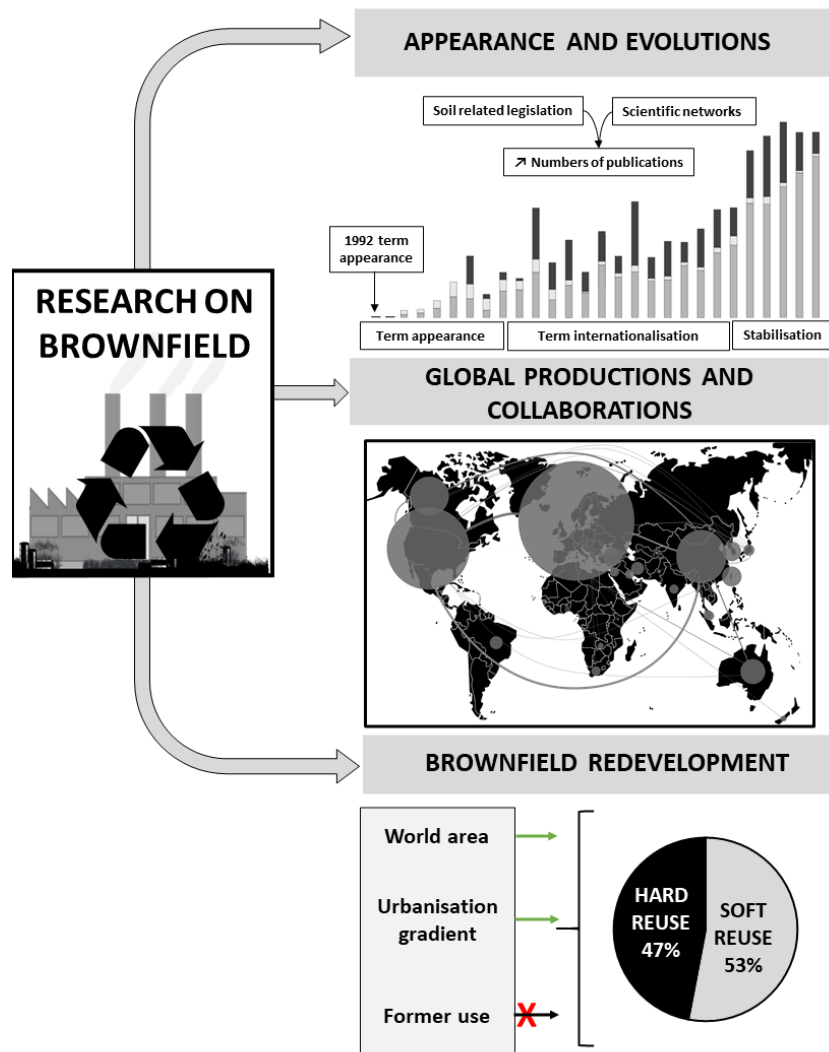
18 ROZAN Anne : [anne.rozan@engees.unistra.fr](mailto:anne.rozan@engees.unistra.fr)

19 DESROUSSEAUX Maylis : [maylis.desrousseaux@lecnam.net](mailto:maylis.desrousseaux@lecnam.net)

20 COMBROUX Isabelle : [combroux@unistra.fr](mailto:combroux@unistra.fr)

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### Graphical abstract



### Abstract: (243 mots)

In urban areas, the limitation of sprawl is often confronted to the lack of available space. The central location and the benefit linked to their redevelopment highlighted the potential of brownfield sites for sustainable city planning. This interest led to the development of numerous research areas and topics. However, no comprehensive analysis of brownfield research has been carried out so far. In this review, we analysed research on brownfields topic from term use to an analysis of described study cases. This exploratory research was carried out through an analysis of the scientific literature available on Web of Science database.

Starting in North America, the brownfield term rapidly became popular in the rest of the world, especially Europe. However, except for the United States, no direct legislation specifically related to these sites seems to exist and they often depend on biodiversity, environment or soil pollution directives or laws (e.g. environmental liability directive (EU)). Moreover, the perception of brownfield's potential varies greatly between regions of the world and international collaborations are very limited. The majority of the described type of site reuse are soft reuse (53%) and seem to be more depending of urbanisation gradient and world area than on brownfield past use.

Despite the growing interest for these sites, many questions concerning the future of these sites remain unanswered. Factors influencing the success of their redevelopment are still unclear and further research is strongly needed to ensure genuine sustainable reuse of these sites.

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**Hightlights:**

- Europe is the biggest contributor in brownfield redevelopment research, but People’s republic of China is the country with the highest rate of international collaborations
- Brownfield redevelopments represent real opportunities for sustainable city growth yet except for the US Brownfield legal approach is often indirect through soil or water protection. In Europe, the direct legal responsibility for the management of brownfields is state dependant.
  - Brownfield soft reuse represent majority of studied case in scientific literature
  - Brownfield reuses depend more urban gradient and pressure than on former site use

## 1) Introduction

110 The concept of sustainable development came into prominence in 1987 with the definition given  
111 by Brundtland Commission. This commission defined sustainable development as “the  
112 development that meets the needs of the present without compromising the ability of future  
113 generations to meet their own needs” (Brundtland, 1987). This concept is articulated around three  
114 major pillars that are social, economic, and environmental sustainability (Kahn, 1995). The report  
115 of the open working group mandated after Rio+20 defined 17 major sustainable development  
116 goals to establish a Green economy in the context of sustainable development, eradicate poverty  
117 and create an institutional framework for sustainable development (U.N. General Assembly,  
118 2014). The 11<sup>th</sup> goal stated the need to “make cities and human settlements inclusive, safe,  
119 resilient and sustainable” (Jandl, 2017). The keys to achieve this goal and make city and human  
120 settlement sustainable, include among other aspect: (i) integration of natural environmental  
121 elements, (ii) emphasizing of public transportation, (iii) high quality public realm and (iv) promotion  
122 of compact, efficient and mixed land use (Kenworthy 2006). Yet with around 66% of world  
123 population being urban by 2050 (UN 2014), integrating these key points in future city planning will  
124 be challenging, especially in terms of space availability. The search of available places combining  
125 social improvement, pollution mitigation and limitation of urban sprawl is often confronted to  
126 increasing scarcity of available land in compact urban areas. This highlights the potential of old  
127 urban industrial sites and make their regeneration a vital part of sustainable land use (Hombre,  
128 2014).

129 Old industrial sites, commonly called ‘brownfields’ (Tyman, 2008), are often located in inner cities  
130 or close suburbs, near or within deprived neighborhood (Gallagher and Jackson, 2008; Hird, 1993;  
131 Smary and DeWitt, 1998). Therefore, they present high sustainable redevelopment potential.  
132 Incited by a growing interest for this sites, numerous research fields associated with the  
133 redevelopment of brownfields emerged. These research fields encompass brownfield site  
134 remediation (Petrová et al., 2017; Song et al., 2019), legal and incentives tools analysis  
135 (Vanheusden, 2009; Thornton et al., 2007), social impact and perception (Loures and Vaz, 2018;

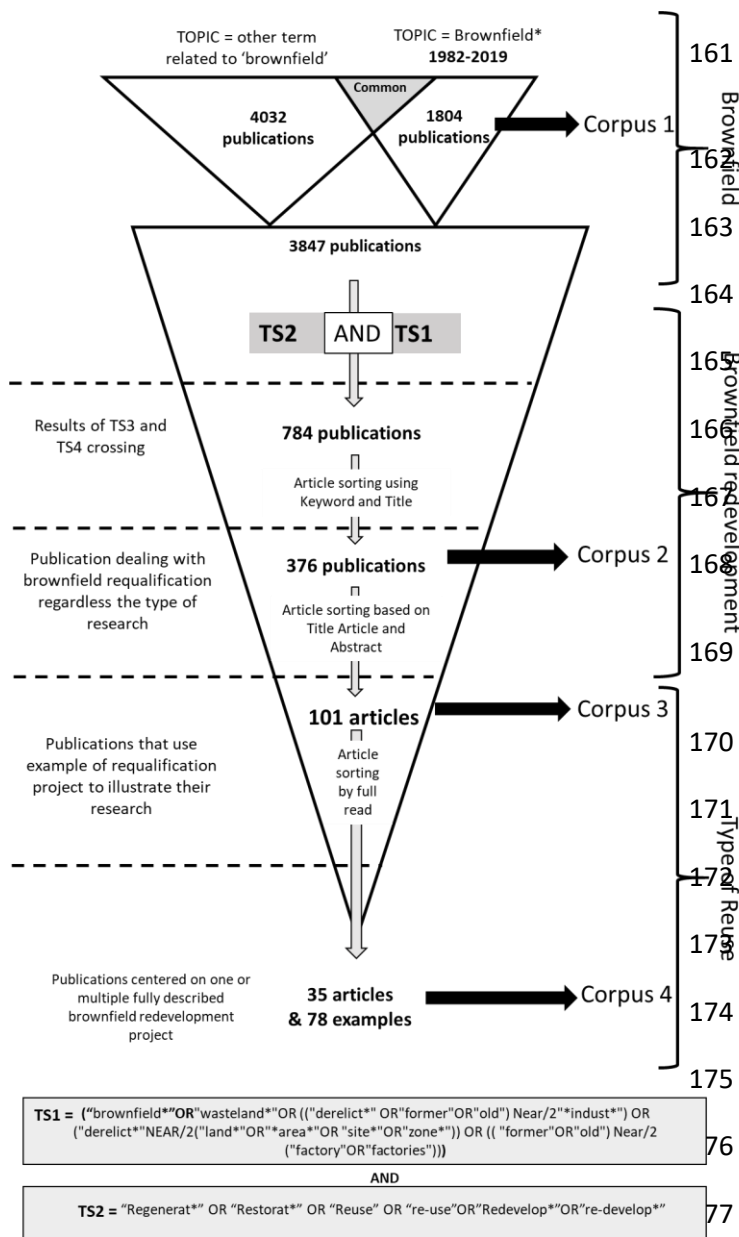
136 Loures, 2015; Gallagher and Jackson, 2008), or stakeholder collaborations (Limasset et al., 2018,  
137 Gallagher and Jackson, 2008; Frantál et al., 2015).

138 However, the lack of common agreement on a precise definition (Loures and Vaz, 2018; Alker et  
139 al., 2000) sometimes leads to a misunderstanding of what is considered or not as a brownfield.  
140 This represents a significant barrier to a global perception of their potentials. The principal shift in  
141 the definition of brownfields is the compulsory former presence of soil pollution (Thornton et al.,  
142 2007, Adams et al., 2010). United States legislation defines brownfields as “real properties, the  
143 expansion, redevelopment or reuse of which may be complicated by the presence or potential  
144 presence of hazardous substance pollutant or contaminant” (Brownfield Act, 2002). This definition  
145 is mostly used in the United states (US), Canada and Northern or Eastern European countries,  
146 where development pressure may lighter (Oliver et al. 2005). In opposition, the definition use in  
147 the United Kingdom argues that “not all brownfield land is contaminated nor derelict” (POST, 1998;  
148 Meyer, 2004). In order to improve and characterize future research needs, a clear definition is  
149 needed and review of the main studies conducted on the topic of brownfields and their  
150 redevelopment would be welcome.

151 Through this review of scientific literature, we gave an overview of the studies dealing with  
152 brownfields thematic considering use of 'brownfield' term itself to the reuse of these sites. A  
153 temporal analysis was done and linked to countries contribution, legal approach, and industrial  
154 history. We especially analysed the geography of collaborations. Due to the potential of  
155 brownfields for sustainable city development, we focused on how the topic is addressed in  
156 scientific literature. We also studied how different factors including surroundings, countries or site  
157 previous use influence the redevelopment of brownfields sites.

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**Figure 1: Schematic method for the bibliographic study of 'brownfield' term conducted on WOS database.**

The three phases pictured represent the formation of 4 bibliographic corpora. Selection method leading to the obtention of the different corpus is fully described. And these corpus are the base of following analysis TS = Topic section

181 impact number of publications were highlighted using data from WOS analytic tool "meeting  
 182 titles". Apart scientific conferences and events it is also known that the enactment of a statutory  
 183 text or treaty can have a strong impact in publications of some research field. For example, the  
 184 European water framework directive led to a massive increase of publication in water research

2.1) Selection of bibliography

Bibliographical research was done at the beginning of 2020 on Web of Science (WOS) platform, using web of science core collection database. The research was done on documents published between 1975 and 2019. The study protocol was divided into three major phases described in figure 1.

2.1.1: The term 'brownfield' : origins and use

For the period between 1992-2019, a specific search of the term 'Brownfield\*' has been done in the topic section (TS) regardless the type of publication. It led to a result of 1804 publications, we thereafter called Corpus 1. All use of the term brownfield before 1992 were not affiliated to our meaning of brownfield (e.g. family names, site name etc...) and were removed from the corpus for the analysis. Associated research events (i.e. conferences; symposium....) that could

185 area (Boeuf and Fritsch, 2016) that's why a quick literature review of European, Chinese, and  
186 American policies has been done.

### 187 2.1.2) Bibliographical study of "brownfield redevelopment" research field

188 All the exploratory analysis was done in 'Topic' section for the period 1975-2019 and only  
189 reviews and articles were selected. From preliminary research, four different synonyms of the  
190 term brownfield have been selected: 'wasteland'; 'industry'; 'factory' and 'derelict' associated  
191 with dereliction adjectives like 'former'; 'old' or 'derelict'. Other terms like abandoned, 'vacant',  
192 'ancient' etc. did not fit our requirements in term of relevance of publications. These terms were  
193 merged into the following equation (TS1):

194 TS1 = ("brownfield\*"OR"wasteland\*"OR (("derelict\*"OR" former" OR "old" ) Near/2  
195 "\*indust\*"OR("derelict\*"NEAR/2("land\*"OR "\*area\*"OR"site\*"OR"zone\*"))OR((  
196 "former" OR"old") Near/2 ("factory"OR"factories")))

197 The second step was the selection of the term associated with the concept of 'redevelopment'  
198 (See equation TS2 in fig1). Four terms were selected out of a preliminary list of 19 due to their  
199 usual use in association with brownfields: 'redevelopment (and re-development)',  
200 'regeneration', 'reuse (and re-use)', and 'restoration'. The crossing of these 4 terms (TS2) with  
201 TS1 led to the final following equation for the bibliographic search:

202 **Topic=** TS1 AND TS2 = ("Regener\*" OR "Restor\*" OR "reuse"OR"re-use" OR"redevelop\*"  
203 OR"re-develop\*")

204 A screening was done on the 784 results, keywords and title were analyzed and when no clear  
205 link with brownfield redevelopment appeared the publication was removed from the corpus.  
206 The remaining 376 publications formed the corpus 2 (see fig. 1).

### 207 2.1.3) Bibliographical study of the type of reuse

208 We then analysed how brownfields were redeveloped and which factors could possibly impact  
209 their transformation. Title and abstract of the corpus 2 were analysed. The articles that



210 described specific redevelopment project formed corpus 3 (101 articles). All these articles were  
211 analysed. The articles that fully described one or multiple projects, from brownfield past to  
212 current redevelopment, were kept in corpus 4 (fig.1).

## 213 2.2) Article analysis

214 Using corpus 2, collaborations and contributions of each country/area were highlighted  
215 using R bibliometrix package tools (Aria et Cuccurullo, 2017). Affiliation of every authors were  
216 considered. For each publication, the selected country contribution corresponded to the  
217 proportion of authors affiliated to the selected country. The global contribution of each  
218 country/area was estimated by summing these proportions. For this analysis Europe  
219 (continent) was considered as one single entity. When it comes to collaborations, multiple  
220 country publication (MCP) were extracted. Number of countries co-occurrence in all corpus  
221 correspond to their number of collaborations.

222 A term occurrence analysis was made on publication titles using wordcloud R package  
223 (Fellows, 2018). We only present here the results for Europe, US and PRC since they present  
224 a sufficient number of publications for this analysis. Terms present in at least 10% of the  
225 publication titles were represented in wordcloud and the word "Brownfield", strongly  
226 predominant, has been removed from the figure.

227 For the study of the type of reuse, information like site former use, size, surrounding  
228 context and reuse type were considered and extracted from each article. Former uses were  
229 categorized using ISIC sections (International Standard Industrial Classification of All  
230 Economic Activities; 2008) which led to 6 different categories. ISIC sections were also used to  
231 categorise the reuse types but were complemented by two lacking categories: residential areas  
232 (housing as dominant purpose) and natural area. Site surrounding context was divided in 3  
233 categories: urban; suburban and rural. Decisions were made using André et al. (2014) decision  
234 tree.

235

236 2.3) Statistical analysis

237 A Chi 2 test was used to evaluate the independence between former use and future trend in  
238 brownfield redevelopment and was followed by a network analysis performed with R “Bipartite  
239 package” (Dormann et al., 2008). A multiple component analysis was done on the 78 detailed  
240 examples presented in the 35 publications of corpus 4. This was done to highlight potential  
241 links between brownfield redevelopment project characteristics and their reuse using  
242 “factomineR” package (Lê et al., 2008).

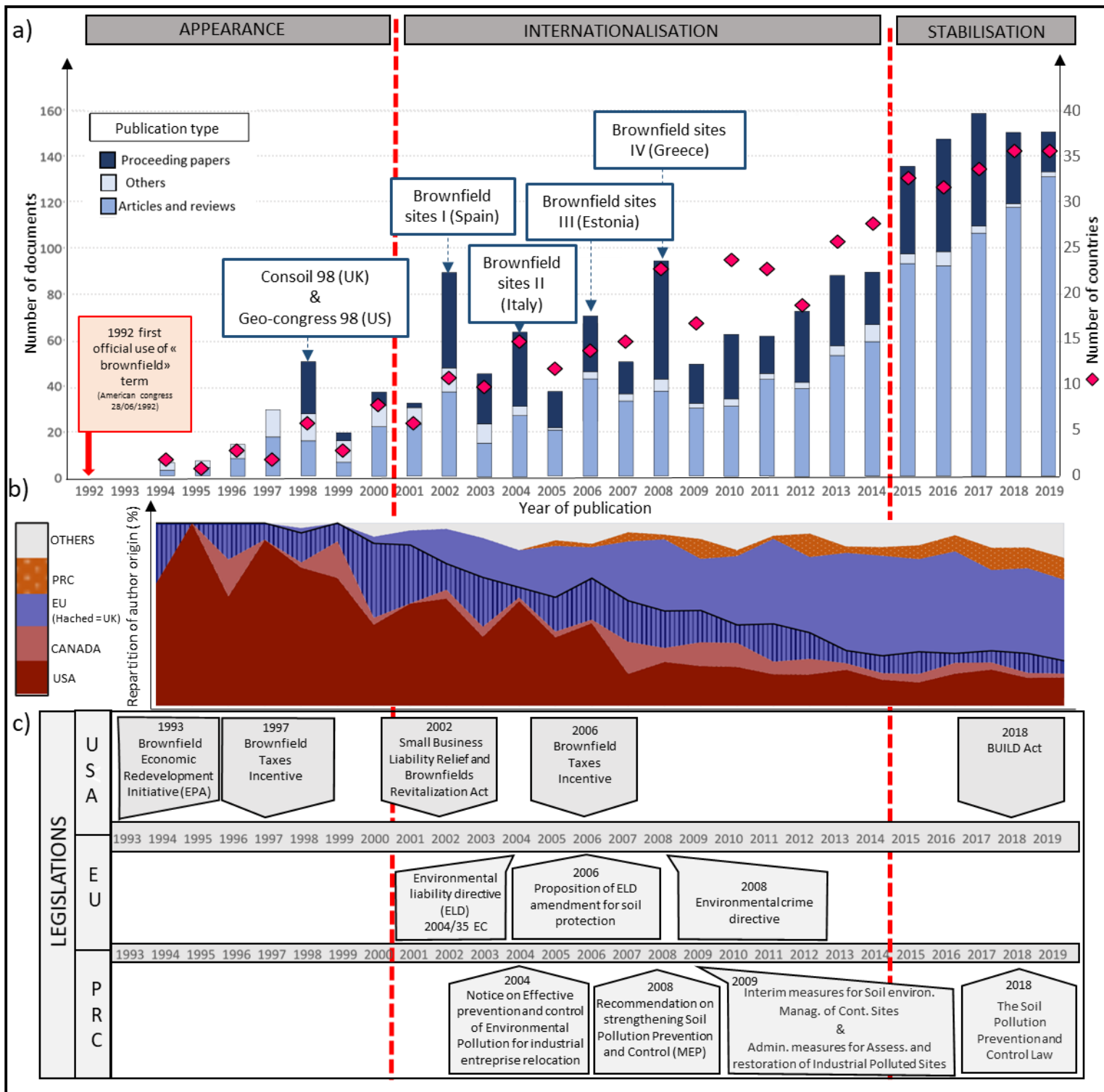
243 **3) Results and discussion**

244 3.1) ‘Brownfields’: origins and uses of the term.

245 The term brownfield was officially introduced during a session of American congress field  
246 hearing on the 28<sup>th</sup> of June 1992 (Dehoorne et al., 2016; Jones & Welsh, 2010). It was created  
247 in opposition to the term ‘greenfield’, which was basically referring to sites that didn’t face any  
248 previous development pressure nor infrastructure (Green, 2016; Greenberg et al., 2001). For  
249 this review we considered as brownfields, all former industrial sites, factories, manufacturing  
250 area, quarries, mines (and other type of extraction site), developed military sites with military  
251 abandoned infrastructures, warehouses, abandoned waste management sites, harbours,  
252 railroads and roads if part of a transport hub. In opposition, agricultural brownfields with no  
253 constructed building, single building with no affiliated land and abandoned single road or rail  
254 track were not considered as brownfield sites.

255 For the period 1992-2019, 1804 publications were found using the term ‘brownfield\*’ in their  
256 topic on WOS database. Despite the fluctuations in its definition the use of the term ‘brownfield’  
257 increased strongly in the last 20 years from less than 40 publications in 2000 to 150 in 2019  
258 (figure 2a). Three different periods could be distinguished in the use of the term ‘brownfield’  
259 which are : appearance, internationalisation, and stabilisation phases.

260



**Figure 2: Evolution of the use of the term “brownfield” in scientific literature**

Bibliographical analysis of the term Brownfield in Web of Science core collection for years 1975 to 2019 (1804 documents).

**a)** Temporal evolution of the number and type of publications. Conferences that potentially led to an increase in publications are indicated in blue box. Pink diamonds represent the number of countries publishing documents with “brownfield” term in abstract, title or keywords.

**b)** Repartition of publication author origins according to the author addresses indicated in WOS database. For the EU (blue) the hatched part corresponds to articles from UK.

**c)** Comparison of EU, USA and PRC legislations and major programs devoted to brownfield redevelopment.

Dotted red lines delimitate major phases in the use of the term ‘brownfield’.

262 3.1.1) The appearance of the term brownfield in literature

263 Appeared in the early 90s on WOS database, the term brownfield was, for the first decade,  
264 mostly used in English-speaking countries with a predominance of the United States (20 to 40  
265 occurrences per year; figure 2b). In 1993, US Environmental Protection Agency (EPA)  
266 established the “brownfield economic redevelopment initiative” (figure 2c). Through this pilot  
267 program local governments could apply for federal funds to assess brownfields and create the  
268 partnerships necessary to address barriers to reuse. The objectives were to promote less  
269 contaminated site redevelopment than the one concerned by “Superfund legislation” (Reisch  
270 and Bearden, 2003; US EPA, 2006). After its inception in 1994, this initiative quickly became  
271 a pillar for contaminated sites management (Thornton et al., 2007) also leading to the first  
272 appearance of the term brownfield in WOS database in 1994 (Figure 2a). Later, other incitation  
273 methods have been set in the US such as the ‘Brownfield taxes incentives’ in 1997, 2002  
274 ‘Brownfield Act’ or 2018 ‘Build Act Provision’ (figure 2c). These legislations have strongly  
275 contributed to encourage clean-up of brownfields in the US (Sousa; 2005). In Europe, the  
276 legislation and research on derelict land started during the 80’s (Grimski and Ferber, 2001).  
277 The use of the term brownfield therefore only started to spread to these countries during the  
278 early 2000’s (Figure 2b).

279

280 3.1.2) Internationalisation of the term ‘brownfield’: Europe and People’s Republic  
281 of China cases

282 An internationalisation of the use of the term ‘brownfield’, characterized by the increasing  
283 number of countries involved and especially European countries (Figure 2a & 2b), was  
284 observed at the beginning of 2000. Four major international symposiums could possibly  
285 explain the diffusion of ‘brownfield’ term around Europe. The first International Conference on  
286 ‘Assessment, Rehabilitation and Development of Brownfield Sites’ held in 2002, was hosted  
287 by the Wessex Institute of Technology in Cadiz Spain. Following this symposium, and for all  
288 the other that followed, all proceeding papers were published in books called “brownfield sites”.

289 The publications of these books every two years led to a significant increase in the number of  
290 publications related to brownfield subject. In 2002 the proceeding papers issued from the first  
291 conference represented almost 40% all publications using "brownfield" in their topic.

292 The early 2000's was also characterized by the development of multiple European scientific  
293 networks centred on brownfields assessment or regeneration like CABERNET (Concerted  
294 Action on Brownfield and Economic Regeneration *Network*) (2002-2005). According to  
295 Nathanail et al. (2007), the CABERNET project produced four major outcomes including  
296 conceptual models creation, multi-stakeholder approach, and recommendation for future  
297 research on brownfield topic and European policies.

298 In contrast to the United States, the legal approach to brownfield sites in the European Union  
299 is indirect. The management of brownfields is based on texts on the protection of the  
300 environment, water and soil which will oblige the Member States to ensure the management  
301 of these sites. One of these examples is the environmental liability directive (2004/35/EC)  
302 which establish an environmental responsibility framework using the polluter-pays principle.  
303 This directive applied to water and biodiversity can also be applied for soil compartment,  
304 leading to significant impact on polluted brownfields (Garcia Burgues, 2009). Except for these  
305 kinds of indirect impacts, brownfields issues remain closely linked to states level leading to  
306 limited EU legal competence. In September 2006, an amendment of environmental liability  
307 directive part of the "thematic strategy for soil protection" was proposed by the European  
308 Commission (figure 2c) (Vanheusden, 2009). Implementation of this directive would have  
309 resulted in member states implementing measures to prevent soil pollution, by limiting the input  
310 of hazardous substances on or in the soil, identification and inventory and remediation of  
311 contaminated sites on their territory. However, some countries, including France and Germany,  
312 were opposed to the implementation of this directive. They emphasised the principle of  
313 subsidiarity and the negative impacts of the directive on the measures already implemented at  
314 the national level (Desrousseaux, 2014 ; Vanheusden, 2009). These oppositions led to a failure  
315 in the establishment of common policies in the European union. On figure 2 we can see that

316 the submission of this amendment is quickly followed by the “environmental crime directive “  
317 with which brownfields sites contamination may be seen and treated as a criminal offense  
318 (Vanheusden, 2009). The proposition of amendment and the environmental crime directive  
319 appearance coincide with a slight but constant increase of European research for the  
320 ‘brownfield’ subject with, since 2006, a constant increase of European countries participation  
321 (figure 2b).

322 In People’s Republic of China, research studies on brownfields were more recent (figure 2b)  
323 and also often soil pollution related. According to Li et al. (2015) three different periods can be  
324 observed in PRC policies with soil pollution management. The initial stage from, 1979 to 1982,  
325 stood when where China started to formulate principles of soil protection. It was followed by  
326 the period of prevention and control of soil pollution from 1983 to 2003. Then in 2004 policies  
327 shifted from the principle of prevention to the principle of remediation of soil pollution. The  
328 beginning of this third period coincided with the appearance of Chinese authors in the scientific  
329 bibliography (figure 2b). During this period multiple legal documents were published (figure  
330 2c) (e.g. “the special act on national soil status, survey and Pollution prevention (2004), the  
331 « Notices on Effective prevention and control of environmental pollution for industrial  
332 enterprise” (2004) or “Administrative measure for assessment and restoration of Industrial  
333 polluted site “(2009)). The explosion of the number of administrative, legal or technical  
334 documents publication during this period is clearly described in Li et al. (2015).

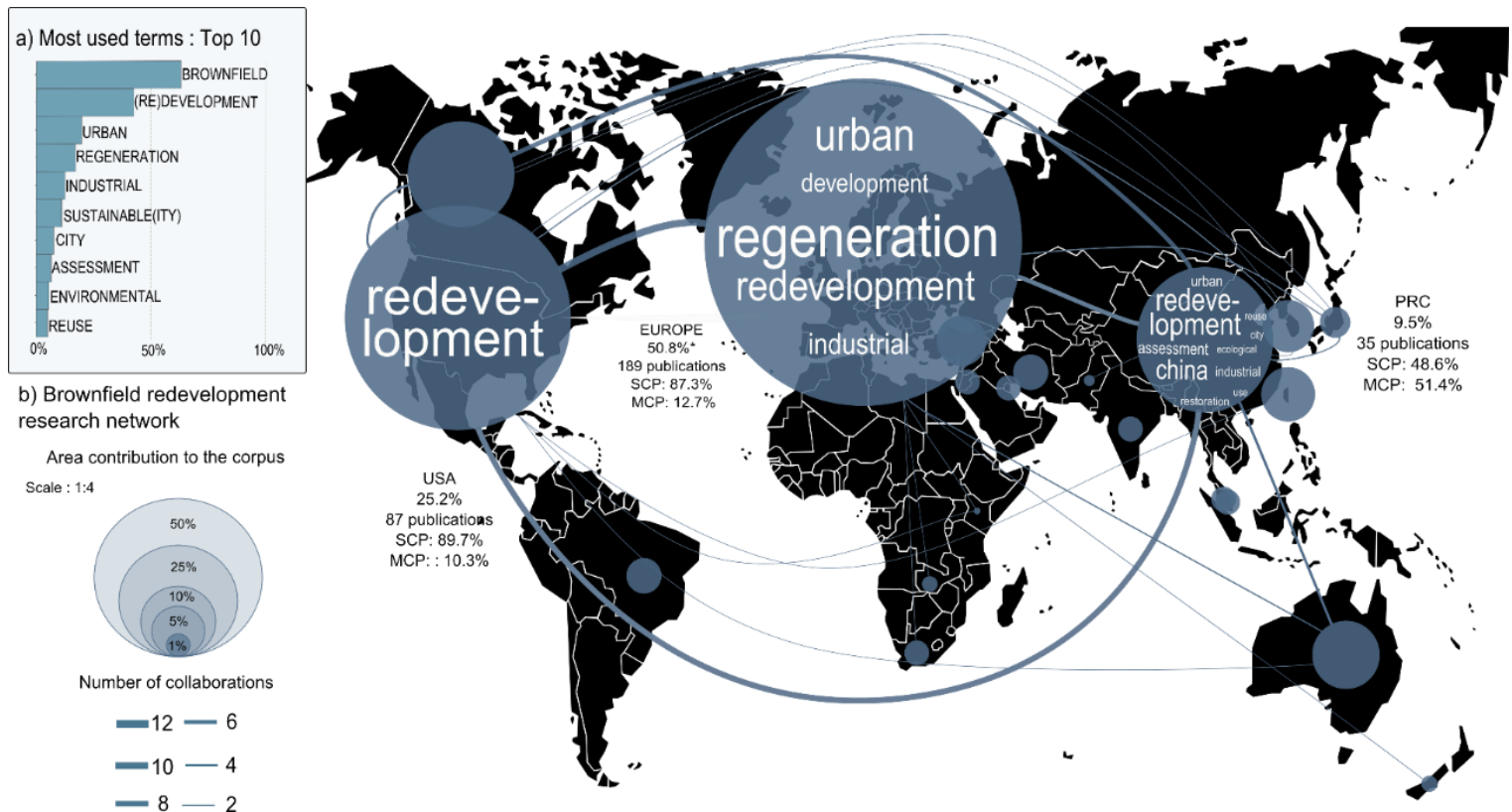
### 335 3.1.3) Brownfield term current and potential future use

336 A third period started since 2014 when the term brownfield became the reference term in  
337 articles dealing with industrials sites redevelopment projects. The number publications per year  
338 seems to have stabilized over the past 5 years around 150 publications per year. Authors from  
339 more than 35 countries used this term with a strong dominance of European countries (Figure  
340 2 a & b). However, a period of 5 year is not enough to conclude to a real stabilization in the  
341 amount of scientific publications. Further studies on brownfield research production are  
342 needed to ensure this stabilisation phase. Furthermore, authors from new countries would for

343 sure join brownfield research in close future as the growing number of the publications from  
344 the “other countries” category in (figure 2b) let suppose. The deindustrialization processes, at  
345 the origin of brownfield sites creation, first started in the US in the late 60s quickly followed by  
346 European countries during the 70's (Rowthorn et al., 1997, Adams et al., 2010). A same pattern  
347 seemed to occur in asian countries in late 80s explaining the delayed appearance of China in  
348 brownfield research (figure 2b). In a close future the contribution of other countries that are  
349 currently facing post-industrial society shift would therefore certainly increase.

### 350 3.2) Brownfields regeneration as a research field

351 An advanced research on Web of Science core database returned 382 publications dealing  
352 with at least one or multiple aspect of brownfield redevelopment. The analysis of the top 10  
353 most used words in titles, showed that the term 'brownfield' present in more than 63% of them  
354 and often directly associated with the notion of regeneration or redevelopment and derived  
355 adjectives (44% of the case) (Figure 3a). This mean that in all term used in our research (e.g.  
356 wasteland; industrial sites etc...), 'brownfield' is the most used term one and often related to  
357 the idea of site redevelopment. The fact that these sites represent potential opportunities for  
358 sustainable urban development (Dorsey, 2003) is also reflected in the results obtained, given  
359 that the terms 'urban', 'city', 'environmental' and 'sustainable' represent 4 of the 10 most used  
360 terms in the publications titles.



**Figure 3: Global perception and collaborations in the brownfield regeneration research**

**a)** Top ten of the words present in whole corpus publication titles

**b)** Map of countries collaborations and word associated with brownfield redevelopment for the period 1975 to 2019. The size of circles represent on the countries/area is proportionate to their contribution into the corpus. Countries of European continent were merged into one single entity. Blue lines represent the collaborations between countries, wider they are more the countries share common publications. Wordcloud analysis has been done on publication titles, word present in less than 10% of the titles were removed. The term 'brownfield' was also removed for clarity reasons. **MCP**: Multiple countries publications **SCP**: Single country publication.

361 More than the half of the contributions were originated from European Union and close  
 362 countries (51%) (Figure 3b), followed by the USA with 25% and People's Republic of China  
 363 (PRC) with almost 10% of the global production. Collaborations between areas was quite  
 364 limited and most collaborations happened between the five former industrial areas which are  
 365 Europe, China, USA, Canada, and Australia but never exceeding 11 multiple countries  
 366 publications (MCP) (Europe/USA). European and american authors mostly tend to publish  
 367 with authors from the same country with only 13 to 16% of multiple country publications (MCP)  
 368 and 84 to 87% of single country publications. The results are even the same between members  
 369 of the European Union (15.8% of internal MCP). On the opposite Chinese authors tend to seek  
 370 for collaborators out of their country with more than 51% of their publications which are MCPs.



371 That could be explained by the fact that chinese legislation on brownfield assessment and  
372 redevelopment is relatively recent (3.1) compared to american and european ones.

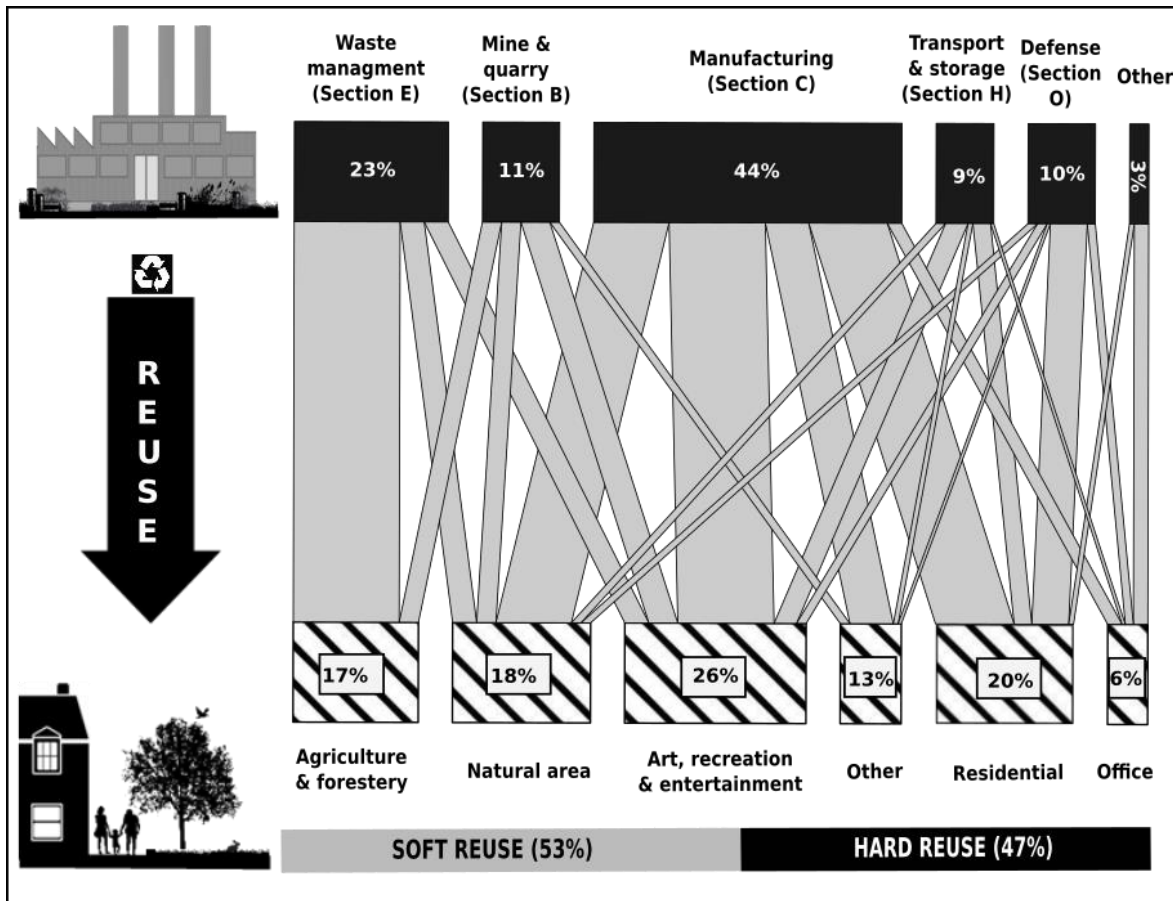
373 Regardless the area, the term brownfield and redevelopment were part of the most used terms  
374 in each of the considered areas. However, considering different global areas, they were  
375 associated with different other terms (Fig 3b). These differences in language would explain the  
376 poor intercontinental collaborations in this research field. Silverthorne (2006) recognise through  
377 a literature review that definitions of regeneration success are strongly influenced by local  
378 values, between countries, stakeholders, and projects. One clear example is the use of the  
379 word 'regeneration' in the European countries versus 'redevelopment' (Figure 3a). The term  
380 'regeneration' corresponds to an approach that do not exclude the possible reuse of the old  
381 infrastructure (Nathanail, 2011) taking in account past cultural and historical impact of some of  
382 these sites. At the opposite redevelopment, used in other area of the world, involves the  
383 creation of a whole new landscapes (Nathanail, 2011). Furthermore, Adam et al. 2010  
384 highlighted specific differences between England and US perception of brownfield  
385 redevelopment. In fact, in England brownfields were seen as real opportunities for housing  
386 creation and greenfield preservation in urban area. At the opposite in the US brownfield sites  
387 redevelopment is often seen with a desire of economic improvement and greenfield  
388 consumption seems to stay more attractive than brownfield redevelopment for residential  
389 reuse (Adams et al., 2010).

### 390 3.3) Brownfield from past trend to future prospect

391 Osman et al., (2015) showed in Czech Republic, that brownfield characteristics like size,  
392 transportation availability, typology, or characteristic of surrounding strongly influence  
393 brownfield redevelopment successes and projects. Out of the 101 selected publications 35  
394 were selected (see 2.2) and described a total of 91 brownfields redevelopment examples. Only  
395 the 78 that clearly display information like brownfield precise description or brownfield  
396 surrounding context were kept for analysis. Usually a major part of brownfields is, according  
397 to ISIC classification (International Standard Industrial Classification of All Economic Activities;

398 2008), former manufacture (Section C - *e.g.* chemical industry, metal product manufacture or  
399 textile industry etc...). They represent in our corpus more than 44% of all brownfields. They're  
400 followed by waste management (23%), mine and quarry (11%), military (10%), transport and  
401 storage (9%). More than a quarter of these sites transformation (26.5%) led the creation of  
402 recreational like art district, greenspace or park. 20% of the detailed project included residential  
403 or natural area creation and 18% agriculture or forestry other types of transformation were less  
404 present (Figure 4). 35% of the publication present project with more than one transformation.

405 Soft- reuse is defined as "an intended temporary or final re-uses of brownfield sites which are  
406 not based on built constructions or infrastructure" (Bardos et *al.*, 2016). It represents more than  
407 half (53%) of the reuse in the study case from the scientific literature. These could be explained  
408 by the change of perception and the global agreement of positive impact brownfield soft reuse  
409 on society, economy and environment (Bardos et *al.*, 2016). However, it can also be explained  
410 by the fact research projects were more developed in the case of reuse as greenspace. This  
411 could lead to an overrepresentation of this type of site reuse in scientific literature.



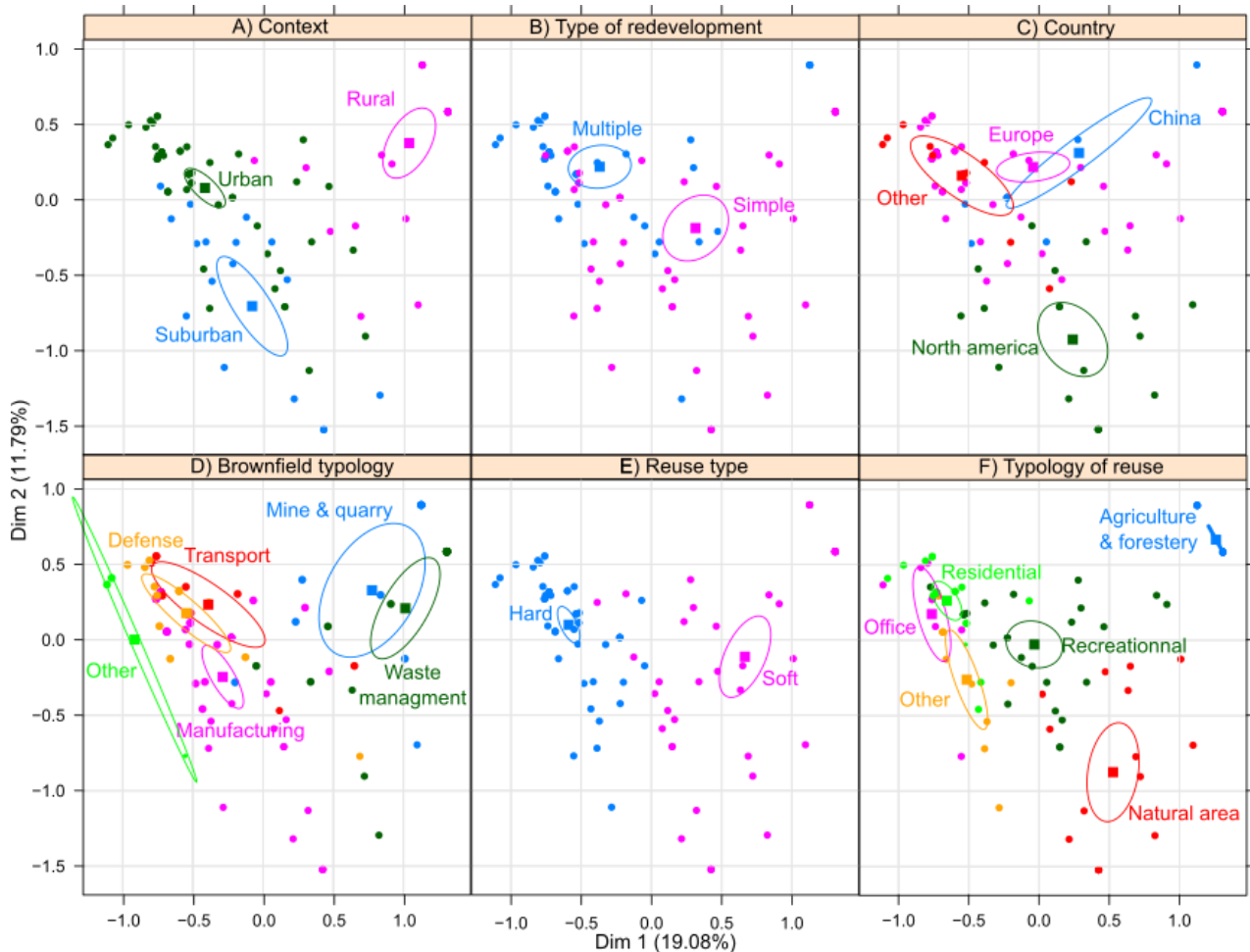
**Figure 4: Flux diagram of past uses and reuses of brownfields in scientific literature**

Black squares represent past (plain) uses. Dashed square represent future uses of brownfields. Larger they are more frequent this kind redevelopment is studied in scientific literature. The size of grey bars represents the future use of different type of brownfield (in percentage).

412 A Chi2 test revealed a significant dependence between brownfield past trends and future  
 413 prospect with a Pvalue of  $2.2e^{-16}$ . Most of the former landfill tend to be transformed in  
 414 agricultural zone, then natural area or recreation area (Fig 4). Actually most of the articles  
 415 dealing with waste management brownfield tend to be transformed in managed forest (e.g  
 416 Rawlinson et al., 2004) and, when close to city, in parks and recreational areas (e.g. Klenosky  
 417 et al., 2017; Li et al., 2019). It is also the case for former mine or quarry which tend more often  
 418 to have a soft reuse. Defence brownfields which tend to be transformed into residential area  
 419 in the major part of the cases. The other brownfield types did not exhibit any trend in term of  
 420 reuse (Figure 4).

421 Other factors than past use can also potentially impact brownfield reuse (Fig. 5). Soft reuse  
 422 tend to be more frequent after mine and quarry or waste management use, especially in rural

423 context. Sites present in an urban context seemed to be more correlated with hard reuse  
 424 project whereas rural sites have more often a soft reuse (Fig.5). Recreational sites which could  
 425 be included in hard reuse (like museum) or in soft reuse (like parks) are located in our MCA in  
 426 the buffer zone between hard and soft reuse sites (Fig 5).



**Figure 5: Multiple component analysis of different brownfield characteristics that could potentially affect their regeneration**

For each case same colour dot are part of a same group. Coloured square represent the barycentre of each group.

427 Redevelopment into natural areas occurred mainly in suburban and rural areas independently  
 428 from the past use (Fig 5a,d &f), especially in North America. Furthermore, American  
 429 brownfields seem to be less multi-type with only one type of redevelopment in general. No  
 430 significant correlation link between past use and future prospect seem to be highlighted in this  
 431 analysis (except for mine, quarry, and waste management more correlated to soft reuse). We  
 432 could thus emphasize that former uses (and potential pollution) are not any more compelling

433 the reuse of brownfields sites. Their reuses are mainly imposed by the actual need of land  
434 uses.

435 Multiple site factors seem to influence brownfield reuse and especially soft and hard reuse.  
436 Soft reuse represents the majority of studied cases in the literature. However, residential area  
437 creation, commercial site creation or other hard reuse could potentially be more present in grey  
438 literature or project without any scientific studies, leading to a potential bias in our analysis.  
439 The majority of soft reuse are currently concentrated in suburban and rural areas, whatever  
440 they are mostly needed in urban area (Haaland and van den Bosch, 2015 ; Wolch et *al.*, 2014).

441 Research on brownfield redevelopment was strongly developed in the last decades.  
442 However, there is still a gap in the understanding of underlying social and technical factors that  
443 influence their reuse. Furthermore, there is a huge lack of feedback on mid- and long-term  
444 success evaluation in terms of social, ecological or sustainability perspectives.

#### 445 **4) Conclusion and perspective**

446 The desire for urban renewal and the integration of sustainable measures have led to an  
447 expansion of research on brownfields. Even if popularized in the late 90's and the increase of  
448 available data, the problem of brownfields is still often studied and considered only on a local  
449 or national scale. Limited exchanges between countries, and those that despite attempts to  
450 set up a common definition (e.g. Alker et *al.*; 2000), lead to the existence of disparities in the  
451 perception or management of this type of sites (e.g. Adam et *al.* 2010). These sites often need  
452 a strong legal support to ensure their redevelopment, yet with the exception of the Us, these  
453 sites are often approached indirectly for the rest of the world through the prism of polluted sites  
454 and soils and environmental liability.

455 It is widely recognized that these sites and their redevelopment can be part of a sustainable  
456 development approach (Dorsey, 2003 ; Sousa, 2008). They can enable the integration of  
457 ecosystem services and a reconnection with nature in urban and peri-urban environments (e.g.  
458 De Valck et al., 2019 ; De Sousa, 2003). Vaz and Loures (2018) clearly puts forward the fact  
459 that, to do so, it is important to understand that all brownfields are not equal and that a more  
460 contextual approach is necessary. We have highlighted that, in scientific literature, apart from  
461 a few special cases such as mines and gravel pits, the past of these brownfields does not  
462 represent a determining factor in the type of redevelopment that is applied. The context in  
463 which these wastelands are found in terms of level of urbanization seems to be more  
464 preponderant.

465 Although scientific literature currently describes a certain number of cases of redevelopment,  
466 little attention has yet been paid to the success evaluation of this redevelopment. If we also  
467 wish to understand the impact of these projects and particularly those integrating green and/or  
468 natural spaces on the provision of ecosystem services or on human well-being, it will necessary  
469 to set up evaluation tools specific to this type of site and thus considering all aspects of  
470 brownfields redevelopment.

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