An ex-ante evaluation of brownfield redevelopment benefits at a regional scale

Introduction

Brownfield Redevelopment (BFR) is an issue of growing concern for urban planners and managers all over the world, especially in former industrialized regions of Europe, North America and in emerging economies (De Sousa 2004; Panagos et al. 2013; U.S. EPA 2016; EPA 2017). Brownfields are often a source of nuisance for nearby residents (Gayer et al. 2000; Longo and Alberini 2006; Lesage et al. 2007), particularly in the case of contaminated sites (environmental and human health risks) or derelict buildings (risk of accidents, illegal occupation and crime). Soil and water contamination often require rehabilitation that may entail high remediation costs, complex administrative procedures and unexpected delays. The risks of future liability, stigma and uncertainty on remediation costs, all linked to the residual contamination, are elements that need to be well accounted for (Bartke 2011). BFR is thus often hampered for economic reasons. In particular, the cost of managing abandoned buildings and chemical pollutants in soil and groundwater can far exceed the expected financial benefits on which private investors base their decisions. However, many indirect benefits can help justifying public investment in brownfield redevelopment projects, but these are difficult to assess in monetary terms and often remain unrecognized in decision support tools.

The observation of these difficulties has led regional and local authorities to intervene financially in the implementation of projects aiming to foster the redevelopment of urban brownfields (Lafeuille and Steichen 2015). The existence of numerous economic, social and environmental benefits, not taken into account by private investors, justify this public intervention (De Sousa 2003; EC 2012; Schädler et al. 2012). In doing so, they enable communities to avoid the costs associated with urban sprawl, particularly in terms of infrastructure construction (transport, communication, energy) and environmental costs (road transport pollution, consumption of natural and agricultural land, etc.). BFR can also offer opportunities in terms of recreational activities, production of environmental services, improving the living environment of the populations living near the sites, and contribute to the revaluation of real estate in these areas.

Most efforts in literature address valuing BFR benefits for single sites (Ameller et al. 2020). However, urban planning at regional scales can require ex-ante analyses for managing portfolios of sites and future land use activities. As the deployment of economic valuation methods in several dozens of sites would require human and financial resources beyond the reach of stakeholders. A simpler but robust alternative approach is therefore needed. In this paper we address this gap by presenting a benefit transfer approach for the ex-ante monetary assessment of BFR benefits at a regional scale. The implementation of the approach is illustrated with a small portfolio of BFR options in an industrial zone in south Lyon, France. The content of this paper includes a brief overview in regard to BFR benefits and economic valuation methods, the presentation of the case study and methodology, the identification and estimation of benefits of the BFR portfolio, and lastly, it concludes with a discussion on the advantages and disadvantages of the approach.

State of the art

Literature addressing BFR benefits primarily considers three types of benefits: economic (private profit), social (employment, quality of life) and environmental (De Sousa 2002; Turvani and Tonin 2008; Bardos et al. 2016). It often makes a distinction between the benefits derived from the cleanup of contaminated sites and site reuse (new activity). BFR benefits identified in literature can also be organized according to its nature and scale within an urban planning perspective.

BFR projects generate benefits at different spatial scales, ranging from the project site to the metropolitan territory to which the redeveloped site belongs (Figure 1). At the local scale (depicted with zone ❶ in Figure 1), BFR generates direct benefits most often associated with the rise of property values and the creation of added value by the new activities established there (commercial, residential, services, etc.). These are mainly private benefits for the investors of BFR projects. If the site is reconverted into a recreational park, it can generate non-market benefits for the local population who will be able to access this space – often nearby residents (De Sousa 2003).

In the immediate proximity of the brownfield (depicted with zone ❷), BFR reduces or eliminates health and/or environmental risks and various nuisances for local residents and workers. This generates indirect benefits, i.e. those that manifest themselves off-site, which often also materialize through a rise of surrounding property values. Economists have traditionally measured these benefits using hedonic pricing (Haninger et al. 2012; Linn 2013).

BFR projects also generate benefits beyond this scale: they can also contribute revitalizing the economy of peripheral neighborhoods (❸), by attracting investment and creating jobs on the periphery of redeveloped areas (Jenkins et al. 2006; Paull 2008).

On the scale of the urban or metropolitan territory (❹), BFR makes it possible to densify urban planning, which indirectly avoids the construction of public infrastructures such as water, electricity, sanitation, public transport and road networks, reduces transport costs (Mashayekh et al. 2012), energy consumption and air pollution. When BFR is used to recreate urban ecosystems, it can contribute to the city's climate change adaptation objectives (e.g. controlling urban heat), to ensure the preservation of green and blue ecological spaces, and reduce air pollution (Zhong et al. 2020). Thus, BFR makes it possible to avoid costs, both financial and environmental, which globally benefit the entire population of the metropolitan area.

BFR can also generate environmental benefits outside the metropolitan perimeter (❺) by avoiding external urban growth. This contributes to reducing the consumption of natural and agricultural areas, enabling the preservation of numerous ecosystem services associated with these areas.

Finally, BFR can also help eliminating environmental nuisances which, depending on the case, can extend beyond the sites and their immediate proximity (❻), as contaminants present in the soil can, for example, migrate through groundwater several dozen kilometers away from the sites, generating diffuse risk in regard to human health and the environment.

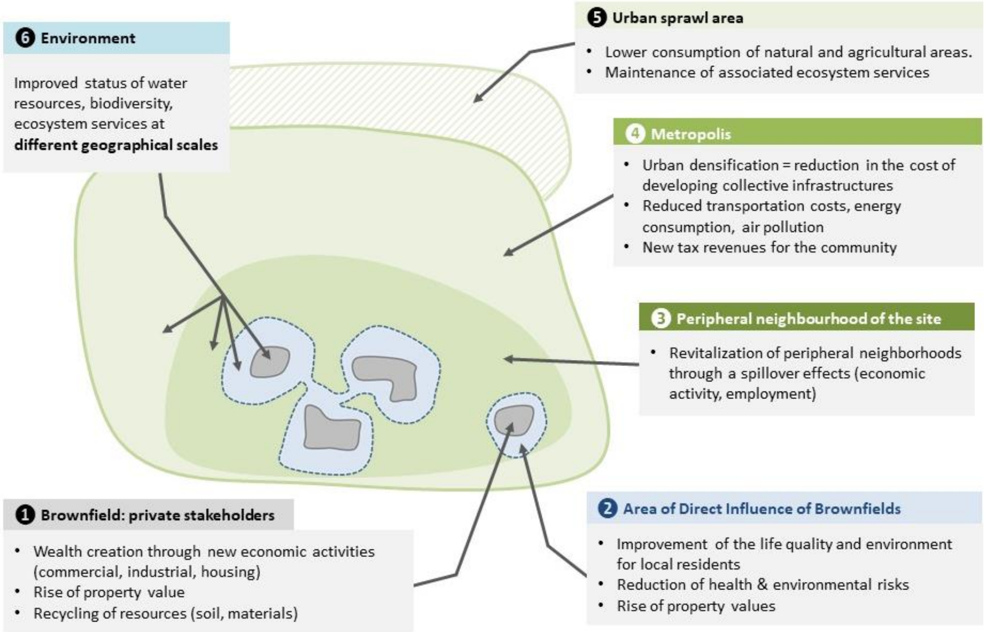

Figure 1 - The spatial scales and nature of benefits associated with BFR.

Urban planning ex-ante analyses of a portfolio of BFR options involve thus multiple benefits, which vary according to the sites and the implemented future land use activities.

Which economic evaluation methods are suitable for a regional scale approach?

The most widely used method to value the impacts of BFR is that of hedonic pricing (Ameller et al. 2020), which consists on identifying statistical differences between property values impacted by brownfields and others. Hedonic pricing studies are arguably better suited for residential zones due to the number of properties and frequency of transactions. However, property values hardly reflect global BFR benefits such as improved water regulation, reduced GHG emissions or avoided negative externalities of urban sprawl. The hedonic pricing method is well suited to assess BFR benefits of projects that have already been implemented (ex-post), and particularly for cases that involve commercial and residential areas, for which real state values are frequently sensitive to improvements in near surroundings.

The second economic method that can be used to value BFR benefits is the avoided cost method (Farber et al. 2002; Christie et al. 2012). An example of avoiding costs through BFR is accounting for the opportunity to reduce urban sprawl. Costs of urban sprawl include expenditures on creating public infrastructure and services, transport costs due to longer distances, GHG emissions, and even health-related costs (Trubka et al. 2010a; Trubka et al. 2010b; Trubka et al. 2010c). For instance, De Sousa (2002) carried a CBA concerning industrial and residential development on brownfields and greenfields in the Greater Area of Toronto. The author concluded that both industrial and residential scenarios resulted in significantly higher net benefits by redeveloping brownfield sites as compared to greenfield development, where transport costs played a substantial role. Other studies indicate that compact city development report savings as high as 20 to 45% in land resources, 15 to 25% in the construction of local roads and 7 to 15% in the provision of water and sewage facilities, as compared to market driven suburbanization (EEA 2006). In a general note, it is clear that avoided costs can help assessing some of the BFR benefits (but not all of them). At the same time, the approach for estimation remains affordable even within the territorial scope, and results can be reliable.

Both property values and avoided costs are known as revealed preferences methods because they use market information to deduce (or 'reveal') the monetary value of benefits. On the other hand, stated preferences directly ask individuals to elicit their willingness to pay for a certain benefit. This is the case of the contingent valuation and choice modelling approaches. For example, stated preferences approaches have been used to estimate the monetary values of preferences for reducing the human health risks associated to contaminated sites (Alberini et al. 2007a; Tonin et al. 2012). Furthermore, Powell (2002) used a contingent valuation survey to complement results of a property values study on the preferences of proximity to a hazardous waste site. Stated preferences are knowingly useful and well suited to explore non-market values, especially in absence of prior information. Although there is current need to continue carrying stated preferences studies to improve data availability (Ameller et al. 2020), such methods are designed to assess a reduced number of benefits (frequently only one). Consequently, it would be costly and complicated to carry stated preference experiences to evaluate separately the multiple benefits of a portfolio of sites and possible future land use activities.

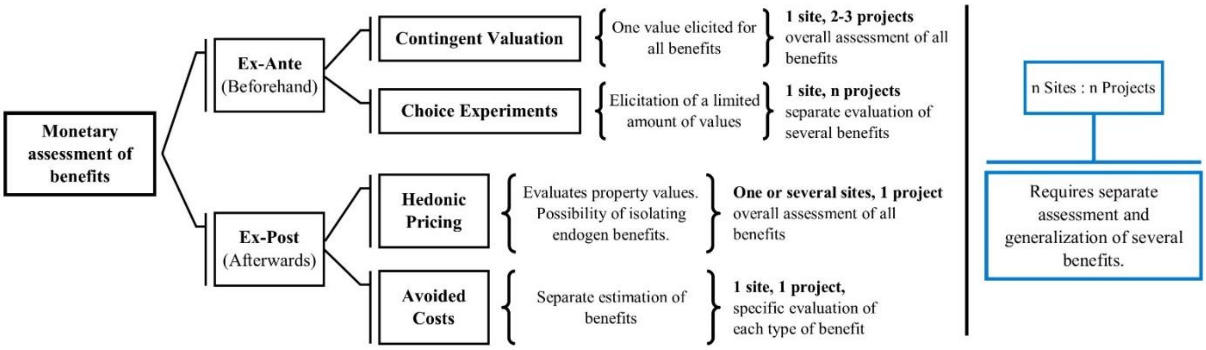

Figure 2 - Typology of economic methods used to evaluate the benefits of BFR.

None of the previously described methods is in itself designed to evaluate all the potential benefits of implementing various project alternatives at different sites (Figure 2). In consequence, an effort on this scale would require either the use of several evaluation methods simultaneously, or an approach based on benefit transfer.

Material and methods

The case study

To illustrate the empirical application of this analysis, the approach is applied to a small portfolio of brownfields of the "Vallée de la Chimie" or "Valley of Chemical Industry" (VoCI), which is a large industrial area embedded within 12 municipalities located at the south of Lyon. Since 2010, an Urban Planning Agency have been supporting the redevelopment of about thirty brownfields (representing 180 ha) through the call for projects ("Appel des 30!", also known as "A30!"). This paper deals with a portfolio of five of these sites located at the municipality of Saint-Fons (Figure 3), and addresses the monetary valuation of benefits for five possible future land use activities (Table 1).

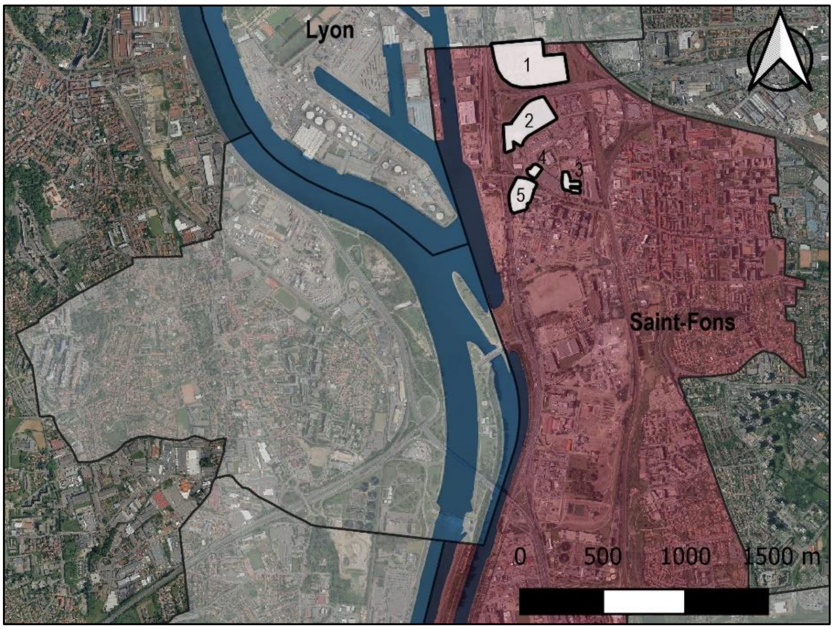

Figure 3 - Selected sites of the case study

	Future Land Use activities
1	**Soil recycling factory** is a private initiative seeking to produce artificial functional soils by recycling inert soil (silt, mud, gravel) generated by urban development works (excavations, constructions) and organic waste (compost). Currently, the demand for fertile soil of the metropolis is met by importing natural fertile soil.
2	**Biomass growing** consists in generating an economic return while simultaneously contributing to a greener landscape and ecological services at the scale of the territory. The installation of urban forests would therefore produce biomass to supply local energy production units which are currently based on domestic waste incineration; it would also open the possibility of simultaneously developing public walks and ecological corridors.
3	**Solar energy** consists in the integral concession and use of sites for the implementation of photovoltaic panels, thus contributing to reach sustainable development objectives (10 to 15% of renewable energies by 2020).
4	**Biomass incineration plant** involves creating new infrastructure combining incinerators, waste recycling units, and biomass burning units with the purpose of producing electrical energy.
5	**Industrial redevelopment projects** (IRP) relate to three domains which are politically encouraged in the VoCI to generate economic dynamism, tax incomes and employment: the chemical industrial production, clean-tech initiatives and innovative initiatives.

Table 1 - Envisaged future land use activities

Methodology

The approach used in this study relies on the use of simple benefit transfer functions. Benefit transfer consists in using economic information obtained at one case study to make inferences about the economic value of environmental goods and services at another place and time. Using this approach, economic estimates are either transferred as monetary value units or as value functions conditioned on explanatory variables that define the attributes of the new case study (Wilson and Hoehn 2006). Figure

4 provides an overview of this 3 steps approach. The first step consisted in identifying the main benefits (b_1 to b_k) that would be generated by each possible future use activity (j_1 to j_n) on each site (i_1 to i_n). This was organised using a set of matrixes -one per site- to represent the expected benefits of each future use activity. Thus, each cell [b, j] taking the value 1 if the concerned benefit is expected to appear with the implementation of a certain future use activity, and zero otherwise. Step 2 consisted in establishing a coherent way for valuing the benefits of each future use activity using references in literature and the data obtained from interviews with the urban planners of the VoCI. Finally, the third step consisted in constructing very simple benefit transfer functions (as a function of the size of the site) to assess a monetary value for each cell with expected benefits within the matrixes. The three steps of this approach (identification, estimation and extrapolation) were presented and discussed with the experts of the Metropolitan Council.

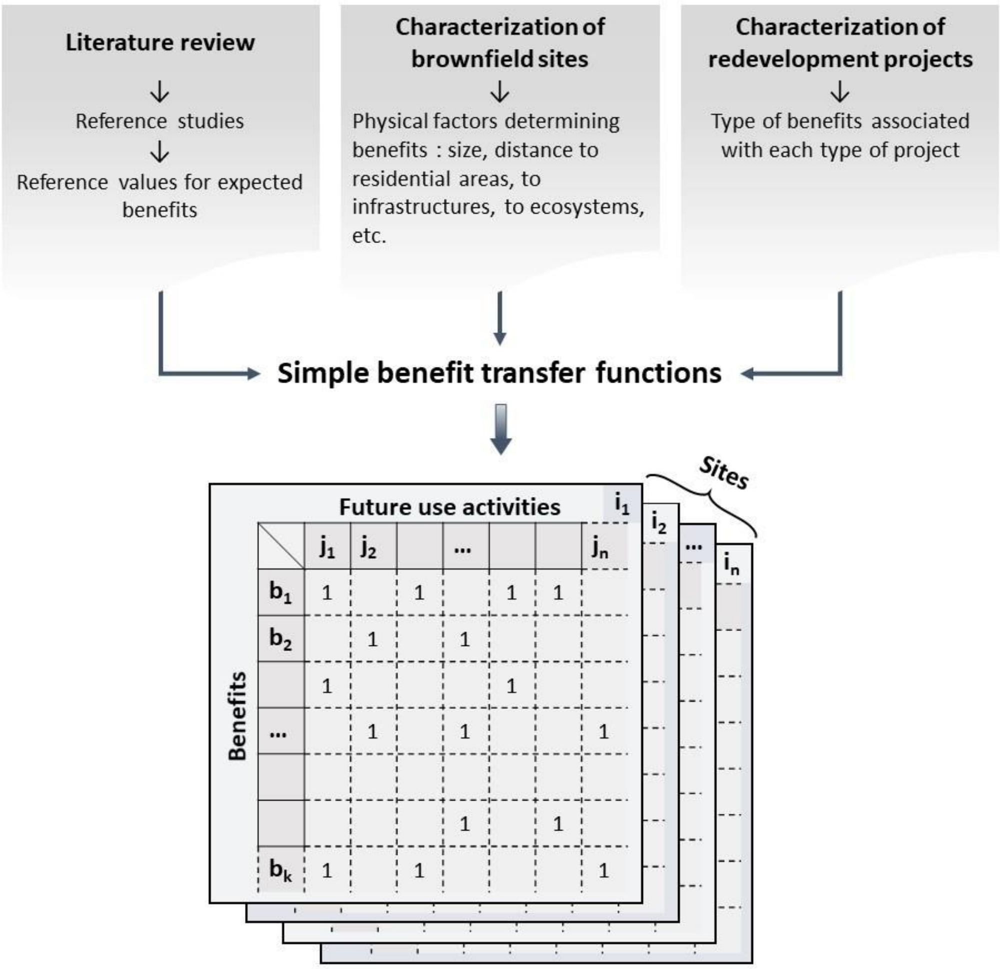

Figure 4 The benefit transfer approach and the matrix of expected benefits.

Results

This section details the identification, estimation and valuation of each type of benefit, using the approach described above.

Identifying the benefits of BFR opportunities

Table 2 presents and organizes the list of identified benefits of each future land use activity, classifying them into private, social or environmental.

	Soil recycling factory	Biomass growing	Solar energy farm	Biomass energy plant	IRP
Private Benefits					
Private revenues / Added Value	✓	✓	✓	✓	✓
Reduced transport costs	✓	✓			
Biomass recovery		✓			
Image/Reputation			✓		
Social Benefits					
Local tax revenues	✓			✓	✓
Job creation	✓			✓	✓
Environmental Benefits					
Reducing CO_2 emissions	✓	✓	✓	✓	
CO_2 sequestration		✓			
Reducing urban sprawl	✓	✓		✓	✓
Water regulation		✓			
Reducing the import of fertile soil	✓				
Biodiversity		✓			

Table 2 - List of identified benefits.

The use of in-depth interviews for the qualitative identification of the benefits was a key element of the research. The regional approach requires accounting for values involving multiple stakeholders. Within the context of an industrial zone as VoCI, this study aims at including all benefits accruing to private investors and the community. For the former, the analysis accounts for the creation of value as an important element for a healthy growing economy. This also allows assessing the financial viability of the activity. As for the latter, this study includes the community by accounting for the budget of public institutions. Certain benefits such as the value of existence of biodiversity, the improvement of aesthetic characteristics of the area, or enhancing quality-life by supressing nuisances were initially identified as potential benefits, but were later excluded from the estimation because existing reference studies were generally not transferable to the selected sites of the VoCI case study.

Estimating Private benefits

The estimation of private benefits of the three first future land use activities include the net revenue for investors which was evaluated using data provided in their proposals to A30! (2018). Reduction in transport costs (avoided cost) is also estimated as side-benefits.

The soil-recycling factory was the only activity with a detailed business plan available, with a detailed financial proposition for a 4.5ha project. Table 3 displays the financial flow planning for a period of 20 years and for a private actualisation rate of 6%. For sake of comparison, the total net value is divided by 20 and by 4.5, which equals an average private revenue of 925€/ha/year. The soil recycling expert validated the estimated value explaining that the dynamics of the activity are still at a research and redevelopment stage, for which investors were satisfied with a balanced net value.

As for another example, the installation cost of a solar farm of 100 kWc (minimum 0.5 ha) can vary from €78500 to €120000 excluding taxes[1]. According to the interviews, this alternative reaches financial equilibrium in approximately 12 years and the return rate over investment lays around 3% for a period of 20 years. Mean indicators also help assessing the annual income of solar farms, the average capacity of the equipment is 1658.92 kWc/ha, the mean solar energy production in France is 900kWh/kWc, and the reference of market price for solar energy is 0.2617€/kWh. This adds up to an annual income of 390725 €/ha. More information on the potentials of renewable energy on brownfields is available in literature (Adelaja et al. 2010).

The description of the industrial activities is too general to expect any specific estimation of income. Given that urban-planners had an expected density of employment per hectare for industrial activity, the statistical indicators of added value and employment were used as proxy for measuring direct private benefits[2]. Current prices of 2016 were actualized to 2019 by a factor of 1.04.

In addition to the expected cash flows stemming from main activities, some redevelopments can produce side-line financial benefits such as reducing transport costs. Implementing a soil-recycling factory, or producing biomass in the VoCI help reducing transport distances. Table 4 shows how transport costs

[1] Source : https://terresolaire.com – Accessed 15/05/2020.
[2] Source : www.insee.fr – Slate: '6.209D Emploi intérieur total par branche en nombre d'équivalents temps plein', and '6.201D Valeur ajoutée brute par branche à prix courants' – Accessed 30/07/2019

savings are calculated using production estimations, average distances, and references for fuel consumption and price[3].

Year (n)	**Annual cash flow**	***i*=6% $(1+i)^n$**	**Actual flow**
1	- 89 250 €	1,060	-84 198 €
2	- 42 679 €	1,124	-37 984 €
3	21 321 €	1,191	17 902 €
4	21 321 €	1,262	16 889 €
5	21 321 €	1,338	15 933 €
6	21 321 €	1,419	15 031 €
7	21 321 €	1,504	14 180 €
8	21 321 €	1,594	13 377 €
9	21 321 €	1,689	12 620 €
10	21 321 €	1,791	11 906 €
11	21 321 €	1,898	11 232 €
12	21 321 €	2,012	10 596 €
13	21 321 €	2,133	9 996 €
14	21 321 €	2,261	9 430 €
15	21 321 €	2,397	8 897 €
16	21 321 €	2,540	8 393 €
17	21 321 €	2,693	7 918 €
18	21 321 €	2,854	7 469 €
19	21 321 €	3,026	7 047 €
20	21 321 €	3,207	6 648 €
	Total net value		**83 283 €**

Table 3 - Financial cash flow of a soil-recycling factory.

[3] Formula and reference values of fuel consumption based on the formation available in: Guide méthodologique 'Information CO2 des prestations de transport'. Octobre 2012. Ministère de l'écologie, du Développement durable et de l'Energie. p. 76-82.

The following table presents the main direct financial benefits for the redevelopment activities considered in the assessment as well as the assumptions made to value those benefits.

Future use alternative	Primary private benefit	Secondary private benefit
1. Soil recycling factory	**Private revenue** 83 000 € net cumulated private benefit over 20 years (according to business plan of the company, see table 3) 925 € $year^{-1}$ ha^{-1}	**Reduced transport costs** Δ distance travelled (↘150000 km/year) × average consumption of the reference vehicle (0,27 ℓ/km) × fuel prices (1,51 €/ℓ) 61 155 € $year^{-1}$ ha^{-1}
2. Biomass growing	**Private revenue** [selling price (30 €/MWh) - cost (18€/MWh)] × yearly production (10 tn/ha) 247 € $year^{-1}$ ha^{-1}	**Reduced transport costs** Δ distance travelled (↘91 km/year) × fuel consumption (0,3ℓ/km) × fuel prices (1,51 €/ℓ) 42 € $year^{-1}$ ha^{-1}
3. Solar energy farm	**Private revenue** Nominal power (1658,92 KWp/ha) × expected performance (900 kWh/ KWp) × expected selling rate (0,262 €/kWh) 390 725 € $year^{-1}$ ha^{-1}	
4. Biomass energy plant	**Added value** Expected added value (306 885,3 €/FTE/year) × expected number of employees (24 FTE/ha) 7 365 247 € $year^{-1}$ ha^{-1}	
5. Industrial Redevelopment Projects (IRP)	**Added value** Expected added value (183 041,6 €/FTE/year) × expected number of employees (17 FTE/ha) 3 111 707 € $year^{-1}$ ha^{-1}	

Table 4 - Summary of the private benefits estimation.

Social benefits

During the interviews, the direct social benefits of BFR for the community involving the enhancement of neighbourhood life-quality was considered marginal by the interviewee, as brownfields are nested within a large industrial zone, and their redevelopment only marginally improves the quality of life of residents. Moreover, the literature search did not allow finding any study assessing BFR social benefits for a similar context, which impeded the use of literature references to approximate the value for this benefit.

BFR also contributes to social benefits by increasing employment and tax based revenues. For the former, Table 5 displays the average ratio of direct jobs creation for each future land use activity as expected by local urban planners. This was not monetized but kept as a separate indicator.

	Jobs creation per hectare
Soil recycling factory	0.7
Biomass growing	0.1
Solar energy farm	0.3
Biomass energy plant	24
IRP	17

Table 5 - Expected job creation per hectare by future land use activity.

- *Increased tax incomes*

Concerning tax-base revenues, this study accounts for local taxes only, which include the real estate taxes (built and not built), the real estate business contribution (CFE) and business contribution on added value (CVAE). The estimation of taxes relies firstly on the relevance of taxes for each future land use activity, this was validated by urban planning administration as shown in Table 6. This under the assumption that sites are currently uniquely paying for the unbuilt real estate tax and once the future use activity is implemented, all the surface is accounted for as built real estate (if it corresponds with Table 6). The gain on local taxes is thus calculated by adding the CFE, CVAE and the difference between built (B) and not-build taxes (NB). The calculation of these taxes is available under request.

	NB Real estate	B Real estate	CFE	CVAE
Soil recycling factory	✓	✓	✓	✓
Biomass growing	✓			
Solar energy farm	✓			
Biomass energy plant	✓	✓	✓	✓
IRP	✓	✓	✓	✓

Table 6 - Legal correspondence of taxes according to the urban planning administration.

- *Life quality improvements*

A point of impasse was found when trying to assess benefits concerning the quality of life of inhabitants such as: suppression of brownfield nuisances, health improvement, and aesthetic and/or cultural values. The difficulty is that no references were found suitable to transfer the value of these benefits due to the particular context of the VoCI case study.

The literature provides several studies addressing the evaluation of social values. For instance, Letombe and Zuindeau (2001) carried a hedonic pricing study on the districts of Lens, finding that visibility of industrial brownfields may reduce residential property values by 10%. A different model of the same study evidenced that homes increased their value when they were far away from brownfields by approximately 1% for a distance of 100 meters. Similarly, another study concerning transactions of apartments on the city of Angers, found that proximity of green spaces (less than 500m) increased the value of property values by approximately 50€/m^2 (Choumert 2010; ASTERES 2016). A study carried in Lyon (Roebeling et al. 2017), used a model based on property values to find that brownfield redevelopment can increase real estate (rental) value by around 22% (this varied among a set of scenarios). Social values can also be approached using other valuation methods. Alberini et al (2007b) used a choice experiment to estimate the willingness to pay for clean-up programs for sustained health-risk reductions in Venice, Milan, Bari and Naples. Other literature examples also show how willingness to pay surveys can be used to elicit the recreational values (e.g. implementation of parks and vegetation areas Harnik and Crompton 2014).

However, none of the references found in literature provided values for a context similar to the VoCI case study. In fact, brownfield sites (depicted with ❶ in Figure 5) only represent a fraction of the VoCI industrial zone (❷), which means that improvements remain relatively marginal at the level of the whole valley (since most industrial sites and landscapes will in operation). On top of that, brownfields are frequently distanced by more than 500m (❸) from residential zones (❹), which exceeds the thresholds parameters signalled within the references found in literature. Also, the residential zones and brownfields are frequently separated by some type of physical barrier such as difference in elevation, vegetation, railway lines, or highways (❺), which also isolates the effects of BFR. It was therefore uncertain to determine whether inhabitants would actually perceive the isolated impacts of BFR or if these impacts would remain mitigated by the overall perception of the industrial zone. In view of this, estimations concerning life quality improvements were not included in this study.

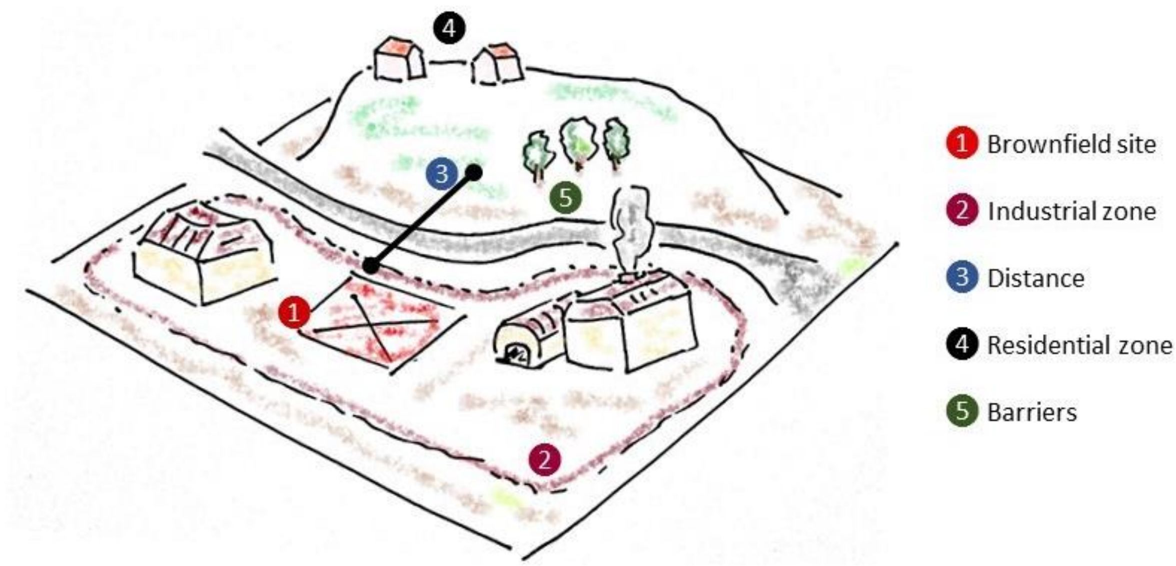

Figure 5 VoCI characteristics that condition the evaluation of social values.

Environmental benefits

- *Reduction of net CO_2 emission*

Avoided cost is the conventional approach to value reduction of CO_2 emissions (De Valck et al. 2019). Biomass growing offers three different sources for this benefit: CO_2 sequestration from growing plants, lesser emission of CO_2 due to a net gain in comparison to the emissions of traditional energy production (Solar power plants & Biomass energy plant), and lesser emission of CO_2 due to reducing transport distances. Generally, the monetary value for a tonne of CO_2 is estimated from the results of different climate models, the marginal cost of 20 €/ton/CO_2 in 2010 is expected to rise up between 95 €/ton/CO_2 and 320 €/ton/CO_2 equivalent by 2040 (Aertsens et al. 2013). For the scope of the study, the following estimations use a reference value of 40 €/ton/CO_2.

For example, 1 hectare of willow plantation stores approximately 7 ton/CO_2/year in the aerial parts, and 4 ton/CO_2 in the roots, or 0.2 ton/CO_2/year considering a 20-year plantation (INNOBIOMA 2019). If the biomass production is orientated towards energy production (biomass incinerator), this means that the carbon stored in the aerial parts is released during combustion, so only 0.2 ton/CO_2/year are truly being stored. However, producing energy at a neutral CO_2 emission still represents a net gain in comparison to fossil fuel combustion, this allows reducing 15 ton/CO_2/ha/year (INNOBIOMA 2019). In addition, setting biomass growing and incineration in the same territory may reduce the distances of transport between these activities. If the status-quo average distance is 50km, knowing that the average distance between sites lays around 4.5 km, the production requires transporting around 15 ton/ha/year, and an appropriate vehicle for that volume emits 156 g CO_2/t.km (MEDDE 2012: 78). Reducing transport distances would avoid an approximate of 0.213 t CO_2 emissions per hectare per year. One limitation of this study is that benefits associated with reducing carbon emissions and sequestration do not account for other important anthropogenic greenhouse gases (e.g. CH4 & N2O; See Forster et al. 2007).

- *Reducing urban sprawl*

In the metropolitan area of Lyon, inhabitants travel in average 3.6 times per day, for which 23 km is the average distance travelled per person per working day (SYTRAL 2016). The corresponding aggregated emissions lay around 1780 t per day, individual emissions are 2.51 kg/day in average for all active individuals, and 4.5 kg/day for individuals that go to work by car (Bouzouina et al. 2013). On this regard, reducing urban sprawl through BFR in VoCI can help avoiding transport costs including expenditures, time, and GHG emissions. Furthermore, urban -planners had no means to estimate ex-ante the travelling times or distances of future employees. Avoided transport costs through reducing urban sprawl was therefore not accounted for.

Notwithstanding, BFR reducing the pressure on greenfields outside the city also allows preserving ecosystem services. In the previously referred study of De Sousa (2002), the author argued that it was difficult to place an economic value on natural regions, and used the value of agricultural lands instead. In 2019, France average agricultural added value is about 1159€ per hectare. For the time being, there are studies that estimate the lower bound of French meadows environmental value between 600 and 1000€/ha/year (Puydarrieux and Devaux 2013: 27; CEV 2019). On top of that, the ratio of greenfields surface saved through BFR is arguably higher than 1, as there is also need for roads and public services. Sherk (2002) place this ratio at 4.5 hectares saved from being converted from rural to urban uses per hectare of BFR, as for industrial purposes, one brownfield hectare redeveloped would protect 6.2 greenfield hectares. This study includes these ratios and a conservative reference value of 600€/ha/year of ecosystem services (Table 7).

	Factor	Avoided costs
Soil recycling factory	4.5	2 700 €
Biomass growing	1	600 €
Solar energy farm	0	-
Biomass energy plant	6.2	3 720 €
IRP	6.2	3 720 €

Table 7 - Avoided costs, preserving Ecosystem Services by reducing urban sprawl

- *Ecosystem Services: Water regulation*

Regulating ecosystem services helps maintaining the quality of air, water and soil. These services are often taken for granted, but when they are damaged, the resulting losses can be substantial and difficult to restore. Regulating services include carbon sequestration, improving local air quality, moderation of extreme events, wastewater treatment, erosion prevention and maintenance of soil fertility, pollination, biological control, and regulation of water flow (Gundimeda et al. 2018). In this regard, redeveloping brownfields into green-oriented activities results in improvements of regulating services (Elmqvist et al. 2015; Cundy et al. 2016; Livesley et al. 2016). Besides carbon sequestration, which has already been addressed, biomass growing can actively provide other regulating ecosystem services. Table 8 recalls the findings of Elmqvist et al. (2015) on the monetary benefits of urban green spaces.

Service	Studies reviewed (n)	Range	Average value (€/ha/y)
Pollution and air quality regulation	9	59 - 2085	641 €
Carbon sequestration (annual flow)	5	57 - 695	391 €
Carbon storage (stock value)	3	1898 - 5127	3 094 €
Storm water reduction	6	609 - 2515	913 €
Energy savings/temperature regulation	4	34 - 1889	1 398 €
Recreation and other amenity services	2	2112 - 10413	6 263 €
Positive health effects	1		18 684 €
Total (excl. health effects and carbon storage)		3180 - 17597	9 606 €

Table 8 - Ecosystem services in urban areas. Adapted from Elmqvist et al. (2015: 103).

Water regulation is accounted for by adapting the estimates of McPherson et al. (2005). The authors estimated the avoided costs by virtue of municipal forests in five cities in USA, for which benefits included energy savings, CO_2 sequestration, air quality, storm water reduction, property increase and aesthetics. The estimation adapts low and upper bound estimates concerning water regulation (per tree), which were updated and converted to $€_{2019}$, giving 2.02 up to 32.46 € per tree per year. Then, these values were aggregated to a reference of 15000 plants/ha. In order to maintain a conservative approach, only the lower bound was taken, this equals 30 300€/ha. As this result concerns a relatively dense vegetation, it is natural that monetary value results higher than the references shown in Table 8, which concerns urban forests among others such as parks, gardens, landfills, campus areas, lakes, and pounds.

Ecosystem services concerning air quality, pollution and heat regulation where excluded from the study due to the abovementioned isolation of the sites (previous section). Both activities provide habitat for biodiversity: a small range of species such as rabbits, birds and insects (supporting services). As these species are not particularly rare and would also be isolated from inhabitants, it was considered that the marginal monetary value of option (inheritance or existence) of this service is close to zero.

- *Reducing the use of vegetable soil*

Population growth and the accompanying construction of housing, infrastructure and landscaping generate a high demand for topsoil in Lyon metropolitan area. That demand is currently met with importing fertile soil which often provides from agricultural land stripping. As part of its sustainable development policy, Lyon Metropolitan Council has decided to fully stop the import of agricultural topsoil for all works commissioned or financially supported by the Council. The proposed strategy consists in substituting imported topsoil with artificial soils produced in soil recycling factories located within the boundaries of the metropolitan area. Hence, installing such soil recycling factories in brownfields of the VoCI would reduce the stripping of agricultural land outside the city, preserving ecological services provided by those soils. Soil functions include: biodiversity pool, nutrient cycling, soil formation and water cycling (Jónsson and Davíðsdóttir 2016). These functions support ecosystem services such as biological control of pest and diseases, climate and gas regulation, hydrological control, filtering nutrients and contaminants, recycling wastes and detoxification, biomass production, clean water and raw materials provision, and cultural services. The preservation of natural topsoils in their initial location outside the city thus represent an environmental benefit associated with the construction soil recycling factories in brownfields of VoCI.

Quantifying this benefit has proven to be difficult, mainly due to lack of existing studies that could be used for a benefit transfer approach. The only study found was conducted in China, which sets limits on the possibility to transfer results. Xiao Yu et al. (2003) estimated the conservation value of soils in Qinghai-Tibet Plateau taking into account the protection of soil fertility, reduction of soil disuse and decrease of soil deposit. The final estimates of the authors rise up to 559.01 Million of 2003 Yuan, for saving a total amount of 377 tons of soil, which is roughly equivalent to 0.28 $€_{2019}$ per ton. Considering that each hectare dedicated to soil recycling stations would avoid the extraction of approximately 14 000 tons of fertile to soil per year. These estimates would set the benefits of soil conservation to 3920€/ha/year.

Given the very specific context of this study, it was considered not possible to extrapolate these results to the VoCI case study. Instead, the reference which assesses at 600€/ha/year the value (lower bound) of ecosystem services of French meadows (Puydarrieux and Devaux 2013: 27) was used to estimate the value of topsoil conservation. Knowing that greenfield stripping yields 4800 tons of vegetable soil (by digging 30cm deep), each hectare of soil recycling station would save 2.91 hectares of greenfields each year, which avoids an environmental cost of 1790€/ha/year.

Aggregation of benefits

The benefits identified in this study have been estimated in monetary values per hectare and per year (with a horizon of 20 years) to enable comparison. Table 9 display all the final estimates. These can be used to calculated the net present value (as illustrated in Table 3) of each BFR option. The separate evaluation of benefits enables using different discount rates for private social and environmental benefits. Urban planners can carry a CBA, contrasting these benefits with the costs of investment and the costs of rehabilitation to optimise the allocation of future land use activities of the portfolio.

Re-use alternative	**Benefits (€ $ha^{-1}year^{-1}$)**		
	Private	**Social**	**Environmental**
1. Soil recycling factory	**Private revenue** 925 €	**Tax revenues** 3690 €	**Reducing the use of vegetable soil** 1 790 €
	Reduced transport costs 61 155 €	**Job creation** 0.7 FTE	**Reducing CO_2 emissions** 2 520 €
			Reducing urban sprawl 2 700 €
2. Biomass growing	**Private revenue** 247 €	**Tax revenues** - €	**Water regulation.** 30 300 €
	Reduced transport costs 42 €	**Job creation** 0.1 FTE	**Biodiversity** - €
			Sequestration & reducing emissions of CO_2 608 €
			Reducing CO_2 emissions (∇ transport distances) 9 €
			Reducing urban sprawl 600 €
3. Solar energy farm	**Private revenue** 390 725 €	**Tax revenues** - €	**Reducing CO_2 emissions** 282 480 €
		Job creation 0.3 FTE	
4. Biomass energy plant	**Added value** 7 365 247 €	**Tax revenues** 251 458 €	**Reducing CO_2 emissions** 800 000 €
		Job creation 24 FTE	**Reducing urban sprawl** 2 700 €
5. Industrial redevelopment projects	**Added value** 3 111 707 €	**Tax revenues** 291 378 €	**Reducing urban sprawl** 3 720 €
		Job creation 17 FTE	

Table 9 - Benefits of BFR in VoCI.

Discussion and conclusion

The main methodological challenge addressed in this part of the research was to perform an ex-ante evaluation of the multiple benefits associated with several types of projects that can be implemented on a significant number of sites. The proposed approach consisted of three stages: 1) identifying and characterizing the various benefits of the projects under consideration; 2) identifying economic studies in the literature that have evaluated these benefits in similar contexts; and 3) deducing reference values (standardized) that would allow the extrapolation of estimates to the sites of the VoCI case study.

The completion of the work revealed many difficulties at each of these stages, not all of which could be resolved. The first concerns the quantification of the impacts of the BFR projects under consideration. Furthermore, literature does not provide enough reference studies to cover all the types of benefits in contexts comparable to the VoCI case study. In some cases, these contexts were very different from that of the chemical valley and were not transposed (e.g. Chinese study on the use of vegetable soils). Another limitation of the benefit transfer approach is the uncertainty linked to choice when several reference values are available, e.g. the choice of carbon price (40€/ton CO_2), for which market values can be found as low as 5 €/tCO_2, while other studies place a value of 90€/ton CO_2 (See Therond et al. 2017). Finally, the transfer of values had to be carried out in a very simple way - i.e. on a per hectare basis - due to the absence of meta-analysis for more detailed transfer functions, and this even for the benefits best documented in literature.

In spite of these limitations, the methodology portrayed in this paper does exhibit how regional ex-ante approaches can be approached, especially for types of case studies that are well documented in literature. A very recent study also exhibits the usefulness of benefit transfer to evaluate BFR benefits (Chateau et al. 2020). The results obtained in this paper invite further development and use of the benefit transfer approach to unleash enhanced economic analyses of BFR at regional scales. Hence, more site-specific studies valuing the benefits of brownfield redevelopment are required to improve availability of references for regional scale evaluations.

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