Estimation of Comparative Life Cycle Costs and Greenhouse Gas Emissions of Residential Brownfield and Greenfield Developments

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1. Abstract

This paper describes an approach to estimate life cycle costs and greenhouse gas emissions for residential brownfield and greenfield developments. The approach has been implemented in a spreadsheet estimation model that can be used to estimate the comparative life cycle costs and greenhouse gas emissions of major elements of residential brownfield redevelopments. The spreadsheet is available for download at http://www.cmu.edu/steinbrenner/brownfields/index.html. The estimation model includes default values and ranges based on a sample of US residential brownfield and greenfield developments and other literature sources. Model users can enter information about their own developments and compare life cycle costs and emissions with the sample for individual characteristics. Five major characteristics are included for the life cycle assessment of brownfields compared to greenfields, including brownfield remediation, residential building construction, infrastructure costs, residential building utilities and maintenance, and resident travel. Based upon the sample of brownfield and greenfield developments included, the brownfield developments tend to have lower average overall impacts due to lower travel costs associated with infill development closer to city centers despite costs associated with remediation. These averages show that a brownfield development can save each person $150 annually, compared with a greenfield development. Greenhouse gas emissions savings are an average of $1,200 kg$CO_{2e}$ per year per person. However, design decisions with respect to building type and density have large effects on overall development impacts for either brownfields or greenfields.

2. Introduction

Brownfields are properties with the presence or suspected presence of hazardous contaminants (EPA 2009). As a result, brownfield development generally incurs initial costs for environmental remediation. Despite this cost, brownfield development is being encouraged to improve overall metropolitan environmental quality and to reduce pressure for development of green spaces (Wernstedt 2006, Greenburg 2002). Brownfield development may also aid in the reduction of greenhouse gas (GHG) and other pollution emissions (Mashayekh 2012a).

While there are various federal, state and local programs and incentives in place to encourage brownfield redevelopment, there is little literature on the actual life cycle economic, environmental, and social impacts of such development (Nagengast 2011). This paper is intended to present an approach to estimate the overall life cycle costs and GHG emissions resulting from residential brownfield developments relative to traditional (greenfield) developments.

For this paper, we focus on the major categories of expenditure and GHG emissions that might differ between brownfield and greenfield developments. These categories are:

1- Remediation
2- Building Construction
3- Infrastructure
4- Utilities and Maintenance
5- Travel

Brownfield developments might have significantly lower infrastructure cost due to their compact nature and pre-existing infrastructure, such as roadways and pipelines, but may require significant capital for remediation before redevelopment begins (Burchell 2005, Leinberger 2009, Altshuler 1993). There may be other systematic differences between developments associated with income levels, diets, government expenditures, demographics or other factors, but these are not included within our scope of analysis.

We developed a spreadsheet tool which includes default and ranges of values for five different impact categories based upon a sample of brownfield and greenfield sites and other data from the literature. The tool is available for download on at http://www.cmu.edu/steinbrenner/brownfields/index.html . This tool is intended to be useful as a screening and benchmarking tool for developers and urban planners considering a new development. We encourage those using the tool to input the data that are specific to their projects and developments. In cases where data is not available for a specific project, the default data or ranges specified in the model may be used.

3. Data

A set of brownfield (BF) and greenfield (GF) development sites were identified in Nagengast (2011) and further refined by Mashayekh (2012b). This set of developments is used to develop default values of development characteristics and impacts as well as a range of characteristics and impacts. Users of the spreadsheet are encouraged to add their own development characteristics or customize the spreadsheet by adding additional criteria.

Our development sample includes pairs of two relatively large (more than 100 dwelling units within each development) residential brownfield and two greenfield developments with similar characteristics and building dates (developments completed within the last twenty years) in Baltimore, Chicago, Minneapolis, and Pittsburgh.. In Tables 1 and 2, we show data on the distance to center city, development density and walkability (measured on a scale of zero to one hundred depending on the number of amenities within 1.6 km of the site (Hoehner 2005)). On average, brownfield developments are 6 times closer to the center city, have 5 times more households per acre and have double the walkability index compared with greenfield developments. Table 1 lists data on brownfields and Table 2 presents data on greenfields. Site selection was not controlled for biases. We do acknowledge that the socio-economic characteristics of many of the infill and/or brownfield developments' residents are different than the general population. While lack of data on demographics of the brownfield/greenfield developments' residents might be viewed as a caveat in this study, the travel models used and the data generated from these models had many of the behavioral factors incorporated in them.

In addition to the comparison between brownfield and actual greenfield developments, brownfields were also compared to fast growing metropolitan neighborhoods in Table 2. These alternative greenfield locations were identified based on the fastest growing (by population) census tracts from 2000 to 2009 in each metropolitan area. Table 2 shows that brownfield redevelopments are ten times closer to city centers and have much higher development densities and walkability indexes compared with the fastest growing areas. The fastest growing census track in each metropolitan area was even more remote from the center city than the identified greenfield developments, reflecting the continuing sprawling development of these metropolitan areas.

Comparisons of development density and of long term impacts can be done on the basis of household impacts or per capita. In this paper, we summarize impacts on a per capita basis, but we provide average household size for those wishing to normalize on a per household basis. The average household size for brownfields is 2.4 people/households (Table 1), whereas greenfields have a household size of 2.6 people/household (Table 2) (Census 2010).

Metropolitan Area	Brownfield Distance to Center City (km)		Brownfield Development Density (Household/acre)		Brownfield Walkability Index	
	BF1	BF 2	BF 1	BF 2	BF 1	BF 2
Pittsburgh, PA	9	10	6	27	45	82
Baltimore, MD	5	2	14	18	78	94
Minneapolis, MN	4	1	6	58	66	92
Chicago, IL	8	14	11	11	75	78
Average	6.6		18.9		76.2	

Table 1: Distance to Center City, Development Density and Walkability in Brownfield Redevelopment Neighborhoods (Sources: Google Maps (2011) for Distance to Center City, Google Maps and Specific Information from Developers and Planning Organizations for Density and Hoehner 2005, for walkability).

Metropolitan Area	Greenfield Distance to City Center (km)			Greenfield Development Density (household/acre)			Greenfield Walkabilty Index		
	GF 1	GF 2	FG	GF 1	GF 2	FG	GF 1	GF 2	FG
Pittsburgh, PA	44	22	53	1	2	0.2	6	43	91
Baltimore, MD	29	38	56	3	2	0.1	43	55	26
Minneapolis, MN	29	14	54	3	11	0.2	74	65	0
Chicago, IL	56	39	93	0.6	3	0.2	29	57	0
Average	33.8			3.2			46.5		

Table 2: Distance to Center City, Development Density and Walkability in Greenfields and the Fastest Growing (FG) Census Tracts (Sources: Google Maps for Distance to Center City, Google Maps and Specific Information from Developers and Planning Organizations for Density and Hoehner 2005, for walkability).

Data on BF and GF development characteristics has been compiled from a variety of sources (Nagengast 2011, Mashayekh 2012b). Whenever possible, we obtained publically available data in which the developments occurred, such as US Census data by tract and origin-destination trips by zone from regional planning agencies. Case study interviews with individuals knowledgeable about particular developments were also used to augment these public data sets. For some items, regional or national averages were used for characteristics such as construction costs, energy use and maintenance. Impact measures are calculated or come from published data, such as the Texas Transportation Institute congestion reports (TTI 2009) and the economic input-output life cycle assessment model (CMUGDI 2011).

3.1 Basic Information on Developments

Basic information is intended to provide general characteristics concerning different BF and GF developments (Table 3). Since impacts are estimated as averages per capita in this research, this basic information provides a means to scale up individual impact estimates to entire developments. In assessing a new proposed development, the sample range can indicate whether or not the new development conforms to our sample. Our sample (“Sample” column in Table 3) is consisted of sixteen BF and GF sites in four cities of Pittsburgh, Minneapolis, Baltimore and Chicago.

Characteristic	Default (Median) Value	Sample Range
Size (acres)	35	3-145
Distance to city center	6.4	1-14
Number of Households	325	59-900
Household Size	2.4	1-6
Development Density	21	5-66

Table 3: Basic Information for Residential Brownfield and Greenfield Developments Based upon the Sample of Brownfield and Greenfield Developments in four cities of Pittsburgh, Minneapolis, Baltimore and Chicago

3.2 Remediation

A typical brownfield development requires varying degrees of remediation and cleanup. Brownfield remediation costs vary depending upon:

- extent and type of contamination present;
- brownfield size; and,
- proposed end use and desired level of remediation.

Among the least expensive remediation processes is to cap the brownfield site with new soil and use bioremediation. Mashayekh (2012b) assembled a set of eight remediation cost estimates from literature. The range of estimates is more than an order of magnitude, from \$ 22,000/acre to \$ 580,000/acre, adjusted to 2010 dollars. Even within the city of Chicago, a range of \$ 25,000/acre. To \$530,000/acre is reported for remediation strategies (Chicago 2003).

In practice, the highest remediation costs can be avoided by not redeveloping sites with these high costs. Selecting lower cost remediation sites allows more land redevelopment for the same fixed budget. In the eight remediation studies assembled by Mashayekh (2012b), only three included remediation costs in excess of \$ 100,000/acre. Following Mashayekh (2012b), we use an average point estimate of \$190,000/acre, with a 90% range of \$ 24,000 to \$ 550,000/acre for remediation costs. These costs have been adjusted in Table 4 to reflect 2012 figures based on the Bureau of Labor Statistics inflation rates (BLS 2012).[1]

[1] The wide range of remediation cost illustrated in Table 4 results in a significant amount of uncertainty in the cost-benefit analysis of BF and GF developments. In other words, costs and cost savings associated with BF and GF developments are significantly sensitive to remediation cost of the developments. Therefore, it is important that those who wish to use the model presented in this paper and the associated spreadsheet, use remediation costs specific to their projects to conduct a more accurate comparison.

	Default (Median) Value	Range
$ per acre	237,000	30,000-685,000
mt CO_2e per acre	605	76-1,750
$ per capita	10,970	1,390-31,710
mt CO e per capita	28	3.5-81

Table 4: Median and Ranges of Costs and Emissions for BF Site Remediation (Adjusted 2012 Costs)

The Economic-Input-Output Life Cycle Assessment (EIOLCA) tool (www.eiolca.net) was used to estimate greenhouse gas emissions based upon these remediation costs (Hendrickson 2005). The EIOLCA tool uses economic activity from US sectors to estimate energy and GHG emissions. Using the EIOLCA "other nonresidential construction" sector to represent remediation activity, $ 237,000 would represent roughly 605 mt CO_2 equivalent GHG emissions (CMUGDI 2011). Using the range of remediation costs illustrated in Table 4, 76 to 1,750 mt CO_2 equivalent GHG emissions is estimated. These values are based on the average impact per dollar amount assumed in the EIOLCA model and do not include any uncertainty within the EIOLCA model.

3.3 Building Construction

The costs and emissions from building construction can vary significantly among developments due to design decisions on the part of developers or other owners and the underlying costs of building components. Of course, the exact same buildings could be built on a brownfield and greenfield development. For example, a residential development in the Pittsburgh region (Peter's Township) is built partly on a brownfield and partly on greenfields; the two portions of the development have essentially the same types of buildings. In this analysis, we use identical default values for BF and GF construction in the spreadsheet calculation tool since the building construction decision is not inherent in brownfield characteristics, whereas remediation costs are. While default costs are the assumed to be the same, the main different between BF and GF developments within this context comes from the density of each development. In practice, our sample of brownfield and greenfield developments suggests that residences (and households) are smaller for brownfield developments and there is a higher proportion of multi-family housing.

Table 5 shows the average estimates of costs and emissions for developments. Costs are taken from RS Means (2012) while emissions come from the economic input-output life cycle assessment tool (CMUGDI 2012) using the "Residential permanent site single- and multi- family structures" sector. The average costs estimates were based on average construction quality for a 186 sq. meter, two story, detached single family home with an unfinished basement. Low costs were calculated from an economy construction of an interior 93 sq. meter, 2 story row house with no basement, while high costs were luxury construction of a two story, 334 sq. meter, detached single family home with a finished basement.

	Default (Average) Value	Range
Size (sq.m.)	186	93-334
Cost per unit area ($/sq.m.)	1130	1120-1600
Total Costs ($)	210,000	100,000- 540,000
Greenhouse Gas Emissions (mt	139	66-360
Cost per capita ($/person)	87,500	41,700-225,000
Emissions per capita (mt	58	28-150

Table 5: Default and Range of Building Construction Costs and Greenhouse Gas Emissions

3.4 Development Infrastructure

As with building construction, the costs and emissions associated with development infrastructure can be expected to vary considerably due to different component standards, terrain effects and scale economies. For this analysis, infrastructure includes local water distribution, sewage, storm water pipes and roadways. Private infrastructure for electricity and telecommunications could also be required. More generally, infrastructure costs might also include expansions to regional water treatment plants or roadway networks. Payments for utilities such as power and natural gas include the capital costs of providing these services and are estimated in Section 3.5. .

The literature on development infrastructure tends to focus upon effects of different lot sizes and the financial implications of different densities (Speir 2002, Najafi 2006, Mohamed 2009). Our estimates of median and ranges of infrastructure costs are taken from Najafi et. al. (2006) in Table 6. They used a sample of sixteen residential developments in Michigan and estimated the required physical infrastructure investments. Najafi et al. used RS Means cost figures to convert physical infrastructure into cost estimates (as done above for building costs). Subsequently, they analyzed variations with density and fiscal implications, but we simply use their estimates of costs directly and convert them into GHG emissions (Table 6). The EIOLCA model was used to convert the GHG emissions impact of the infrastructure costs (CMUGDI 2011; Hendrickson 2005).

	Road	Sewer	Water	Total
Length (ft/lot)	56 (35-116)	63 (42-164)	60 (27-164)	N/A
Capital Cost ($/lot)	3,200 (2,000-6,700)	2,100 (1,400-5,600)	3,000 (1,400-8,400)	8,300 (4,800-20,700)
Greenhouse Gas Emissions (mt CO /lot)	5.7 (3.6-12)	3.7 (2.5-10)	5.3 (2.5-15)	14.7 (8.5-37)

Table 6: Typical Capital and Operating Costs for Residential Developments modified from Najafi et al. (2006) for 2012 dollars

3.5 Building Utility & Maintenance

Building utility consumption and costs partially stem from housing construction design decisions made by developers and owners as well as household technology, demographic and socio-economic factors. In theory, the same housing could be placed in either type of development once remediation was completed. However, as shown in Table 3, development densities are higher and average household size lower in our sample of brownfield developments, resulting in variations in utility expenditures.

Other research comparing urban to suburban developments have found differences in utilities. Kaza (2010) found a small savings in residential energy use with greater density except for a 25% reduction per household moving to multi-family (+5) apartments from single family detached housing. In a Toronto housing study of different development densities, Norman. (2006) found that low-density suburban development had significantly larger GHG emissions than high density, multi-family, multi-story (+5) apartment buildings. Of course, numerous other factors may influence GHG emissions, such as micro-climate variations, energy efficiency building features, income, appliances and heating, lighting, ventilation, and air conditioning choices (NRC 2010). However, the fraction of multi-family dwelling in a development is likely to be a systematic difference between developments.

Since utility expenditures for the select brownfield and greenfield locations were not available, two public datasets were analyzed instead. Both the Residential Energy Consumption Survey and Consumer Expenditure Survey (CES) list annual household utility information. For this research, the Consumer Expenditure Survey (CES 2009) data was used. This CES dataset was chosen because it was more current at the time the research was conducted also provided values for water costs and household maintenance. The CES separates urban respondent's data into "Central City" and "Other Urban." We assume the former is a proxy for brownfields and the latter for greenfields.

Examining the CES data, greenfield developments have higher utility and maintenance costs compared to brownfields. On average, greenfield households spent 16% more on utility bills (electricity, natural gas and water) and 25% more on household maintenance than residences in brownfields annually (Table 7). The total difference including utilities and maintenance between developments is 19% as seen in Table 7.

	Central City (Brownfield) Cost ($)	Other Urban (Greenfield) Cost ($)	Percent Change from BF to GF (%)
Electricity	1,249	1,555	20
Natural Gas	498	555	10
Water	486	533	9
Total Utilities	2,233	2,643	16
Maintenance	977	1306	25
Total Annual Housing Costs	3,210	3,949	19

Table 7: Average Annual Household Utility and Maintenance Expenditures adjusted to 2012 dollars ($/household/year) (CES 2009)

3.6 Residential Travel

Nagengast (2011) using 2000 decennial census data and Mashayekh (2012b) using travel demand models examined the effect of residential brownfield developments on travel activity and travel costs. Both studies concluded that residential brownfield developments result in significant reductions in vehicle kilometers traveled (VKT) as well as the reductions in consequential greenhouse gas emissions.

Focusing on commute trips with census data and using the EIOLCA model, Nagengast (2011) reports that brownfield developments analyzed in the study are nearer to downtown, have residents that use public transportation more frequently for commuting, have similar average travel times to work and lower energy and greenhouse gas emissions for commuting. On average, the greenfield development commuters consume one-third more energy annually. Similar results are found for GHG emissions from commuting trips compared with brownfield developments.

Utilizing air pollution valuation data and travel demand models for various counties, Mashayekh (2012b) reports an average 52% reduction in brownfield developments' VKT compared with greenfield developments. Also on average, brownfield developments result in a time and fuel cost reduction of 60% and an external environmental cost saving of 66%. These external environmental costs are based on public health effects of conventional air pollution emissions. Reductions of VKT and its consequential greenhouse gas emissions are mainly due to the close downtown location of brownfield developments and fewer trips taken by the residents of these developments.

In a study done in the City of Toronto, Canada by Norman et. al. (2006), annual greenhouse gas emissions associated with automotive transportation is reported as 5,180 kg CO_2 eq./person/year for low density developments and 1,420 kg CO_2 eq./person per year for very high density inner-city developments. Low density developments were single detached dwellings with 19 houses/hectare while high density had apartments with more than five stories at 150 units/hectare (Norman 2006). While these CO_2eq figures are higher than the average GHG shown in Table 8, the difference can partially be attributed to the household size (person/household) used in each of the studies. Household size in Norman (2006) was assumed to be 3 persons per household.

Key transportation metrics are quantified in Table 8 to better outline the commuting variations between developments. One metric is the number of annual home-based work trips by automobile. The difference between BF and GF types of developments is 71 vehicle trips. One possible reason for the reduction of automobile trips is the use of public transit for brownfield commuters. Nagengast (2011) identified that 18% of brownfield residents use public transit. Using the same modal share percentage and allocated to the 71 vehicle trips, results in about 11 trips per person annually transferred to mass transit systems. The impact on the annual environment costs resulted from public transit usage will be insignificant.

Transportation Metric	**Type of**	**BF**	**GF**
Average Annual VKT (km/person/year)	HBW	1,007	2,484
	HBNW	1,840	2,979
Average Distance (km/trip)	HBW	11	18
	HBNW	7	10
Average Annual # of Trips (#/person/year)	HBW	94	165
	HBNW	269	304
Average Annual Cost of Time ($/person/year)	All Types	658	1,269
Average Annual Cost of Fuel ($/person/year)	All Types	179	346
Average GHG Emissions for Travel (kg/person/year)	All Types	337	648
Average Annual Environmental Costs ($/person)	All Types	114	329

Table 8: Summary comparison of travel measures between brownfields and Greenfields (HBW: home based work, HBNW: home based non-work); Source: Mashayekh (2012b) (All costs are adjusted to 2012 costs)

3.7 Summary of Default Value Results

Table 9 shows an annual summary of the assumed default values for typical brownfield and greenfield residential developments which is used in the comparison spreadsheet. These default values represent the average within a range of values described in the above sections. In these summaries, capital costs for remediation and construction are converted into annual amounts assuming a 30 year planning horizon and a 5% discount factor. Remediation GHG emissions are simply divided equally among the thirty years. Remediation costs are assumed to be $ 237,000/acre with 12 households per acre and 2.4 individuals per household, all Mashayekh (2012b) rates adjusted to 2012 rates. Building energy savings are based on the 5% estimate developed above. Travel costs, costs of time and emissions come from Table 8.

While brownfield developments have costs for remediation and housing construction per capita, their inner city location results in savings in travel costs. Brownfield and greenfield sites can be compared using the 'impact comparison' columns in Table 9. These impact comparison columns are calculated by subtracting brownfield values from greenfield values. Therefore, a positive number indicates a lower cost or GHG value for brownfields compared with greenfields. A negative number indicates greenfields have lower cost or GHG value than brownfields. . Overall, the brownfield development is estimated to have 1% lower annual costs ($152/year), but 5% higher greenhouse gas emissions ($1,195 kg$CO_{2e}$ per person) compared to greenfield developments (Table 9). Greenhouse gas emissions have similar findings. Of course, these results are subject to considerable variation, especially with regard to building and remediation design decisions.

Categories	Brownfield Developments[1]		Greenfield Developments[2]		Impact Comparison[3]	
	Cost	**GHG Emissions**	**Cost**	**GHG Emissions**	**Cost**	**GHG Emissions**
	$/person/year	**$kgCO_2e$/person/year**	**$/person/year**	**$kgCO_2e$/person/year**	**$/person/year**	**$kgCO_2e$/person/year**
Remediation	692	1,766	0	0	-692	-1,766
Construction					0	0
Infrastructure	67	44	289	122	209	229
Housing	5,692	3,984	5,254	3,678	-438	-289
Building Utility	930	4,040	1,017	4,463	86	423
Electricity	520	2,594	598	2,981	78	387
Natural Gas	208	1,086	213	1,118	5	32
Water	203	360	205	365	2	5
Maintenance	407	285	502	352	95	66
Residential Travel – Fuel	179	337	346	648	167	311
Residential Travel - External Environmental Cost	114	--	329	--	215	--
Travel Time	658	--	1,269	--	611	--
Total	8,740	10,229	8,891	9,262	152	-1,195

[1] *same Table IV as found on "Tab 2: Brownfield Impact" in the spreadsheet downloadable at* http://www.cmu.edu/steinbrenner/brownfields/index.html.

[2] *same Table IV as found on "Tab 3: Greenfield Impact" in the spreadsheet downloadable at* http://www.cmu.edu/steinbrenner/brownfields/index.html.

[3] *Differences in cost and GHG emissions between greenfield and brownfield developments. A positive number indicates a lower cost or GHG value for brownfields compared with greenfields. A negative number indicates greenfields have lower cost or GHG values than brownfields.*

Table 9: Summary of average cost and greenhouse gas emission by impact category between brownfield and greenfield developments.

4. Scenario Analysis

To illustrate the range of outcomes possible, Table 10 below shows the comparison of best and worst development scenarios. The best development scenario refers to the lower bound value in a specific category while the worst scenario refers to the higher bound. Within our estimated data ranges, it is possible to have brownfield developments, which have higher costs and emissions per capita than greenfield developments. Having brownfield developments with lower costs and emissions is also both possible and more likely based upon our default values.

Results of this section show that in the worst case scenario brownfield developments not only do not save but costs in extra annual $9,259 per person and extra annual $100,160 kg$CO_2$e of GHG emissions per person. In the best case scenario, brownfield developments generate $9,509 per person per year, which translates to $37,392 Kg$CO_2$e of GHG per person per year.

Category	Brownfield Best Scenario Minus Greenfield Worst Scenario		Brownfield Worst Scenario Minus Greenfield Best Scenario	
	Cost ($/person/year)	GHG (kgCO_2e/person/ year)	Cost ($/person/year)	GHG (kgCO_2e/person /year)
Remediation	-174	-444	-2,026	-5,171
Utilities	5,924	100,227	-6,418	-32,599
Maintenance	95	67	95	67
Travel Fuel Cost	306	311	-41	311
Travel External Cost	845		-360	
Travel Time Cost	2,262		-759	
Total	9,259	100,160	-9,509	-37,392

Table 10: Comparison of Best and Worst Scenarios for Brownfield and Greenfield Developments for Data Ranges

5. Conclusions

Overall, we conclude that brownfield developments are more likely to have slightly lower costs and emissions per resident than comparable greenfield developments based on average values presented in this research. Despite incurring significant remediation costs, brownfields tend to be closer to center cities than greenfields which results in lower overall travel costs per resident.

Our estimates presented in this paper and in the supplemental spreadsheet, are subject to considerable variability among developments in terms of costs and GHG emissions. Regarding life cycle costs, the largest categories in our default expenditures are housing construction, building utilities and travel time. Building design decisions could significantly influence the overall life cycle costs. For cost savings, the factors with greatest sensitivity are the value of travel time, the cost of remediation and the external environmental costs of pollution emissions. In terms of GHG emissions, the largest differences between brownfield and greenfield estimates are travel fuel combustion emissions, building utility emissions, and building construction emissions. The final estimates are sensitive to the assumed amounts of remediation, travel, utility use and construction estimates.

Design decisions with respect to building construction, location, building utilities and development density can significantly influence the overall costs and impacts of both brownfield and greenfield developments. If these factors are not carefully considered, remediation cost of brownfield developments could offset savings from housing or travel. Design decisions with respect to buildings or infrastructure could make brownfield developments more expensive than greenfields. For example, targeting high income development could lead to more expensive buildings and more concentrated travel in brownfields. Therefore, we encourage the use of site-specific data in making comparisons between brownfield and greenfield developments.

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