Defining targets and limits to urban sprawl: Are proposed greenbelt scenarios sufficient to achieve these benchmarks for Montreal by 2070?

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ABSTRACT

Defining targets and limits to urban sprawl: Are proposed greenbelt scenarios sufficient to achieve these benchmarks for Montreal by 2070?

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Increasing awareness of the negative effects of urban sprawl has ignited a significant debate on this issue in Montreal and has emerged as a serious concern. Rapid increase in urban sprawl between 1951 and 2016 within the Montreal Census Metropolitan Area (CMA) highlights the urgency of addressing this challenge. Efforts to protect Montreal's forests, agricultural lands, and other open areas from further urban sprawl have become increasingly important. This study assesses several greenbelt scenarios as potential strategies to control urban sprawl. To explore potential future pathways and provide guidance for future planning, this study proposes targets, limits, and warning values to urban sprawl as a reference framework. Various urban development scenarios for the Montreal CMA and its Census Subdivisions (CSDs) until 2070 are developed and evaluated. Scenarios 1 to 3 are evaluated as unsustainable, scenario 4 represents a transitional range toward sustainability, scenario 5 is somewhat sustainable, and scenario 6 is sustainable. The Montreal CMA is surrounded by valuable natural areas, including agricultural lands which provide an opportunity to establish a greenbelt around built-up-areas. This study assesses four greenbelt scenarios to evaluate their potential for curbing urban sprawl. At the CMA level, the analysis reveals that while greenbelt scenarios significantly reduce sprawl compared to the current trend, they remain inefficient to achieve the limit to urban sprawl in Montreal. None of the proposed greenbelt scenarios reaches the desirable limits or targets and fall beyond the warning values. However, at the CSD level, the greenbelt scenarios significantly affect certain areas, with Gore projected to meet its

target and several other CSDs falling within the range between the limit and the warning value, demonstrating effectiveness at curbing urban sprawl. This research demonstrates the potential of greenbelts to positively influence urban development patterns towards sustainability, even if the current proposal does not fully achieve the defined targets and limits. Further improvement and adaptation of these strategies may lead to more sustainable urban development outcomes in the long term. This study introduces a quantitative reference framework for evaluating the effectiveness of potential growth management strategies in the Montreal CMA and its CSDs. The findings offer a valuable perspective on the potential future of urban sprawl and allow for a comparison of various planning alternatives.

Keywords: Built-up area, Dispersion, Future scenarios, Greenbelt, Land up-take, Reference framework, Urban development, Urban Sprawl, Weighted Urban Proliferation (*WUP*), Weighted Sprawl per Capita (*WSPC*).

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Contribution of Authors

As the first author, I took on the responsibilities of conception of the paper, collecting, and correcting data, conducting quantitative calculations, analyzing data and results, and writing the manuscript. The co-author Dr. Jochen Jaeger played a vital role, providing guidance on conception and design, data analysis and interpretation, editing process, and contributing to overall revisions of the manuscript.

Table of Contents

List of Figures

List of Tables

1. Introduction

Currently, uncontrolled and unsustainable urban growth across the planet is one of the most significant challenges related to land-use change (Behnisch et al., 2022). In general, urban sprawl describes low-density and dispersed development which is mostly unsustainable because of its many consequences including negative environmental, social, and economic impacts (EEA and FOEN, 2016).

According to the study by Nazarnia et al. (2016), urban sprawl in Montreal has accelerated since the 1950s. The expansion notably increased at a faster rate during the years 1986-2011. Accordingly, this rapid sprawling in Montreal has profound environmental, social, and economic implications, which will become worse in the future if the current trends continue. These escalating trends demonstrate the urgency to address the issue in Montreal and propose effective de-sprawling measures and evaluate their effectiveness.

In response to increasing challenges in land use planning, the Communauté Métropolitaine de Montréal (CMM) council released the "Plan Métropolitain d'Aménagement et de Développement" (PMAD, 2011), the metropolitan land use and development plan that guide future urban development and land-use concerns in greater Montreal. The PMAD presents the vision for Greater Montreal to build appealing and dynamic living environments that are supposed to adhere to sustainable development (CMM, 2012). This study focuses on Montreal's future urban sprawl, employing scenario development and evaluation to guide more sustainable urban development than current trends.

The establishment of greenbelts surrounding cities or urbanized regions is one strategy used in some nations to control urban sprawl and reduce the proliferation of built-up areas into the open landscape (Baing, 2010; Han, 2019; Kovács et al., 2019). A greenbelt is a green space area including a forest or farmland around a city or region, where the urban expansion and the construction of buildings is restricted (Bengston & Youn, 2006). Many European countries such as Germany (Baing, 2010) and the United Kingdom (Kovács et al., 2019) took advantage of greenbelts to control urban expansion. Pourtaherian & Jaeger (2022) studied about the effectiveness of greenbelts at controlling urban sprawl in European cities. They measured and compared the level of urban sprawl in 60 European cities, 30 with greenbelts and 30 without greenbelts. According to their results, urban sprawl has been considerably slowed down by greenbelts, and in most cases, greenbelts have served to reduce sprawl. The question arises whether a greenbelt could effectively help control urban sprawl in Montreal in the future as well.

To effectively address this question and evaluate alternative planning strategies, it is essential to establish a reference framework. A quantitative reference framework is essential for making informed decisions and improving the effectiveness of urban planning efforts. Proposing a reference framework including targets, limits, and warning values in the context of urban sprawl can contribute to a real change in current unsustainable trends.

In this study, a set of seven reference scenarios is used to establish targets and limits values to curb urban sprawl, inspired by those that have been used in research from Switzerland by Schwick et al. (2018). The seven scenarios are characterized by 1A. continued increase in land uptake per person, 1B. half as much increase in uptake per person, 2. constant land uptake per person as in the base year, 3. urban sprawl increases as much as the number of inhabitant and jobs, 4. urban sprawl increases half as much as the number of inhabitant and jobs, 5. sprawl in 2070 is the same as in the base year, and 6. all new inhabitants and jobs are placed within the built-up area of the base year. Further details about the scenarios are discussed in the Methods section of the current document. In this thesis, Montreal refers to the Census Metropolitan Area (CMA) unless otherwise stated.

The study creates a framework for assessing development strategies and evaluating various greenbelt scenarios in Montreal that are based on the protected agricultural land designated by the Commission de protection du territoire agricole du Québec (CPTAQ), located around Montreal. The focus is on determining their potential effectiveness at curbing urban sprawl and mitigating its associated impacts. The following research questions will be investigated:

1. What is the range of potential sustainable or unsustainable scenarios of future urban development in Montreal? Based on these reference scenarios, what targets and limits to urban sprawl would be reasonable for Montreal?

2. How much would urban sprawl be reduced by the implementation of different scenarios of a greenbelt? Which of these scenarios meet the target and limits mentioned above? Which parts of Montreal would be more strongly affected by the greenbelt in controlling/reducing the urban sprawl than others?

The findings will be helpful for adopting an effective anti-sprawling strategy and for supporting PMAD's vision for a sustainable future of Greater Montreal.

This thesis starts with an overview of relevant literature related to urban sprawl encompassing its definition, causes, and consequences as well as methods to measure urban sprawl. In the third chapter, the study is presented as a manuscript intended for submission to a peer-reviewed journal. This manuscript features an introduction, an explanation of the data and methods employed, and study results, followed by a comprehensive discussion and conclusion.

Chapter 4 subsequently encapsulates the overarching conclusions drawn from the entirety of the thesis.

2. Literature Review

Reviewing the lecture is a necessity to understand the importance of the research. An overview of the topics discussed in this literature review is given in Figure 1.

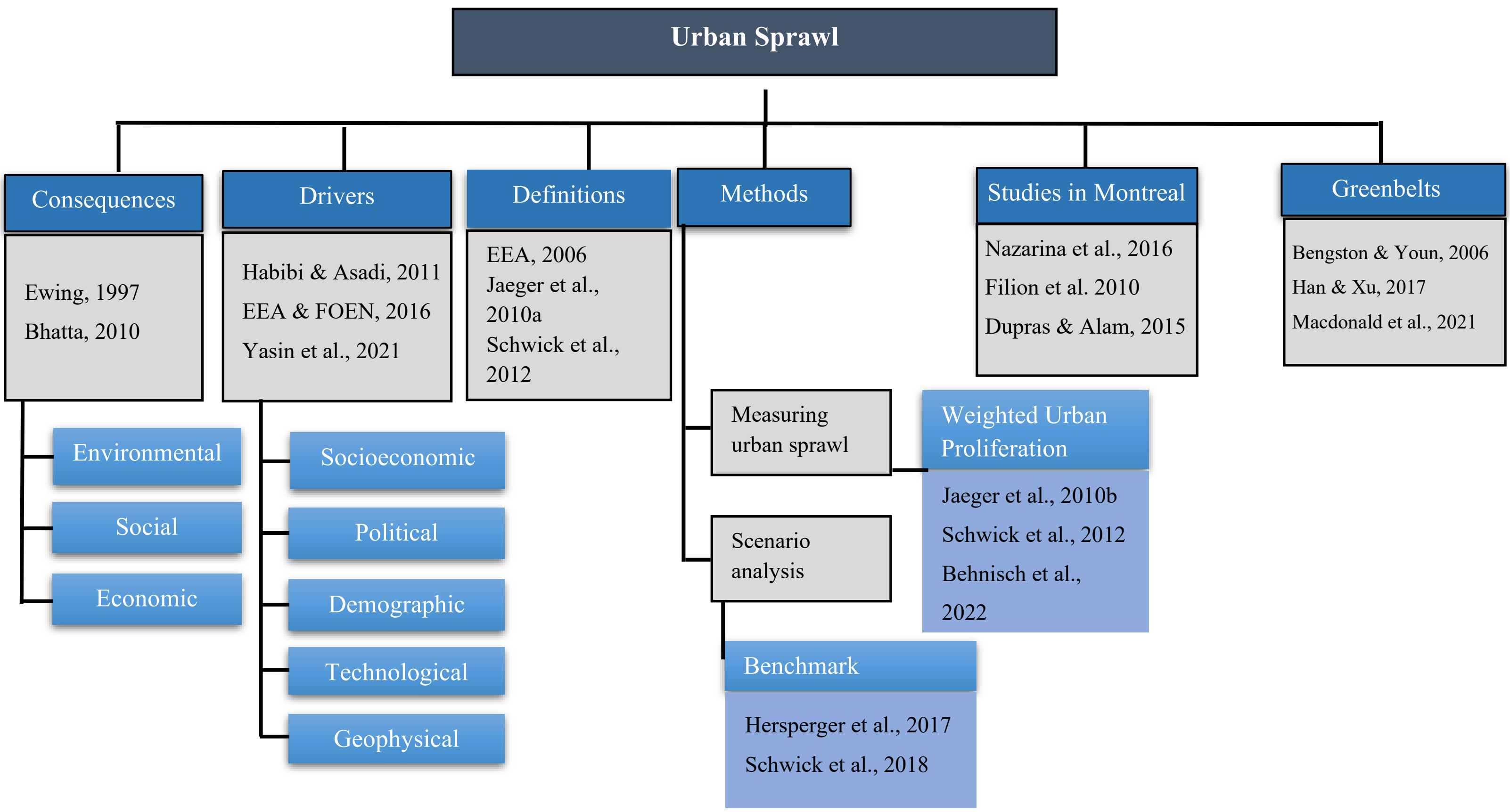


Figure 1 The literature map

2.1 Definitions of urban sprawl

Defining the term "urban sprawl" is a controversial issue in the literature. Despite various available definitions suggested by scholars, there is still no consensus on a definition of urban sprawl. This might be due to several reasons including the different interpretations based on the study fields and disciplines of the authors (Bhatta et al., 2010) or confusion with other similar terms for example suburbanization (Maier et al., 2006). Besides, causes and consequences have frequently been used to define the term urban sprawl, which is ultimately confused with the main concept (Jaeger et al., 2010a). In Table 1, examples of the most common definitions, derived from the literature, are presented. Studying the different definitions is useful to better understand the phenomenon and move forward to evaluate the available methods for measurement and models for making predictions. Schwick et al. (2012), presents one of the satisfactory definitions which differentiates the causes and consequences of urban sprawl from the main concept.

Table 1. Examples of definitions of urban sprawl

Definition	**Reference**
"The process in which the spread of development across the landscape far outpaces population growth. The landscape sprawl creates has four dimensions: a population that is widely dispersed in low-density development; rigidly separated homes, shops, and workplaces; a network of roads marked by huge blocks and poor access; and a lack of well-defined, thriving activity centers, such as downtowns and town centers. Most of the other features usually associated with sprawl – the lack of transportation choices, relative uniformity of housing options or the difficulty of walking – are a result of these conditions".	Ewing et al. (2002, p. 3)
"The physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas".	EEA (2006, p. 6)
"Urban sprawl is visually perceptible. A landscape suffers from urban sprawl if it is permeated by urban development or solitary buildings. For a given total amount of build-up area, the degree of urban sprawl will depend on how	Jaeger et al. (2010a, p. 400)

strongly clumped or dispersed the patches of urban area and buildings are; the lowest degree of sprawl corresponds to the situation when all urban area is clumped together into the shape of a circle. The highest possible degree of sprawl is assumed in an area that is completely built over. Therefore, the more urban area present in a landscape and the more dispersed the urban patches, the higher the degree of urban sprawl".	
"Urban sprawl is a phenomenon that can be visually perceived in the landscape. The more heavily permeated a landscape by buildings, the more sprawled the landscape. Urban sprawl therefore denotes the extent of the area that is built-up and its dispersion in the landscape in relation to the utilization of built-up land for living and work. The more area built over and the more dispersed the buildings, and the less the utilization, the higher the degree of urban sprawl".	Schwick et al. (2012, p. 115)
"An urban development pattern characterised by low population density that can be manifested in multiple ways. That is, an urban area may be sprawled because the population density is, on average, low. Furthermore, urban areas characterised by high average density can be considered sprawled if density varies widely across their footprint, leaving a substantial portion of urban land exposed to very low-density levels. Urban sprawl can also be manifested in development that is discontinuous, strongly scattered and decentralised, where a large number of unconnected fragments are separated by large parts of non-artificial surfaces."	OECD (2018, p. 29)

2.2 Drivers of urban sprawl

Studying drivers of urban sprawl is essential in order to find a proper solution for this phenomenon. According to the literature, the most significant and most common drivers of urban sprawl are divided into the following categories: demographic, socio-economic, political, technological, and geophysical (EEA & FOEN, 2016). Figure 2 summarizes the driving forces of urban sprawl.

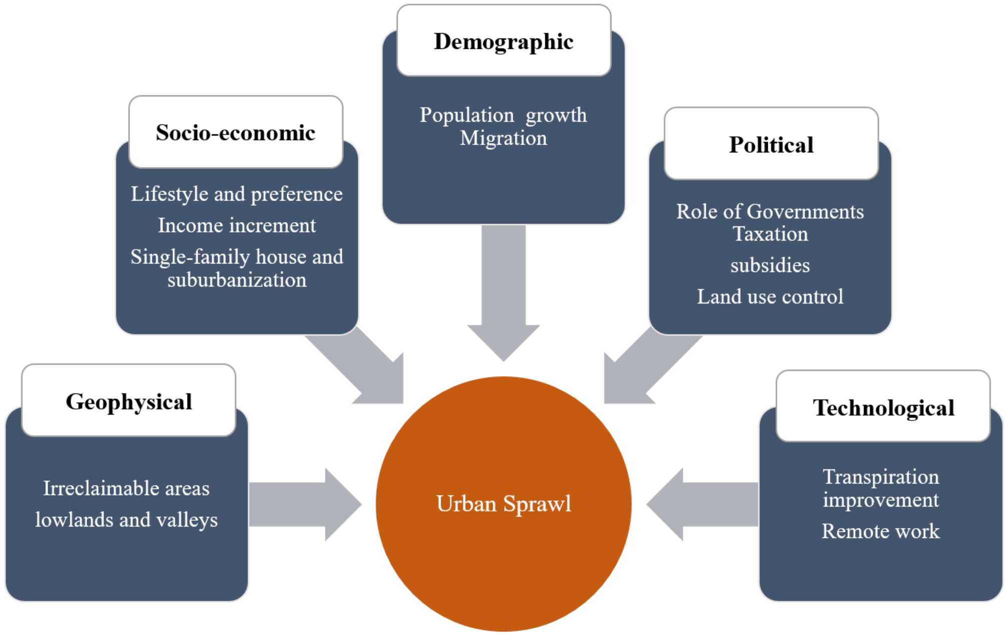


Figure 2 Driving forces of urban sprawl (adapted from EEA & FOEN, 2016)

2.2.1 Demographic drivers

One of the most significant factors that contribute to urban sprawl is the size and demographic structure of the population that affects the proportion of the built-up area. Urban areas usually must expand geographically to accommodate more people as the population grows. Migration and attraction toward urban life is an element that could affect the level of urban sprawl since it would affect the population size and structure (EEA & FOEN, 2016; Fang & Pal, 2016).

2.2.2 Socio-economic drivers

Increasing demands for living in single-family houses, living in low-density areas owning personal automobiles, imposed by societal advertisements for higher consumption levels, are often followed by increased trend toward detached housing and, consequently, increasing sprawl (EEA & FOEN, 2016). Moreover, increasing the gross domestic product (GDP) usually results in urban sprawl increment (Bresson et al., 2004).

2.2.3 Political drivers

Careful planning with a clear vision, adopting and implementing appropriate regulations play an important role in controlling urban growth and preventing urban sprawl (EEA & FOEN, 2016). For instance, governmental policies on taxes have a great impact on urban sprawl (Bart, 2010). Additionally, subsidies for owning vehicles could contribute to urban sprawl while policies that support long-term sustainable measures to restrict the building zones (e.g. through an increase in density) have a higher chance of controlling sprawl (Bertaud & Brueckner, 2005; EEA & FOEN, 2016). According to Cheshire & Sheppard (2002), for example, if limits for greenbelt-related policies were eased, the built-up areas in the town of Reading, located in South-East England would grow by 26 percent.

2.2.4 Technological drivers

Technological advancements have provided conditions that could influence urban sprawl. Transportation means, the quality of roads, and living choices are all being revolutionized by technological innovations. Improvements in transportation have allowed people to travel longer distances and have more options for living outside of cities. Moreover, the feasibility of working remotely contributes to the move of people to suburbs and creating dispersed areas (EEA & FOEN, 2016; Hardill & Green, 2003; Nechyba & Walsh, 2004).

2.2.5 Geophysical drivers

Another significant factor that has an impact on urban sprawl, is the location and land suitability for expanding the built-up areas. Irreclaimable areas are described as lands that are not physically suitable for construction, therefore they would act as limitations to further expansion of the built-up area and help prevent sprawl. On the other hand, suitable lands including lowlands and valleys provide locations for construction. If those lands, particularly agricultural land, are located close to urban areas, they are very likely to be transformed into built-up areas (EEA & FOEN, 2016; Mann, 2009).

2.3 Impacts of urban sprawl

Urban sprawl has both positive and negative impacts. Examples of positive impacts includes expanding and improving more fundamental services (e.g. transportation), facilities and infrastructures as well as enhancing people's quality of life, such as owning a garden. Higher economic production is another example of positive impacts of urban sprawl (Bhatta, 2010). However, the negative consequences of urban sprawl carry more weight and it is a necessity to study the negative impacts in order to step forward towards controlling urban sprawl. According to the literature, the most significant impacts of urban sprawl can be summarized in three categories (EEA & FOEN, 2016).

2.3.1 Environmental impacts

The most significant environmental impacts of sprawl include energy inefficiency due to long-distance commuting which leads to an increase in greenhouse gas emissions, consequently, an increase in air pollution and contribution to climate change (Newman & Kenworthy, 1988).

Furthermore, habitat fragmentation, ecosystem disruption, and loss of wildlife populations are other detrimental impacts of urban sprawl on the environment (Bhatta, 2010). Growth of cities is followed by road and pipeline expansion that permeate natural environments, causing changes in animal movement patterns, and resulting in local extinctions of wildlife populations (Bhatta, 2010; EEA & FOEN, 2016).

2.3.2 Economic impacts

Considerable negative economic impacts of urban sprawl are the high cost of expanding and maintaining infrastructure as well as public services including transportation, road maintenance, electricity, etc. These services in dispersed areas need huge investment (Ewing, 1997, EEA & FOEN, 2016).

2.3.3 Social impacts

The shortage of social interaction and insufficiency of variety in the physical forms of sprawled areas, and deprivation of access to facilities, services, and jobs, that mostly affect children, elderly people, and the poor population, are the most mentioned social impacts of urban sprawl in literature (Ewing, 1997; EEA & FOEN, 2016).

2.4 Urban sprawl in Montreal

Scholars, policymakers, and the public are increasingly agreeing that most Canadian cities are negatively impacted by urban sprawl (Filion et al., 2010; Nazarnia et al., 2016). According to the study by Razin & Rosentraub (2000) about the interlink between urban sprawl and municipal fragmentation in Canadian and U.S. metropolitan cities, the most municipally fragmented cities in Canada are Montreal and Quebec City. Although low fragmentation did not directly connect to high-density urban development, for less sprawling urban development, there may need to be low municipal fragmentation (Razin & Rosentraub, 2000). Murshid (2002) analyzed the urbanization trend in the County of Laprairie, a part of Metropolitan Montreal. Compared to population expansion, the findings demonstrated rising urbanization and land utilization rates. Although built-up area density had increased, residential population density had declined: the average number of people in a household had reduced from 3.3 in 1981 to 2.8 in 1996. Dupras & Alam (2015) investigated the impacts of urban sprawl on the value of ecosystem services in the Montreal Metropolitan Region over a 45-years period. Despite different management practices, the results show that urban sprawl's detrimental effects on ecosystem services have persisted over time. From the period 1991 to 2006, Filion et al. (2010) looked at the balance between standardization and variation in the residential density in Ottawa, Montreal, Toronto, and Vancouver. According to the results of the study, each metropolitan area follows a specific density pattern. Montreal is considered to be a more administratively fragmented and decentralizing metropolis compared to the other three metropolitan areas. On the other hand, Vancouver is experiencing increased density.

Nazarnia et al. (2016) assessed and compared the level of urban sprawl in Montreal, Quebec City, and Zurich between 1951 and 2011. They used the weighted urban proliferation (*WUP*) method to quantitatively measure urban sprawl in the three metropolitan cities.

Results of the study show that metropolitan Montreal has witnessed an explosive rise since 1951 from 0.11 to 12.60 UPU/m^2 (Figure 3). (Urban permeations units (UPU) per square meter is the unit of a measure of urban sprawl, which is also used in this thesis; see section 3.2.4.) The low utilization density and the large degree of dispersion of built-up area account for the astonishingly high value of sprawl in Montreal. The results of Nazarnia et al. (2016) highlight the serious problem of urban sprawl for sustainability in Montreal and the need for more research on how urban sprawl trends may continue or change in the future.

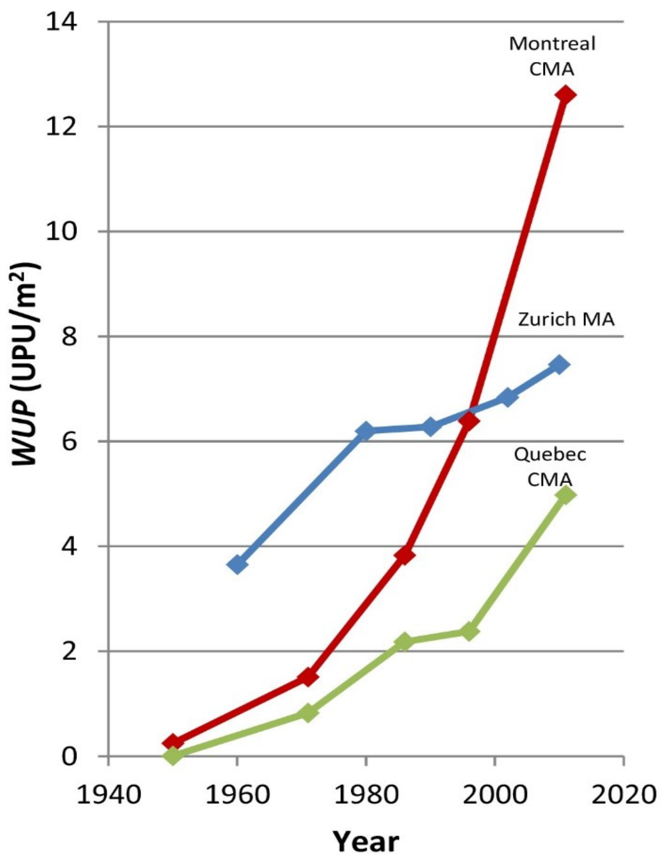


Figure 3 Degree of urban sprawl in Montreal, Quebec City, and Zurich from 1951 to 2011. Urban sprawl increased in all areas. Before 1971, Montreal and Quebec CMAs had similar, lower levels compared to Zurich MA. Since 1971, Montreal CMA has seen a sharper increase in urban sprawl compared to Quebec CMA (source: Nazarnia et al., 2016).

2.5 Greenbelts: a management strategy to control urban sprawl

There are several growth management strategies mentioned in the literature to curb urban sprawl including urban growth boundaries, smart-growth strategies, zoning regulations, greenbelts, densification, and public transportation improvement (Ewing et al., 2022).

One strategy several national governments have used to prevent urban sprawl is the establishment of greenbelts (Baing, 2010; A. T. Han, 2019; Kovács et al., 2019; Ewing et al., 2022). The greenbelt policy originated in the city of London in the 1930s and since then has attracted international attention (Tang et al., 2005; Han and Xu, 2017).

Table 2 includes some of the most common greenbelt definitions used in literature. Similar characteristics of different definitions of greenbelts include a) they are physical open areas surrounding a city, b) embracing a region or city c) the intention is to control and restrict urban expansion, and d) they are preserved and limited (Pourtaherian & Jaeger, 2022).

Table 2. Examples of definitions of greenbelt

Definition	**Reference**
"A greenbelt refers to a physical area of open space, e.g., farmland, forest, or other greenspace, that surrounds a city or metropolitan area, and it is intended to be a permanent barrier to urban expansion. Development is strictly regulated or prohibited on greenbelt land."	Bengston & Youn (2006, p. 2)
"The Greenbelt is a perpetual open area surrounding the city and the built-up area, including the woods, farm land and park etc. It has the functions of controlling the urban sprawl, protecting the farmland, controlling flood and storing water, and acting as the recreation place for citizens etc. The Greenbelt scope is determined by the government, and activities within the area are strictly limited in order to control the urban size and promote the sustainability of the city."	H. Han & Xu (2017, p. 216)
"Greenbelts are a key instrument for safeguarding the environment, providing open space and containing excessive urban expansion in a large number of cities"	Ma & Jin (2019, p. 79)
"The greenbelt policy, one type of urban containment policy, is commonly used as a means of land use control that contains physical expansion of brownfields and protects the environment"	Jeon (2019, p. 328)
"A greenbelt is a large area of mostly open land close to cities and suburbs. If sufficient land can be protected and preserved, then a greenbelt can be formed, which should be difficult for residential and commercial developments to penetrate."	A. T. Han et al. (2022, p. 2)

The greenbelt strategy is an important spatial planning tool in many cities and regions worldwide, for example in, London, Vienna, Melbourne, Hong Kong, Seoul, and Greater Toronto

(Ma & Jin, 2019). In addition, there is recent research in European cities regarding the effectiveness of greenbelts in controlling and curbing the urban sprawl (Pourtaherian & Jaeger, 2022). In their research, authors measured and compared the level of urban sprawl in 60 European cities, 30 with greenbelts and 30 without greenbelts. The results show that the greenbelt is an effective measure in most European cities; urban sprawl has been considerably slowed down by greenbelts, and in most cases, greenbelts have served to reduce sprawl.

In Canada, the idea of the greenbelt has been incorporated into planning strategies since the 1960s, and the first greenbelt was established in the capital city of Ottawa. Toronto's greenbelt (also known as Ontario's greenbelt) was established in 2005, across the Greater Golden Horseshoe (GGH) region, in order to address rapid urban expansion and protect the agricultural and natural lands. The Greenbelt Act passed by the provincial government permitted the development of a Greenbelt Plan in 2005 (Ministry of Municipal Affairs and Housing, 2017). Macdonald et al. (2021) examine the effects of the institutional and governmental structures on the management of greenbelts in southern Ontario and the Frankfurt region. According to their findings, although Toronto's greenbelt policies have successfully stopped growth within the greenbelt, policies have encouraged development of leapfrogging, which is described as development jumping over a greenbelt to reach farmland on the other side. It causes a problem since it entails building roads through a greenbelt, consequently, splitting green places.

2.6 Overview of methods for measuring urban sprawl

In this section, the most commonly used methods for measuring urban sprawl are discussed.

Galster et al. (2001) used eight variables to measure the urban sprawl in 13 cities in the United States. These variables were density, clustering, continuity, nuclearity, concentration, centrality, proximity, and mixed use. Solon (2009) used seven variables of spatial share, mean patch size, shape complexity, patch size coefficient of variance, mean nearest neighbor, interspersion juxtaposition index, and mean proximity index to assess urban sprawl in Warsaw, Poland. Torrens (2006) defined eleven sprawl-related features and used 42 metrics to measure seven of them in Austin, Texas, the USA. There are other studies using multiple variables and factors for evaluating urban sprawl (Hasse & Lathrop, 2003; Tsai, 2005). The drawback of these measurements is that it is unclear which one is the most suitable approach to describe the urban sprawl. The relationships between variables and urban sprawl and the definition used for urban sprawl are unclear. This issue is a concern since the results and interpretations can vary widely depending on the variables used (EEA & FOEN, 2016).

In another study to quantify urban sprawl, Ewing et al. (2002) developed a sprawl index according to four factors (the Four Factor Sprawl Index) and applied it to 83 U.S. cities. The four factors include a) residential density, b) neighborhood mix of homes, jobs, and services, c) accessibility of the street network, and d) strength of activity centers and downtowns. The ultimate degree of the Sprawl Index is obtained through a combination of the values of each factor, and each factor is composed of several indicators. The issue with the method is that combination of many indicators cause complications for the measurements.

Yeh & Li (2001) presented Shannon's Entropy as a measurement method for urban sprawl. According to Yeh & Li (2001), entropy can be used to measure how spatially compact or dispersed urban areas are among *n* zones or wards. Remote sensing data and Geographic Information Systems are used to define the zones. The following equation can be then used to calculate Shannon's Entropy related to the zones:

$H_n = \sum_i^n p_i \log\left({}^{1}\!/_{p_i} \right)$, where

p_i represents the proportion of urban area in the i^{th} zone, and H_n is the value of entropy.

Nazarnia et al. (2019) evaluated the entropy method based on thirteen suitability criteria for measuring urban sprawl. These suitability criteria were developed to understand and examine the metrics introduced for urban sprawl measurement, and ultimately, identifying the suitable measures (Jaeger et al., 2010a). According to the results of the study, the entropy method meets only five of the 13 criteria, and it is not a suitable method for quantifying and measuring urban sprawl (Nazarnia et al., 2019).

Steurer & Bayr (2020) proposed a wide range of methods for measuring three main characteristics of urban sprawl; 1. low population density, 2. low continuity of land use type, and 3. spatial compactness. They discussed several indicators of urban sprawl for each component, such as entropy. They concluded that the entropy method, as a popular method in the literature, can be misleading when measuring discontinuity of land use type and propose Moran's I as a potential alternative for measuring the degree of clustering in an area. In their study, they proposed indicators for measuring each of the three proposed components of urban sprawl separately, but they did not provide a measure to calculate the degree of sprawl as a united measure.

Jaeger et al. (2010b) presented a method for measuring urban sprawl, including the four metrics of urban dispersion (*DIS*), degree of urban permeation of the landscape (*UP*), total sprawl (*TS*), and sprawl per capita (*SPC*):

$$TS = DIS \times \text{urban area}$$

$$UP = TS \,/ size\ of\ the\ landscape\ studied$$

$$SPC = TS / number\ of\ inhabitants$$

Afterwards, based on Jaeger et al. (2010b), Schwick et al. (2012) introduced the Weighted Urban Proliferation (WUP) metrics as a method for measuring urban sprawl, integrating three components. These components are:

1. Percentage of built-up areas (PBA),
2. Dispersion of the built-up areas *(DIS)*, which is the "average weighted distance" of each pair of randomly chosen points within the built-up areas (more detail is provided in Appendix A), and
3. Land uptake per person *(LUP).*

According to the *WUP* method concept, urban sprawl is higher when the built-up areas increase, built-up area becomes more dispersed and the land uptake per person or job increases. *WUP*, which represents the degree of urban sprawl, is calculated as follows:

$WUP = (PBA \times DIS) \times w_1(DIS) \times w_2(LUP)$, where:

$w_1(DIS)$ and $w_2(LUP)$ are weighting functions for dispersion and land uptake per person respectively. *WUP* is expressed in urban permeation units per m^2 of land (UPU/m^2).

Similar to *SPC*, weighted sprawl per capita (*WSPC*) estimates the average contribution of each individual to urban sprawl. The value of WSPC depicts how much urban sprawl is formed on average by each job or person residing in the reporting unit, whereas *WUP* indicates how much sprawl there is in one square meter of the landscape (Behnisch et al.2022).

$WSPC = w_1(DIS) \cdot w_2(LUP) \cdot SPC.$

3. Paper manuscript: Defining targets and limits to urban sprawl: Are proposed greenbelt scenarios sufficient to achieve these benchmarks for Montreal by 2070?

3.1 Introduction

Uncontrolled low-density and dispersed urban development worldwide, frequently examined as "urban sprawl", has become a contentious issue over the last 70 years, primarily due to a range of detrimental environmental, social, and economic impacts (Behnisch et al., 2022). These include the depletion of land rich in biodiversity, increased air pollution, increased energy consumption and CO_2 emissions, the loss of agricultural land, habitat fragmentation, high costs of infrastructure development and maintenance, long commuting times, as well as social isolation among others (Frumkin, 2002; Frenkel and Ashkenazi, 2008; Bhatta, 2010; EEA & FOEN, 2016).

Scholars, policymakers, and the public are increasingly in agreement that urban sprawl is having negative impacts in most Canadian cities (Filion et al., 2010; Nazarnia et al., 2016). Venter et al. (2006) highlighted urbanization as the second most impactful human activity leading to habitat loss in Canada, posing the primary threat to endangered species and biodiversity in the country. Nazarnia et al. (2016) demonstrated that urban sprawl in Montreal has accelerated significantly since the 1950s, massively, surpassing previous rates of expansion. Rapid sprawl in Montreal carries significant and far-reaching implications for the environment, society, and the economy, with the potential for further increase if the current trends persist (Bissonnette et al., 2018; Dupras & Alam, 2015). Consequently, there is an urgent need to address the issues of unsustainable urban expansion and sprawl.

A primary challenge in implementing effective urban planning strategies is the absence of a quantitative reference framework for assessing their effectiveness. Hersperger et al. (2017)

emphasized the critical importance of assessing the outcomes of landscape planning measures. The authors highlighted a significant absence of a structured framework for predicting and evaluating planning outcomes, underscoring the need for a more systematic approach. This gap in quantitative assessment tools hinders the ability to measure the anticipated success and effectiveness of urban planning strategies, making it challenging to adjust future planning endeavors. The development of a quantitative reference framework becomes essential for informed decision-making and urban planning. Proposing a reference framework for urban sprawl could clarify the issue of urban sprawl and contribute a real change in trend. The formulation of scenarios and the establishment of targets to limit urban sprawl, aimed at evaluating the effectiveness of measures to curb urban sprawl and supporting more sustainable forms of urban development, have been discussed in various studies as important areas for potential future studies (Nazarnia et al., 2016; Pourali et al., 2022; and Pourtaherian and Jaeger, 2022).

The establishment of greenbelts around cities has been used in various nations as a strategy to control urban sprawl and prevent the proliferation of built-up areas into the open landscape (Baing, 2010; Han, 2019; Kovács et al., 2019). Defined as perpetual open spaces, such as forests or farmlands encircling cities or regions, greenbelts are designated to prevent excessive urban growth by either prohibiting construction or strictly controlling urban development (Bengston and Youn, 2006). Despite its success in the European context (Pourtaherian and Jaeger, 2022), uncertainties persist regarding the effectiveness of a greenbelt strategy for Montreal because greenbelts have rarely been used in North America. Various programs and initiatives, such as the "Trame verte et bleue" by the Conseil métropolitain de Montréal (CMM) and the Greenbelt Movement (MCV), have advocated for a greenbelt and green- and-blue corridors in greater Montreal for a number of years (Ville de Laval, 2017). These endeavors aim to protect natural areas, integrate and safeguard them in the urban landscape, and control urban sprawl, emphasizing environmental preservation and biodiversity conservation. This goal aligns with the objectives of the COP15 International Biodiversity Summit of December 2022 in Montreal. More than 190 countries agreed about the Kunming-Montreal Global Biodiversity Framework (K-M GBF), which includes ambitious commitments to "halt and reverse biodiversity loss" by 2030. The commitments encompass effective conservation and management of at least 30% of the world's lands, waters, and oceans, as well as ongoing or completed restoration efforts for at least 30% of terrestrial, aquatic, and marine ecosystems (Findlay, 2023).

However, despite the presence of these initiatives, there is a notable absence of concrete actions and of readily available information regarding their establishment and anticipated effectiveness in the Montreal.

The aim of this study is to propose a reference framework that encompasses targets, limits, and warning values for assessing future urban development planning efforts in the Montreal. In this article, Montreal refers to the Census Metropolitan Area (CMA) unless otherwise stated. This is achieved through the development of potential scenarios for the future urban development in Montreal. Additionally, the study aims to assess the effectiveness of various proposed greenbelt scenarios that are based on the protected agricultural lands, designated by the Commission de protection du territoire agricole du Québec (CPTAQ), located around the Montreal CMA, at mitigating urban sprawl within the reference framework. The following research questions are investigated:

1. What is the range of potential sustainable or unsustainable scenarios of future urban development in Montreal? Based on these reference scenarios, what targets and limits to urban sprawl would be reasonable for Montreal and its CSDs?
2. How much would urban sprawl be reduced by the implementation of different scenarios of a greenbelt? Which of these scenarios meet the targets and limits mentioned above? Which parts of Montreal would be more strongly affected by the greenbelt in controlling/reducing urban sprawl than others?

In 2011, the Communauté Métropolitaine de Montréal (CMM) council introduced the "Plan Métropolitain d'Aménagement et de Développement" (PMAD), a metropolitan land-use and urban development plan outlining the future trajectory in Greater Montreal. The PMAD articulates a vision for Greater Montreal, aiming to create attractive and dynamic living environments that align with the principles of sustainable development (CMM, 2012), e.g., through densification and transit-oriented development (TOD).

The findings of this study offer a quantitative perspective on the potential future of urban sprawl and allow for a comparison of future planning alternatives. They will be helpful for adopting a more effective anti-sprawling strategy and for supporting PMAD's vision for a more sustainable future of Montreal. These can also be considered in the new PMAD, which is currently under development.

3.2 Methods

In this study, we first calculated urban sprawl for 2011 and 2016 using the *WUP* and *WSPC* methods. We chose 2016 as the base year, considering the most updated data available. Following this, we defined seven reference scenarios to demonstrate the range of potential urban-sprawl pathways in Montreal and evaluated them based on their sustainability. Our target year for the scenarios is 2070. We then proposed targets and limits to sprawl in Montreal, which form a reference framework to assess the outcomes of potential growth-management strategies.

Next, we defined a set of four greenbelt scenarios for Montreal, which focus on protected agricultural areas. We used the proposed reference framework to evaluate these scenarios, examining whether they meet the targets and limits and assessing their effectiveness in controlling urban sprawl.

3.2.1 Montreal CMM and Montreal CMA

The Communauté métropolitaine de Montréal (CMM) consists of 82 municipalities, including the island of Montreal and its surrounding areas. The purpose of the CMM is to plan and coordinate regional development, transportation, and land-use planning. On the other hand, Census Metropolitan Area (CMA) refers to the geographic region defined by Statistics Canada for statistical purposes. The CMA serves as a standard geographic unit for analyzing and publishing various census data and other demographic information. Basically, the CMM is an administrative organization used for regional planning and development, while the CMA is a geographic region defined for statistical purposes by Statistics Canada.

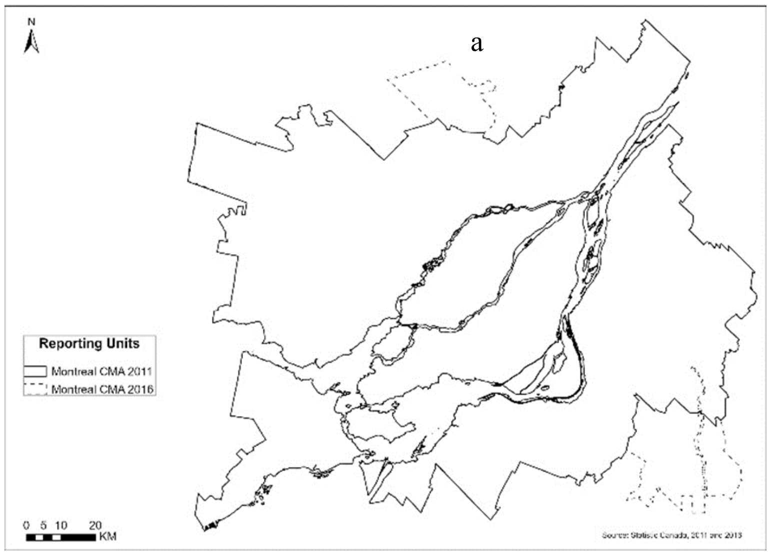
In Canada, municipalities and Census subdivisions (CSDs) are two geographic units used for administrative and statistical purposes. Municipalities are local elected authorities and encompass cities, towns, villages, and both rural and metropolitan municipalities. They are established to provide services that are most efficiently operated locally including waste disposal, public transportation, fire protection, policing, community centers, etc. Census subdivision (CSD) is a term that can refer to either municipalities, as defined by provincial or territorial legislation, or to areas that are considered equivalent to municipalities for statistical purposes. These areas may also include Indian reserves, Indian settlements, and unorganized territories (Statistics Canada, 2022; CMM, n.d.).

3.2.2 Reporting units

This study uses time series analysis. Therefore, it is essential to remain consistent with previous studies, including Nazarnia et al. (2016), which used the Montreal CMA of 2011 as reporting unit. The use the CMA and CSDs also allows for better comparability with other studies conducted throughout Canada, since they are defined consistently across Canada.

According to Statistics Canada Census data (2016), the Montreal Census Metropolitan Area (CMA) is the second most densely populated metropolitan area in Canada, situated in the southwest of Quebec province, where the St-Lawrence and Ottawa Rivers converge (Statistics Canada, 2022). The shapefiles of reporting units were obtained from the Statistics Canada database for 2011 and 2016 (Figure 4) (Statistics Canada, 2011 and 2016).

Montreal CMA Boundaries 2011 and 2016



Census Subdivisions in the Montreal CMA 2011 and 2016

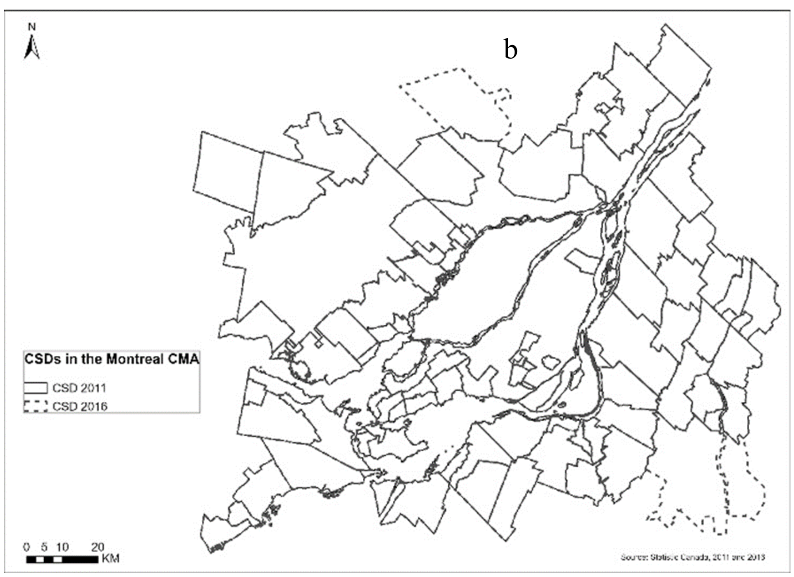


Figure 4 a. Boundaries of Montreal CMA in 2011 and 2016; b. Montreal CSDs in 2011 and 2016 (Statistics Canada, 2011 and 2016)

3.2.2.1 Boundaries for Montreal CMA

The boundaries of the CMAs were used for two points in time (2011 and 2016). To be able to directly compare the values of land uptake per person over time, and due to data availability, the boundary of the CMA for 2011 is used for the calculation of urban sprawl and its components for

2011 and 2016. The boundaries of CMA underwent changes between 2011 and 2016, including some areas within the current CMA (2016 delineation) that were not part of the 2011 delineation. The 2011 CMA encompasses 91 CSDs whereas the 2016 CMA includes 93 CSDs. Two CSDs, Saint-Jean-sur-Richelieu and Saint-Lin-Laurentides, were added. To enable a comparison of urban sprawl within the 2011 CMA's boundary, we calculated the weighted urban proliferation values within the 2011 delineation. Furthermore, the aim of study is to predict potential future changes in urban sprawl based on the results of the study by Nazarnia et al. (2016). That study used the 2011 CMA for all points in time to allow for a direct comparison of the values of land uptake per person over time. We also calculate the urban sprawl for 2016 and 2011 in the delineation of 2016 to compare with the 2011 delineation.

3.2.3 Built-up areas

The most updated and complete Geographic Information System (GIS) data of built-up areas in the Montreal CMA, provided by DMTI, pertains to the year 2016. As a result, for the purpose of this study, 2016 is used as the baseline year for all calculations.

To delineate the built-up areas, we used a combination of the CanMap Suite dataset (DMTI Spatial, 2016) and the Built-up areas of 2011 provided by Nazarnia et al. (2016) in vector format. Tables B.1, C.1, and D.1 in the Appendices B, C and D present a comprehensive list of all layers and features that were considered during the delineation of built-up areas. Tables B.1 and D.1 (Appendices B and D) present spatial data layers from the CanMap Route Logistics (DMTI Spatial, 2011) and CanVec datasets (Natural Resource Canada, 2011), as utilized by Nazarnia et al. (2016) for the delineation of built-up areas, followed by a calculation of urban sprawl for the year 2011.

The selection of built-up area features for 2016 followed the same methodology used by Nazarnia et al. (2016) (see Appendix E for details).

The changes in boundaries of the Montreal CMA between 2011 and 2016 resulted in the inclusion of two additional CSDs. To delineate the built-up areas of Montreal for 2011 within the CMA_{2016}, we employed a method similar to that used by Nazarnia et al. (2016), using the CanVec dataset in conjunction with the CanMap Route Logistics dataset for the year 2011. Figure 5 illustrates the built-up areas for both years within the boundaries of both the 2011 and 2016 CMA. The maps of built-up areas within the CMA_{2016} for 2011 and 2016 are provided in Appendix F (Figure F.1 and F.2). Figure 6 illustrates urban areas in Montreal CMA_{2011} between 1951 and 2016.

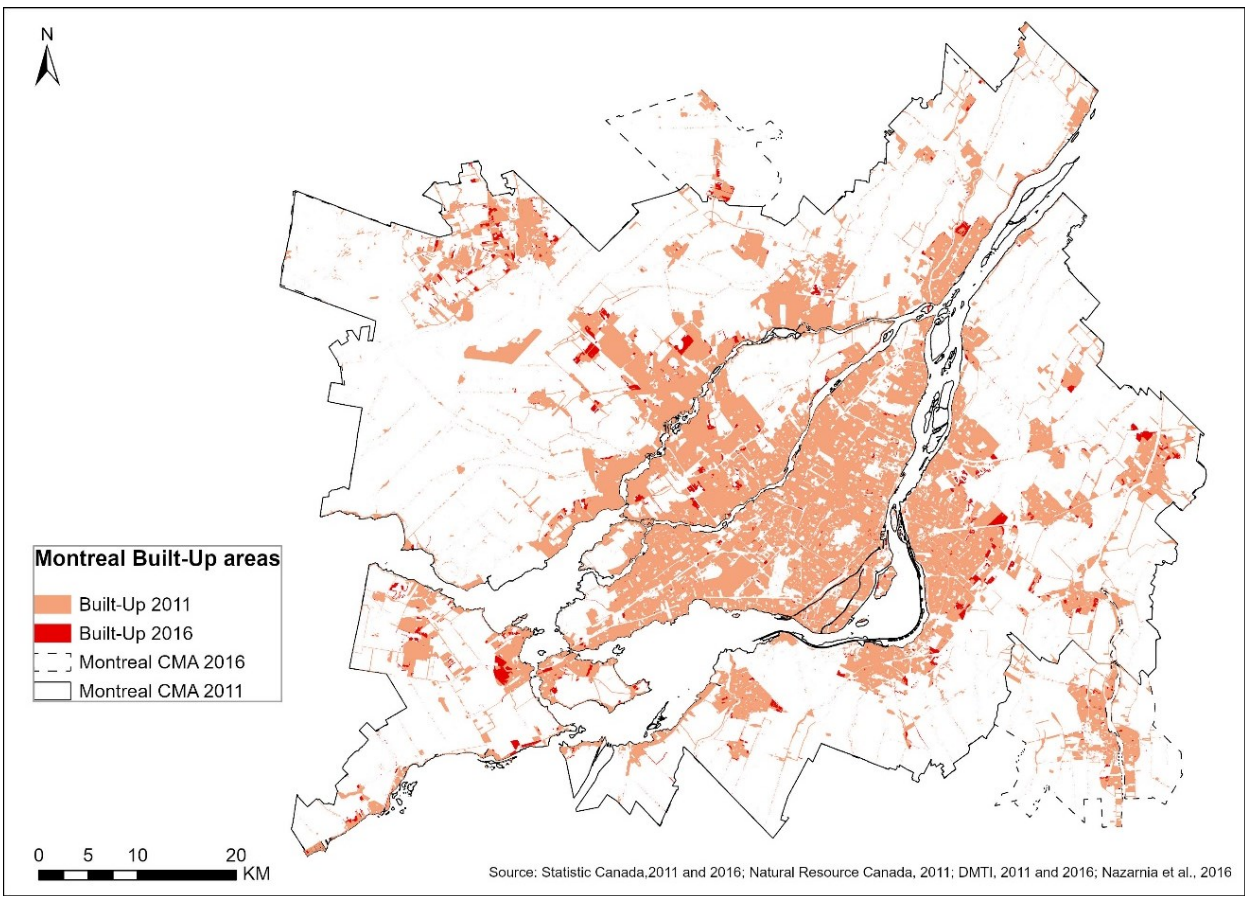


Figure 5 Built up areas in 2011 and 2016 within 2011 and 2016 CMAs (both in one map to see the differences more easily)

After applying all modifications in ArcGIS pro, the vector files of the built-up areas were converted to raster (tiff) format at a resolution of 15 m in accordance with Nazarnia et al. (2016). The projected coordinate system adopted for all GIS files was NAD 1983 UTM Zone 18N. The raster data of built-up areas were used to calculate the urban sprawl metrics.

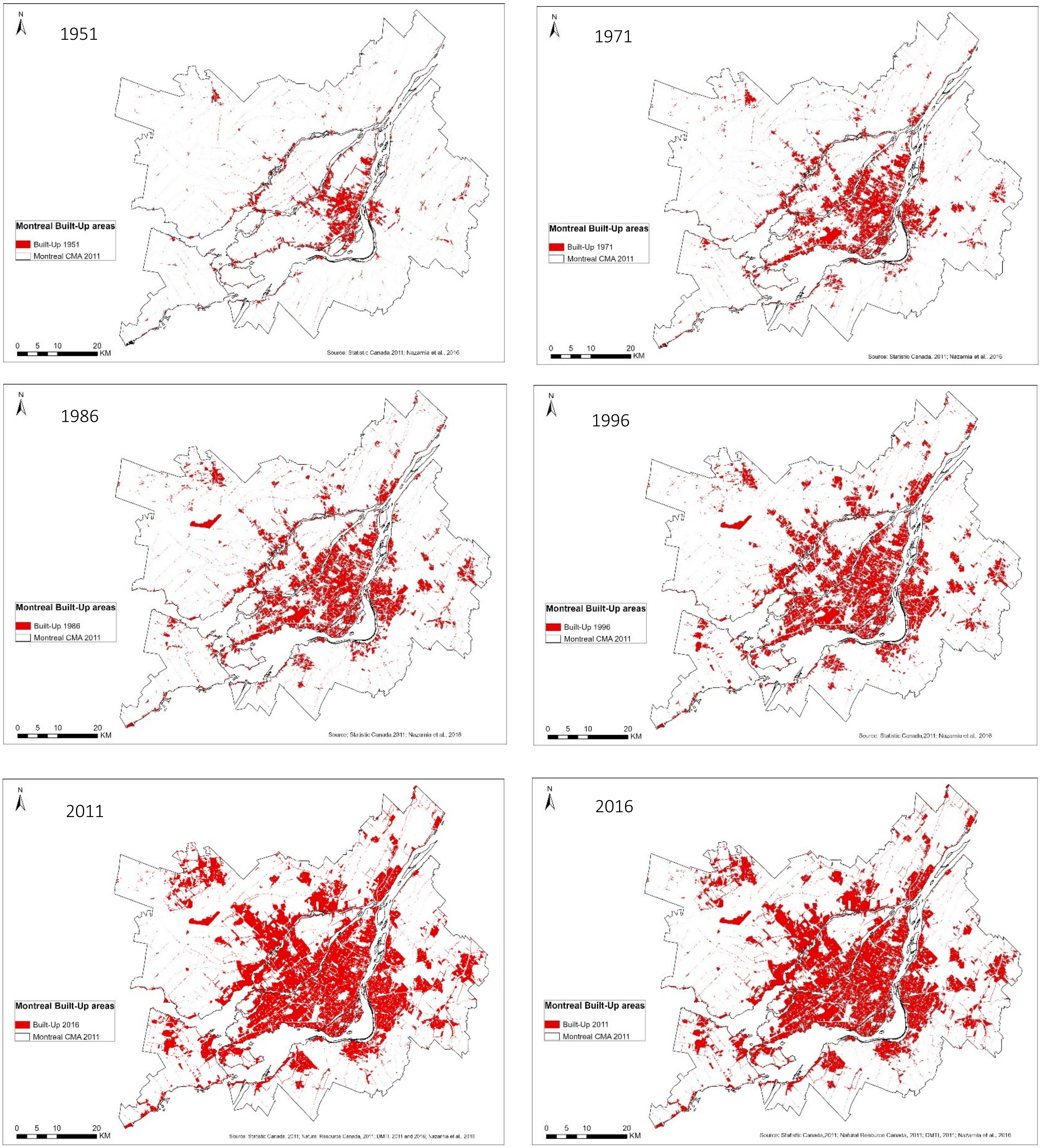


Figure 6 Urban areas in Montreal between 1951 and 2016 within the CMA_{2011} boundaries

3.2.4 Weighted urban proliferation (*WUP*) and weighted sprawl per capita (*WSPC)*

To determine the extent of urban sprawl as an independent metric, Jaeger and Schwick (2014) created the weighted urban proliferation (*WUP*) metric. The *WUP* method is used in the current study for measuring the degree of urban sprawl since it meets all 13 suitability criteria required for quantifying urban sprawl (Jaeger et al., 2010a; Nazarnia et al., 2019). Percentage of built-up area *(PBA),* the dispersion of built-up areas *(DIS),* and land uptake per person *(LUP)* are the three components of the *WUP* metric.

WUP is calculated as follows:

$$WUP = (PBA \times DIS) \times w_1(DIS) \times w_2(LUP),$$

where $w_1(DIS)$ and $w_2(LUP)$ are weighting functions for dispersion and land uptake per person, respectively. *WUP* is expressed in urban permeation units per m^2 of land (UPU/m^2).

The values for $w_1(DIS)$ range from 0.5 to 1.5; lower values are assigned to more compact built-up regions, emphasising the distinctions between compact and dispersed built-up areas more clearly. The values of $w_2(LUP)$ vary from 0 to 1, with larger values denoting greater individual land uptake (Schwick et al., 2012). More detailed explanation about the *WUP* method and its components are presented in several studied including Pourali et al. (2022), Nazarnia et al. (2016), EEA & FOEN (2016), and Appendix A.

To make the calculation *WUP* and its components in the specified reporting unit easy and fast, the urban sprawl metrics (USM) toolset was developed. The Swiss Federal Institute of Forest, Snow and Landscape Research (WSL) provides free access to this geographic information system

(GIS) toolset (Urban Sprawl Metrics (USM) Toolset - WSL), which was created to be used with ArcGIS version 10.1 or higher. The input needed for using the toolset includes:

- the binary built-up area map in ESRI raster format, which may include built-up areas and single structures such as solitary buildings,
- the reporting unit(s) in shapefile or geodatabase format,
- the reporting unit's inhabitants and employment statistics (the user must save this data in the reporting unit's shapefile's attribute table) (Nazarnia et al., 2023).

The USM toolset was used to calculate *WUP* and its components. To commence this process, the feature files of built-up areas were converted to 15 m raster cells using the method outlined by Nazarnia et al. (2016). Upon completion of calculations, the results were presented in an attribute table, which formed a new layer generated by the toolset. The USM toolset can provide comprehensive information regarding several parameters, including *PBA*, *DIS, TS, UP, UD, LUP*, and *WUP*. By analyzing these parameters, it was possible to also calculate weighted sprawl per capita (*WSPC),* which determines the average contribution of each inhabitant or workplace to urban sprawl in a CMA or CSD, in UPU/(inhabitant or job). The *WSPC* metric does not depend on the size of the reporting units, thereby providing a distinct advantage over other methods. *WSPC* metric was calculated as follows.

Sprawl per capita (*SPC*) is calculated by dividing total sprawl (*TS*) by the number of people who live or work in the reporting unit (Jaeger et al., 2010b).

$$SPC = {}^{TS}/_{N_{\text{inh+job}}}.$$

Similar to SPC, $WSPC$ calculates the average contribution of each individual to urban sprawl: (job or person residing in the reporting unit) (Behnisch et al., 2022):

$$WSPC = w_1(DIS) \cdot w_2(LUP) \cdot SPC.$$

3.2.5 Inhabitant and jobs

3.2.5.1 Inhabitants

Data about the population of the Montreal CMAs and CSDs in 2011 and 2016 were retrieved from Statistics Canada, Focus on Geography Series, 2016 Census data base (Statistics Canada, 2017) (Table G.1, Appendix G). The two CSDs of Saint-Jean-sur-Richelieu and Saint-Lin--Laurentides were incorporated into the CMA_{2016}, whereas they were not included in CMA_{2011}.

3.2.5.2 Jobs

We obtained job data from Statistics Canada for 2011 and 2016. These data provided the total number of employees across all professions in each CSD. It also included data on the number of employees who did not work during the reference week of the CSD and those who worked during that week, as well as the number of employees who worked full-time and part-time separately. The data covered all CSDs for 2011 and 2016 (Statistics Canada, 2019; Statistics Canada, 2020). Detailed calculation of total numbers of jobs and results are provided in Appendix H.

3.2.5.3 Population projection for the Montreal CMA and CSDs

We used the population projections for CMAs published by Institut de la statistique du Québec (Broadcast date: 21 October 2022). The potential future projection is based on current trend continuation (reference scenario) spanning the period from 2021 to 2041. In the context of municipalities, population projections refer to municipalities with population of 500 or more as of July 2016, excluding those with populations below 500 in the base year of July 1, 2016. If a municipality had a population of fewer than 500 inhabitants as of July 1, 2016, its population data was combined or grouped together with other small municipalities within a particular Regional County Municipality (MRC), where applicable. This results in population projection at the CSD level for 86 out of 91 CSDs of Montreal CMA 2011. The reason is that two of the CSDs, Kahnawake and Kanesatake, are Indian reserves/settlements, and as a result, there are no population or job data available for these CSDs. Additionally, both L'Île-Dorval and L'Île-Cadieux have populations of less than 500, and there are no population projection data available for these CSDs. Lastly, the two CSDs of L'Épiphanie(V) and L'Épiphanie(PE) are treated as a single municipality in the population projection, i.e., they are considered as one entity in the calculations.

Population projection data are currently available from 2021 to 2041, but we also require projections for 2070. By visually examining the trend and projection (Figure 7), it is evident that the trend begins to approximate a linear projection in later years. Therefore, we extrapolated the population data for Montreal CMA to estimate the population for 2070 using this linear trend. Between 2016 (the base year) and 2021, we performed interpolation to estimate the population. As our reporting unit for time series calculations is Montreal CMA of 2011, we subtracted the population of the two CSDs included in the CMA_{2016} but not in the CMA 2011 from the total potential projection for each year (Table 3).

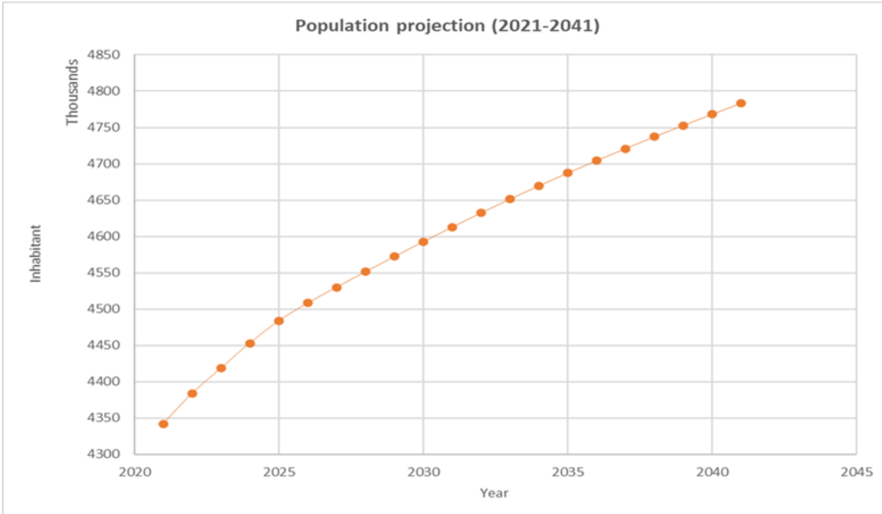


Figure 7 Population projection for the Montreal CMA (2021-2041) (Institut de la statistique du Québec, 2022)

Table 3. Population projection for Montreal CMA (2021-2041) (Institut de la statistique du Québec, 2022)

Year	Population projection (CMA2011)		Year	Population projection (CMA2011)	
2016	3,983,027		2042	4,649,257	Extrapolation
2017	4,030,022	Interpolation	2043	4,663,395	
2018	4,077,017		2044	4,677,533	
2019	4,124,012		2045	4,691,671	
2020	4,171,007		2046	4,705,809	
2021	4,218,003	Population projection by Institut de la statistique du Québec	2047	4,719,947	
2022	4,257,624		2048	4,734,085	
2023	4,290,360		2049	4,748,223	
2024	4,323,434		2050	4,762,361	
2025	4,352,634		2051	4,776,499	
2026	4,375,801		2052	4,790,637	
2027	4,396,322		2053	4,804,775	
2028	4,416,406		2054	4,818,913	
2029	4,436,089		2055	4,833,051	
2030	4,455,387		2056	4,847,189	
2031	4,474,299		2057	4,861,327	
2032	4,492,839		2058	4,875,465	
2033	4,510,710		2059	4,889,603	
2034	4,527,964		2060	4,903,741	
2035	4,544,655		2061	4,917,879	
2036	4,560,808		2062	4,932,017	
2037	4,576,474		2063	4,946,155	
2038	4,591,687		2064	4,960,293	
2039	4,606,512		2065	4,974,431	
2040	4,620,981		2066	4,988,569	
2041	4,635,119		2067	5,002,707	
			2068	5,016,845	
			2069	5,030,983	
			2070	5,045,121	

The available population projections for CSDs also only extends until 2041. As a result, we have calculated population growth values for the CSDs up to 2070 using the following method:

The population increase in Montreal, totaling 1,039,956 residents between 2016 and 2070, will be distributed among the CSDs in the same proportion as the increase in residents between 2016 and 2041. For instance, the number of inhabitants in the CSD of Montreal will increase by 132,179 people between 2016 and 2041, which accounts for 21 percent of the overall increase in the Montreal CMA during the same period. Consequently, the increase from 2016 to 2070 is also projected to be 21 percent of the total increase of 1,039,956 residents, equivalent to 216,612 residents. This projection results in a population of 1,921,3056 people in 2070 in CSD of Montreal, signifying a relative population increase in CSD of Montreal compared to 2016 of 12.7 % (Table I.1, Appendix I).

3.2.6 Reference scenarios for future development of Montreal for 2070

To demonstrate how potential urban sprawl in Montreal could change in the future, seven scenarios were developed, similar to those presented by Schwick et al. (2018) for Switzerland. These scenarios form a reference framework for defining the targets and limits for urban sprawl. These scenarios serve to explore the range of potential development paths. They show what influence certain conditions can have on urban sprawl and illustrate how important it is to quickly address the urban sprawl with spatial planning measures. Various approaches are available to determine scenarios regarding the density and spatial arrangement of built-up areas. Similar to Schwick et al. (2018), we focus on land uptake per person, the size of the built-up area, and the degree of urban sprawl. Accordingly, the seven scenarios are as follows.

3.2.6.1 Scenario 1A: Increasing land uptake per person ("Business as Usual")

In the Business as Usual (BAU) scenario, land uptake per person continues to increase (built-up areas per inhabitant or workplace). This increase is based on the previous increase in built-up areas per person in the period of 45 years between 1971 and 2016. Given the estimated population data from 2016 to 2070, as well as job data, and *LUP*, the corresponding built-up areas for 2070 can be calculated for each year:

Built-up area (m^2) = *LUP* [m^2 / (inhabitants or job)] * Number of jobs and inhabitants

The *PBA* can be calculated by dividing the total area of built-up areas by the total area of the reporting unit. In the case of the Montreal CMA in 2011, the total area of the reporting unit is 4291.69 km^2. In order to estimate potential dispersion for the future, dispersion is estimated as a function of built-up areas for 2070 (detailed explanation is provided in Appendix J).

3.2.6.2 Scenario 1B: Reduced increase in land uptake per person ("Half-trend")

Land uptake per person continues to increase assuming a trend of half the previous increase in demand for built-up areas per person over a 45-year period between 1971 and 2016. This suggests that *LUP* will increase by half as much of the previous observed trend. All other values were calculated using the same methodology as in scenario 1A.

3.2.6.3 Scenario 2: Same land uptake per person as in 2016 ("Constant land uptake per person")

Under the constant *LUP* scenario, *LUP* is assumed to remain constant at the baseline value of 2016. As in the previous scenarios, dispersion is calculated using the quadratic relationship with the built-up area, allowing for the calculation of the value of urban sprawl.

3.2.6.4 Scenario 3: Sprawl increases as much as the number of inhabitants and jobs ("Same increase as population")

According to scenario 3, the value of urban sprawl increases proportionally to the number of inhabitants and jobs until 2070. With knowledge of the values of jobs and inhabitants, as well as of *WUP* and the dispersion as a function of *PBA*, and *LUP* as a function of *PBA* it is possible to iteratively calculate the corresponding value of *PBA, LUP,* and dispersion (see more detailed information in Appendix L).

3.2.6.5 Scenario 4: Sprawl increases only half as much as the number of inhabitants and jobs ("Half increase as population")

In this Scenario, it is assumed that urban sprawl will increase by only half the rate of increase in the number of inhabitants and jobs. All other values were calculated using the same methodology as in Scenario 3.

3.2.6.6 Scenario 5: Urban sprawl in 2070 is the same as in 2016 ("Constant urban sprawl")

Scenario 5 assumes that urban sprawl in the target year of 2070 will remain the same as in 2016. This means that despite population growth, there will be no increase in the value of urban spawl. Using the same method as in Scenario 3 and with the available values of *WUP*, number of jobs, and inhabitants, the values of *DIS* and *LUP* are estimated.

3.2.6.7 Scenario 6: All new inhabitants and jobs are placed within the built-up areas of 2016 ("Constant built-up area")

The constant built-up area scenario assumes that all additional inhabitants will reside and work within the existing built-up areas as of 2016, without creating any new built-up areas. This approach handles population growth through densification of the existing built-up areas. In this scenario, the values of *PBA* and *DIS* in 2070 are the same as in 2016 values in 2070. *LUP* will be calculated based on the number of jobs and inhabitants, and the value of *WUP* will be estimated accordingly.

3.2.7 Reference scenarios for CSDs

The application of scenarios for future development of individual CSDs via population projections serves as an appropriate strategy. This choice is substantiated by the expectation that population dynamics will differ significantly among the various CSDs. These variations in demographic trends underline the importance of accounting for the unique characteristics and potential development path specific to each CSD when formulating future scenarios. Consequently, employing CSD-level population projections is a valuable approach. Moreover, this approach aids in establishing targets and limits at the CSDs level, enhancing the precision of potential future planning efforts. Using population and job data for each CSD, the urban sprawl values for scenarios 4, 5, and 6 can be calculated individually for each CSDs in the period of 2016 to 2070. Since scenarios 1 to 3 are not sustainable and are not used to define reference values, only scenarios 4 to 6 were considered for the calculation of the CSDs.

The approach for calculating the scenarios is nearly identical to that of the CMA. The calculations have been conducted independently for all 86 CSDs, encompassing three scenarios for each CSD. Using the available population and job data for each CSD in 2016, as well as the population projections spanning from 2016 to 2070, job data for the years 2016 to 2070 were computed for each CSD. This estimation is achieved by utilizing the ratio of people employed to the total population for each respective CSD, as detailed in the Job section above.

Scenario 4 assumes that urban sprawl will increase at a rate half as fast as the increase in the number of inhabitants and jobs. To estimate potential dispersion for the future in 2070 for CSDs, we estimated dispersion as a function of *PBA* (for detailed explanation see Appendix K). With all the necessary variables at hand, the value of *WUP* and its components can be calculated as explained in section 3.2.5 for scenario 4, 5 and 6 for 86 CSDs.

3.2.8 Greenbelt scenarios

The Montreal CMA is surrounded by agricultural lands, green spaces, forests, and open areas. This unique natural environment presents an opportunity to establish a greenbelt around the built-up areas. As a response to this opportunity, three greenbelt scenarios for the Montreal CMA have been formulated and explored in this study. The overarching objective is to assess the potential effects of implementing a greenbelt in the Montreal CMA, with a focus on its role in mitigating urban sprawl, with projections reaching as far as the year 2070. Inspired by Constantin's (2012) research, the following greenbelt scenarios for Montreal were selected.

3.2.8.1 Greenbelt scenario 1

Considering the land use types and distinctive features of the Montreal CMA, our approach includes all presently protected agricultural areas, as designated by the Commission de protection du territoire agricole du Québec (CPTAQ) of 2017, updated in 2023-07-31, within the confines of the greenbelt (Figure 8). A fundamental guiding principle in this endeavor was to ensure that these designated greenbelt areas receive a high level of protection, with a prohibition on any form of urban development within them.

To ensure the effect of the greenbelt, in our analysis for the year 2070, all other lands in Montreal, except for areas that should not be constructed (e.g., protected areas, specific parks, …), were classified as "built-up." This classification accounts for the anticipated development trends within the region, considering the city's growth that would not be prevented by the greenbelt.

We employed GIS layers to delineate the greenbelt around Montreal. This greenbelt, representing the protected agricultural areas, is excluded from our calculations for potential future built-up regions. Additionally, we have identified a set of other specific layers that cannot support urban development and are also excluded from the scope of potential built-up areas. The combined approach allows us to obtain a potential assessment of urban sprawl within the Montreal CMA for 2070. The following layers and areas within the Montreal CMA are excluded from potential built-up areas:

1. Current protected agricultural land designated by the Commission de protection du territoire agricole du Québec (2219.6 km^2) (CPTQ, 2017- updated: 2023-07-31).

2. Water bodies (DMTI Spatial, 2021)

3. Indian reserves/settlements (Kahnawake and Kanesatake) (59 km^2) (Statistics Canada, 2011).

4. Protected areas which include the registered protected areas published by Ministry of the Environment, Government of Quebec (Gouvernement du Québec, 2021) and the protected and conserved area defined by the Government of Canada (Government of Canada, 2023).

5. Parks (DMTI Spatial, 2018). The types of parks excluded from potential built-up areas cover botanical gardens, campgrounds, ecological reserves, exhibition grounds, golf courses, national parks, national wildlife areas, natural areas, park reserves, park/sports fields, protected areas,

provincial parks, recreation areas, sanctuaries, territorial parks, wilderness areas, wilderness parks, and wildland parks. The selection of parks followed Pourali et al. (2022) (total areas of protected areas and parks = 151 km^2).

After combining all relevant layers (Union tool) within ArcGIS Pro, the next step involved eliminating existing buildings and built-up areas from these combined layers because they already existed in the suggested greenbelt areas and should be excluded from the greenbelts (Erase tool). Subsequently, we removed the previously identified excluded areas from the entire Montreal CMA dataset, resulting in the creation of the shape file of potential built-up areas for 2070.

3.2.8.2 Greenbelt scenario 2

When analyzing the CMA map alongside the Land Use Type layer, we observed two significant open areas in the CSDs of Gore and Saint Colomban, primarily classified as forests, adjacent to the agricultural zones. We decided to incorporate all open areas within the two CSDs of the Gore and Saint Colomban into the greenbelt (Figure 9). This decision is motivated by several considerations. Firstly, it aligns with the conventional concept of a greenbelt, which is an open green area surrounding urban areas. By including these open areas, we not only expand the greenbelt's coverage but also ensure the protection of forested regions that naturally complement the concept of a greenbelt. Secondly, this expansion is pivotal in protecting forests and undeveloped areas, which plays a significant role in preserving ecological balance and biodiversity within the CSD. The considerable size of the forested areas in these regions makes their inclusion even more substantial. Additionally, by extending the greenbelt to encompass these adjacent forests, we aim to assess the potential impacts on urban sprawl in the Montreal CMA and CSDs level.

In ArcGIS Pro, we made modifications to greenbelt scenario 1 by incorporating the newly mentioned areas into the greenbelt.

3.2.8.3 Greenbelt scenario 3

For greenbelt scenario 3, we have chosen to include the considerable open areas within the Varennes CSD. These open areas, which appear to have agricultural characteristics and are not currently protected according to both CPTAQ (2022) and CMM land use type data for 2022, are integrated into the greenbelt (Figure 10). This modification was made with the aim of assessing the potential impacts and outcomes of expanding the greenbelt by adding these specific open areas within the Varennes CSD, enhancing its overall coverage.

We have identified a noteworthy change in zoning status within the CSD of Varennes, which led us to consider greenbelt scenario 3 for our analysis as a distinct scenario. In the context of the CPTAQ (Commission de protection du territoire agricole du Québec), zoning within agricultural areas is categorized into three zones: 'ZONAGE AGRICOLE' (Agricultural Zoning), 'ZONAGE NON DISPONIBLE' (Zoning Not Available), and 'ZONAGE NON AGRICOLE' (Non-Agricultural Zoning). Specifically, 'ZONAGE NON DISPONIBLE' signifies that there is no municipal zoning regulation available or determined for the territory in question.

The CPTAQ oversees the agricultural zone and authorization requests within Quebec. In the case of Varennes, it was previously classified as 'ZONAGE AGRICOLE' (Agricultural Zoning). However, in the latest update of 2023 its zoning status has changed to 'ZONAGE NON DISPONIBLE' (Zoning Not Available). While the CMM 2022 land use designation recognizes these areas as agricultural, they are not currently protected by the CPTAQ due to their 'ZONAGE

NON DISPONIBLE' classification, indicating a lack of available or determined zoning information.

3.2.8.4 Greenbelt scenario 4

Greenbelt scenario 4 brings together all the areas that were designated as greenbelt from the scenarios 1 to 3, including the protected agricultural lands, the open forested regions adjacent to agricultural zones within the CSDs of The Gore and Saint Colomban, as well as the considerable open agricultural areas within the Varennes CSD. This comprehensive scenario integrates all these areas into a single greenbelt vision for the Montreal CMA (Figure 11).

Upon obtaining shapefiles for all scenarios in 2070, we generated raster files with a resolution of 15 meters using the Feature-to-Raster tool in ArcGIS Pro. These raster layers were then processed using the USM toolset to calculate the potential urban sprawl projection for the year 2070. The reporting units for the CMA and CSDs remained consistent throughout the analysis, using Montreal CMA 2011 as the reference. Urban sprawl assessments were conducted for all four scenarios at the CSD level. This analysis compared the potential urban sprawl dynamics among the scenarios across the individual CSDs.

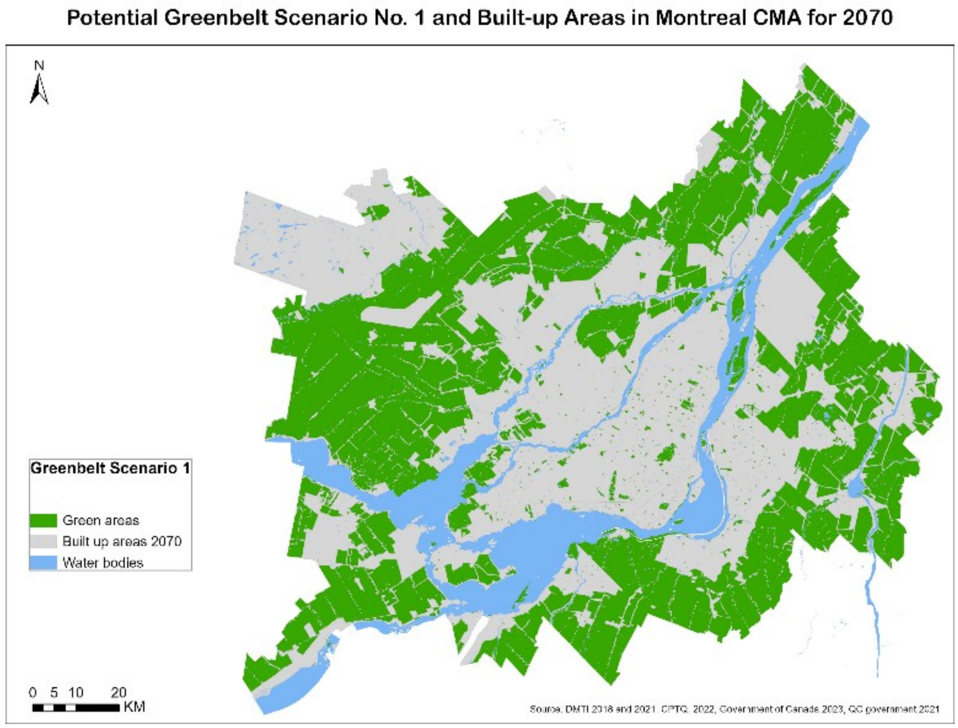


Figure 8 Map of the proposed greenbelt scenarios 1 and potential built-up areas in the Montreal CMA_{2011} for 2070

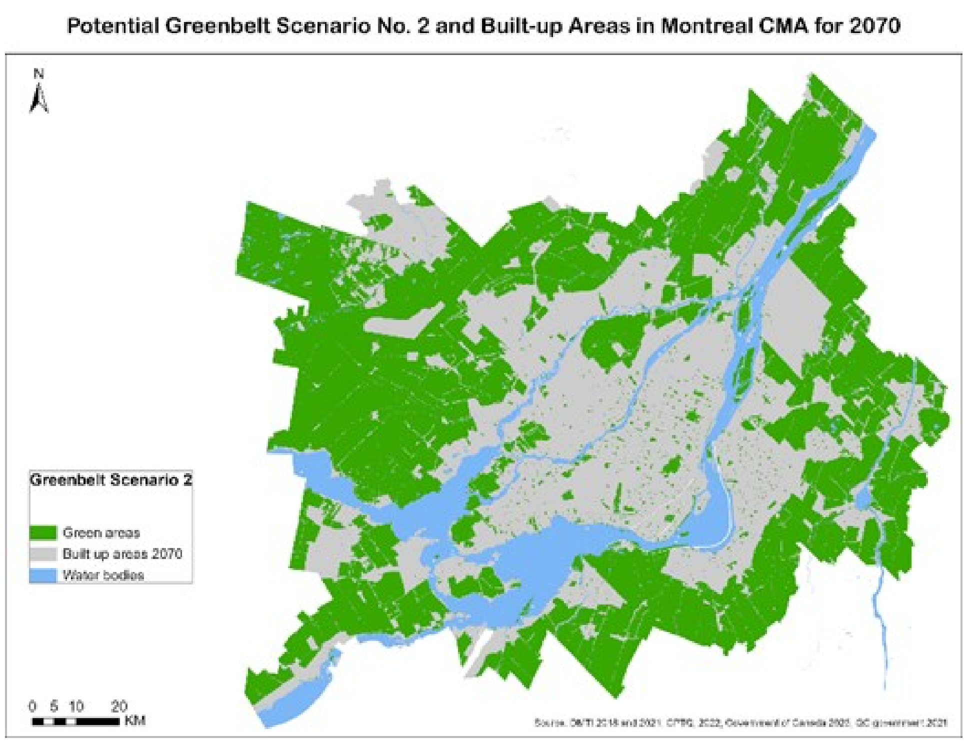


Figure 9 Map of the proposed greenbelt scenarios 2 and potential built-up areas in the Montreal CMA_{2011} for 2070

Potential Greenbelt Scenario No. 3 and Built-up Areas in Montreal CMA for 2070

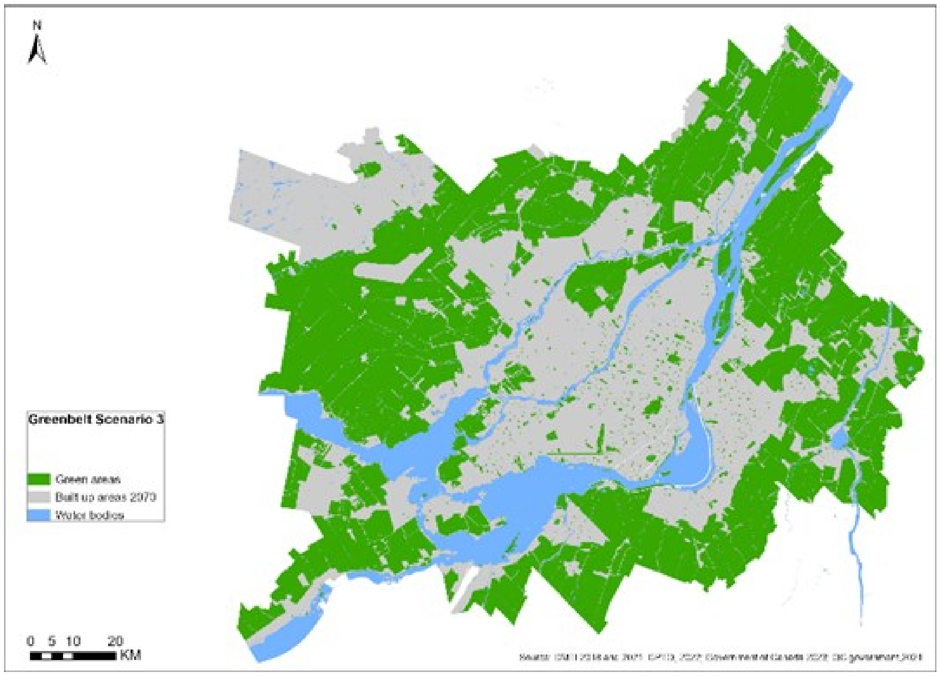


Figure 10 Map of the proposed greenbelt scenarios 3 and potential built-up areas in the Montreal CMA2011 for 2070

Potential Greenbelt Scenario No. 4 and Built-up Areas in Montreal CMA for 2070

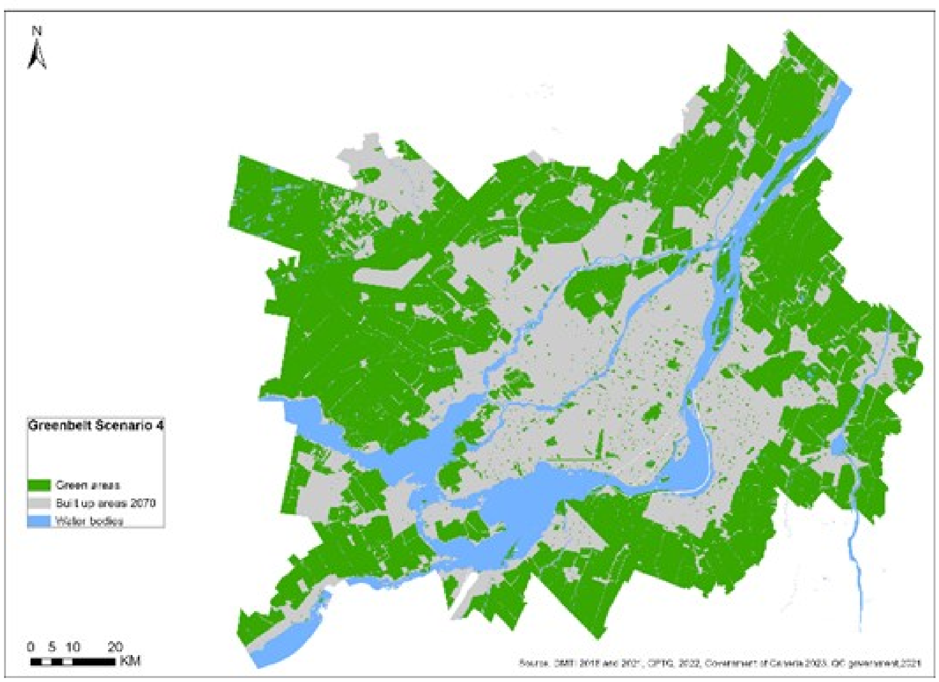


Figure 11 Map of the proposed greenbelt scenarios 4 and potential built-up areas in the Montreal CMA2011 for 2070

3.2.9 Defining targets and limits

Proposing reference values such as targets and limits to address the challenge of urban sprawl could serve as a pivotal step in more effectively controlling this issue and accelerating a substantial change in current trends (Hersperger et al., 2017; Schwick et al., 2018) These targets and limits, when thoughtfully implemented, offer a robust mechanism for regulating prospective urban development. They can play a crucial role in determining the size, spatial arrangement, and density of new designated building zones, with the overarching goal of mitigating factors that contribute to sprawl. In particular, they aid in delineating areas designated to future development, specifying their size, locations, and density. This comprehensive approach ensures that the expansion of urban areas is carefully planned and executed, minimizing sprawl and its associated negative consequences.

Moreover, defining reference values for CSDs can alleviate unproductive competition for desirable building zones. These established reference values would provide a fair and consistent framework for urban planning. They encourage a more coordinated and sustainable approach.

In both literature and practical applications, numerous common reference values or standards for other environmental sectors exist. These environmental standards exhibit varying levels of strictness and enforceability. The establishment of these reference values is based on political negotiation. This process takes into account factors such as the social desirability of different development options, their feasibility and enforceability in practice, and their alignment with scientific recommendations. The relative significance of these three factors in the negotiation process can vary, depending on the specific environmental context. For instance, when establishing reference values for air and water quality, the deliberation process often relies on a wealth of scientifically validated knowledge regarding the effects of pollution and human health and wildlife populations. In contrast, defining reference values for urban sprawl is a more intricate challenge. Several factors contribute to this complexity. First, determining an absolute level of tolerable urban sprawl is scientifically challenging. In addition, the ecological, social, and economic consequences of urban sprawl are diverse, often not easily measurable, and often occur with a certain time delay. However, statements can be made about particular extreme conditions that are certainly not sustainable (e.g., when virtually no land is left for agriculture in a country), as well as about desirable or preventable directions of development. Essentially, reference values are rarely, if ever, purely scientifically derived from data. Instead, they result from the balancing of various goals and requirements that are negotiated in a social and political process (Schwick et al., 2018).

Adopted from Schwick et al (2018), we use "target " to refer to the desired state, while "limit" denotes an obligatory standard that should not be surpassed. In addition, we calculate "warning value" as an additional reference point, at which measures must be intensified to prevent further deterioration and deviation from the limits. It serves as a guide for directing development towards compliance with the established limits. “No deterioration" signifies the level of urban sprawl when the value recorded at a specific reference point in time should not surpassed (Figure 12).

In the current study, we present a proposal for reference values, specifically targets, limits, and warning values related to urban sprawl. First, we determine the most recent values of *WUP* for the Montreal CMA. Subsequently, the values for the CSDs are measured. The process of determining the reference values is as follows.

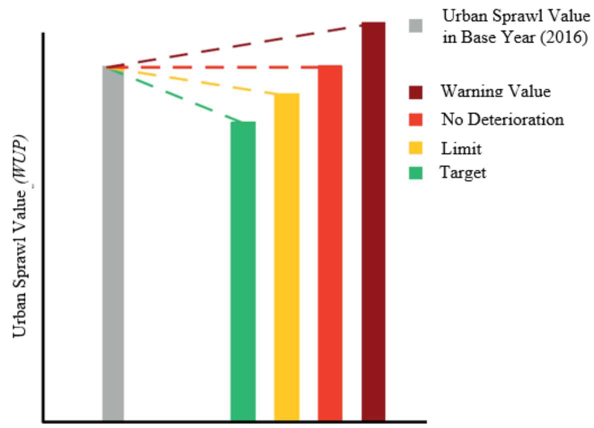


Figure 12 Overview of the establishment of reference values (Schwick et al., 2018).

The essential questions in establishing targets and limits are: What extent of urban sprawl are we willing to accept in the Montreal CMA? What can be regarded as sustainable? What type of landscapes do we envision for our future living spaces? To address these questions, we initiate the process by considering the level of urban sprawl of 2016 and examining various scenarios for future development. Notably, the evaluation of six scenarios for the year 2070 serves as a reference for establishing the targets and limits for Montreal CMA and CSDs.

Scenarios 1 through 3 were deemed unsustainable, scenario 4 falls within the transitional range, and scenario 5 is considered somewhat sustainable. Only scenario 6 was assessed as fully sustainable (Figure 13). To ensure sustainability, the established targets and limits must be more stringent than the anticipated urban sprawl values in scenarios 1 to 3, meaning they should be set lower. The proposed approach suggests that the target should be more ambitious than scenario 5 (somewhat sustainable), and, consequently, a value is recommended that lies between the values of scenarios 5 and 6. For the limit, a recommendation is to establish a value that falls between the target value and the "no deterioration" threshold. As for the warning value, the recommendation is to set it at a level situated midway between the "no deterioration" value (Scenario 5) and Scenario 4, as this represents the transitional zone towards unsustainability. In addition to the reference values for *WUP*, we also provide values for *WSPC* and the three components of *WUP* based on the value of *WUP* for each reference value.

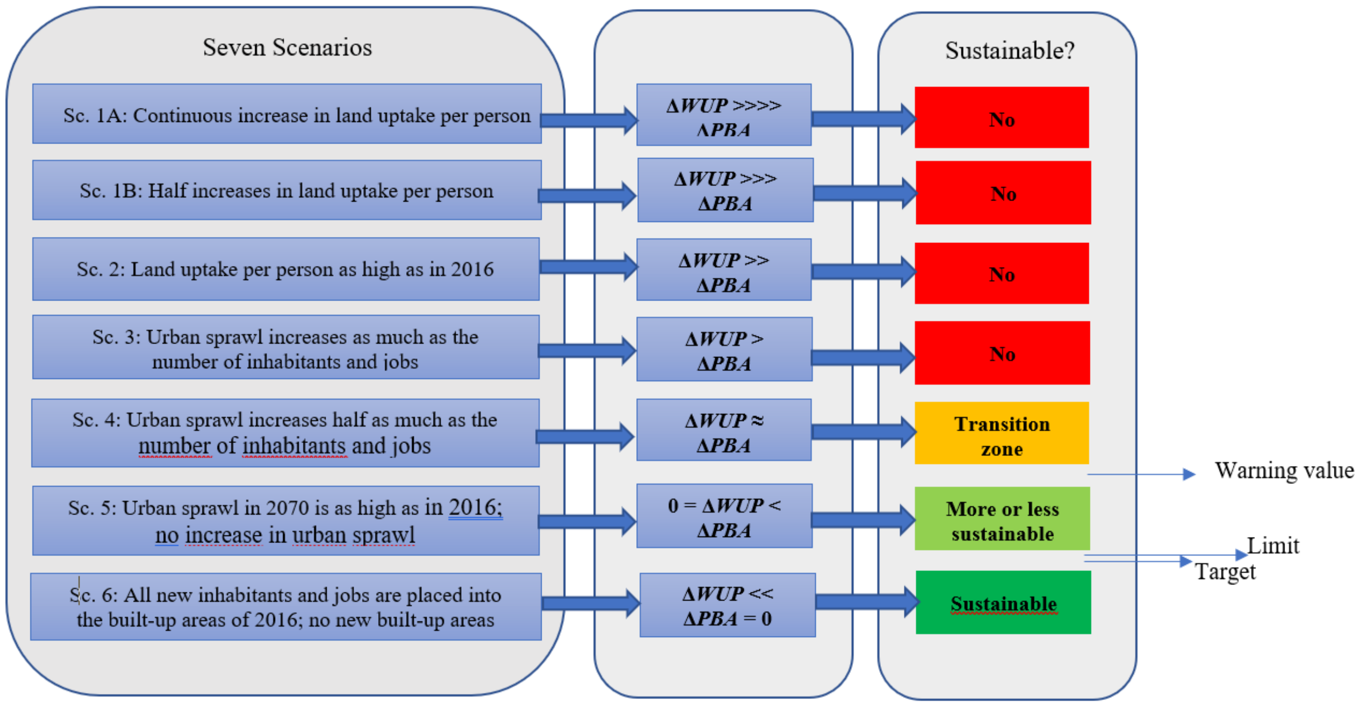


Figure 13 Overview of the seven scenarios for 2070 and their assessment in terms of sustainability. These scenarios can be used to set targets and limits for urban sprawl. (Δ*WUP* = change in *WUP*; Δ*PBA* = change in the percentage of built-up area; Schwick et al., 2018, with modification).

The urban sprawl values for scenarios 4, 5, and 6 were computed for each CSD, and subsequently, the target, limit, and warning values can be established for each CSD in a manner similar to that applied to the Montreal CMA. This entails: The target is set at a level halfway between scenario 5 and scenario 6. The limit is positioned between the target and scenario 5. The warning value is set between scenario 5 and scenario 4. This approach allows for the consistent application of reference values across all CSDs and aligns with the principles employed for the Montreal CMA.

3.3 Reference framework

This section first presents the *WUP* results for 2011 and 2016, used for the reference scenarios. We then present the reference scenarios for 2070 and propose targets and limits for urban sprawl in Montreal.

3.3.1 Values of *WUP* for Montreal CMA in 2011 and 2016

The *WUP* values and their respective components for Montreal in both 2011 and 2016 were computed within the delineated boundaries of both the Montreal CMA based on both the 2011 and the 2016 delineation.

In 2011, the value of *WUP* differed slightly from the calculations made by Nazarnia et al. (2016). This difference can be attributed to the availability of more accurate job data used in the present study compared to those used by Nazarnia et al. (2016). While the difference in results is not substantial, we chose to utilize the more accurate and up-to-date data in our analysis to improve the precision of our analysis.

The *WUP* value for 2011 within the 2011 Montreal CMA was 12.40 UPU/m^2, while for the 2016 delineation, the *WUP* value within boundaries was 12.14 UPU/m^2. For 2016, the *WUP* values were 13.48 UPU/m^2 and 13.22 UPU/m^2 for the 2011 and 2016 Montreal CMA, respectively. The values of *WUP* of both 2011 and 2016 for the 2016 CMA delineation were comparatively lower than the 2011 CMA delineation, which can be attributed to various factors, including differences in topography, and land use patterns. Nevertheless, the trends in *WUP* values exhibited a similar slope for both 2011 and 2016 CMA delineations (Figure 24). Table 4 displays the results of urban sprawl calculations for the years 2011 and 2016 within both CMA, including the *WSPC*, *WUP* values and their components.

Table 4. Values of the urban sprawl metrics in 2011 and 2016 within both CMA delineations of 2011 and 2016

Values of the metrics	**CMA_{2011} 2011**	**CMA_{2011} 2016**	**CMA_{2016} 2011**	**CMA_{2016} 2016**
Inhabitants	3824221	3934078	3983027	4098927
Inhabitants + Jobs	5363885.09	5540650.56	5507004.52	5690344.41
Area of reporting unit (km^2)	4291.69	4291.69	4635.76	4635.76
Built-up area (km^2)	1137.08	1207.11	1190.47	1267.19
PBA	0.264	0.281	0.257	0.273
***DIS*(UPU/m^2)**	47.82	47.92	47.78	47.87
TS(*MUPU*)	54376.61	57846.88	56876.26	60665.82
***UD* ((inh. or job)/km^2)**	4717.2	4590	4625.9	4490.5
***LUP* (m^2/(inh. or job))**	212.0	217.9	216.2	222.7
***WUP* (UPU/m^2)**	12.4	13.48	12.14	13.22
***WSPC (*UPU/ (inhabitant or job))**	9921.36	10441.37	10219.37	10769.95

PBA: proportion of built-up areas
DIS: Dispersion of built-up areas
TS: Total sprawl
UD: Utilization density
LUP: Land uptake per inhabitant or job
WUP: Weighted urban proliferation

3.3.2. Urban sprawl in 2011 and 2016 for Montreal CSDs

The Tables 5 and 6 display the *WUP* and *WSPC* values and their components for CSDs within the Montreal CMA_{2011} for 2011 and 2016. Values of the urban sprawl metrics in 2011 for CSDs of Montreal CMA2011delineation.

Table 5. Values of the urban sprawl metrics in 2011 for CSDs of Montreal CMA_{2011} delineation

CSDUID	CSD Name	Inhabitants	Inhabitants and jobs	urban areas (km^2)	Unit area (km^2)	*PBA*	*DIS* (UPU/m^2)	*TS* (MUPU)	*LUP* (m^2/ (inh. or job))	*WUP* (UPU/m^2)	*WSPC* (UPU/ (inh. or job))
2466023	Montréal	1649519	2524815.5	250.84	365.83	0.69	48.93	12274.21	99.40	5.18	750.55
2458007	Brossard	79273	101080.0	23.07	45.36	0.51	48.87	1127.53	228.20	26.45	11869.53
2470022	Beauharnois	12011	14827.7	7.67	69.56	0.11	43.36	332.33	517.00	4.33	20313.02
2467050	Châteauguay	45904	56648.9	18.80	37.23	0.51	48.09	904.33	332.00	28.05	18434.63
2467025	Delson	7462	10987.9	4.14	7.65	0.54	48.96	202.54	376.50	32.15	22383.53
2472010	Deux-Montagnes	17552	19310.3	5.87	6.15	0.95	48.23	283.30	304.20	52.60	16752.23
2457005	Chambly	25571	31882.6	9.73	27.53	0.35	47.43	461.42	305.10	18.51	15983.04
2466087	Dorval	18208	59450.9	15.79	20.88	0.76	48.89	771.78	265.50	41.78	14673.74
2471025	Saint-Zotique	6773	7574.6	3.05	25.18	0.12	41.43	126.51	403.10	3.84	12765.22
2466107	Beaconsfield	19505	21469.6	8.66	11.00	0.79	48.08	416.31	403.30	44.81	22958.53
2471033	Les Coteaux	4568	5120.3	3.07	11.71	0.26	42.63	131.03	600.30	9.65	22069.53
2472032	Oka	3969	4807.7	3.04	57.74	0.05	41.37	125.95	633.20	1.71	20536.97
2472005	Saint-Eustache	44154	60950.0	16.23	69.79	0.23	47.76	774.93	266.20	12.02	13763.36
2455065	Saint-Mathias-sur-Richelieu	4618	5128.3	3.84	50.11	0.08	45.82	175.89	748.40	3.83	37424.33
2467005	Saint-Mathieu	1879	1879.0	2.14	31.58	0.07	44.14	94.34	1137.50	2.94	49412.03
2467010	Saint-Philippe	5495	5894.8	2.06	62.05	0.03	46.78	96.17	348.70	1.70	17894.68
2459015	Saint-Amable	10870	11819.1	6.57	36.73	0.18	44.46	292.23	556.20	7.85	24395.26
2467045	Mercier	11584	13215.0	5.12	46.40	0.11	45.55	233.37	387.70	5.20	18258.10
2474005	Mirabel	41957	55877.9	34.29	486.38	0.07	44.83	1537.29	613.70	3.22	28027.96
2457025	McMasterville	5615	6484.5	1.94	3.40	0.57	47.68	92.27	298.40	30.19	15829.54
2464008	Terrebonne	106322	131965.0	47.93	154.92	0.31	46.95	2250.65	363.20	16.14	18947.52
2472015	Sainte-Marthe-sur-le-Lac	15689	16976.9	5.52	9.51	0.58	47.14	260.20	325.10	30.15	16889.20
2466102	Kirkland	21253	28776.7	7.42	9.64	0.77	49.45	366.68	257.70	43.37	14528.65
2467040	Saint-Isidore	2581	3016.0	2.21	51.93	0.04	43.18	95.61	734.10	1.67	28754.06
2467030	Sainte-Catherine	16762	19670.1	5.34	9.53	0.56	48.32	257.93	271.40	30.17	14617.13
2471100	Hudson	5135	6228.6	6.70	21.93	0.31	46.40	311.10	1076.40	16.15	56862.09
2466062	Hampstead	7153	7702.0	1.67	1.79	0.93	49.31	82.35	216.80	48.31	11227.60
2460040	L'Épiphanie	3296	3509.1	2.57	54.71	0.05	43.82	112.65	732.50	1.96	30557.97

2476025	Gore	1775	1775.0	1.94	97.50	0.02	37.73	73.20	1092.90	0.47	25816.90
2452007	Lavaltrie	13267	14966.5	8.76	68.46	0.13	44.58	390.50	585.30	5.69	26027.36
2473020	Rosemère	14294	19226.3	8.80	10.69	0.82	49.15	432.67	457.90	50.44	28045.08
2472043	Saint-Placide	1715	1902.1	1.97	43.06	0.05	40.00	78.98	1038.10	1.31	29655.80
2473005	Boisbriand	26816	37901.5	11.23	27.69	0.41	48.69	546.59	296.20	22.81	16664.47
2464015	Mascouche	42491	50152.7	19.01	107.24	0.18	47.76	907.87	379.00	9.82	20997.82
2475017	Saint-Jérôme	68456	96411.4	33.18	91.59	0.36	47.74	1583.96	344.20	19.79	18800.33
2466127	Senneville	920	2271.5	0.86	7.48	0.11	46.98	40.36	378.20	6.03	19856.66
2460035	L'Épiphanie	5353	5867.5	1.93	2.34	0.82	40.38	77.96	329.00	22.88	9124.69
2473035	Sainte-Anne-des-Plaines	14535	17525.1	5.23	92.96	0.06	43.84	229.39	298.60	2.17	11510.54
2471083	Vaudreuil-Dorion	33305	45420.5	16.65	72.35	0.23	46.93	781.60	366.70	12.00	19114.74
2460005	Charlemagne	5853	6825.2	1.62	2.31	0.70	47.99	77.59	236.90	35.14	11893.21
2466142	Dollard-Des Ormeaux	49637	57821.3	12.79	15.20	0.84	49.25	629.67	221.10	43.89	11537.75
2466117	Sainte-Anne-de-Bellevue	5073	9349.3	3.00	10.57	0.28	47.96	143.78	320.70	15.53	17557.78
2471060	L'Île-Perrot	10503	12624.5	4.03	5.46	0.74	47.63	191.72	318.80	39.50	17083.52
2466112	Baie-D'Urfé	3850	7500.0	4.69	6.02	0.78	47.65	223.53	625.50	44.37	35614.51
2471105	Saint-Lazare	19295	21125.3	16.65	66.89	0.25	47.11	784.13	788.00	13.76	43568.98
2466072	Mont-Royal	19503	36439.0	6.54	7.66	0.85	49.50	323.81	179.50	38.25	8040.69
2457020	Saint-Basile-le-Grand	16736	18822.4	7.06	37.03	0.19	46.99	331.53	374.90	10.00	19673.36
2473025	Lorraine	9479	10191.4	4.55	6.02	0.76	48.29	219.79	446.60	44.02	26002.35
2460013	Repentigny	82000	99772.0	25.95	62.71	0.41	47.83	1241.03	260.00	21.33	13406.61
2471050	Les Cèdres	6079	7041.2	5.85	78.18	0.07	44.53	260.38	830.50	3.35	37195.63
2466032	Westmount	19931	32752.3	3.31	4.02	0.82	48.80	161.38	101.00	6.73	826.04
2466007	Montréal-Est	3728	8513.7	6.65	12.48	0.53	48.66	323.74	781.40	32.56	47729.04
2471075	Terrasse-Vaudreuil	1971	2171.0	0.90	1.03	0.87	48.65	43.58	412.60	51.17	24276.88
2471095	L'Île-Cadieux	105	105.0	0.19	0.57	0.33	51.72	9.71	1787.00	23.58	128005.71
2458227	Longueuil	231409	308212.9	61.02	115.54	0.53	48.78	2976.75	198.00	24.95	9353.02
2460028	L'Assomption	20065	25647.3	11.79	100.68	0.12	45.39	535.08	459.60	5.52	21669.05
2459025	Verchères	5692	6741.7	2.62	72.96	0.04	41.11	107.82	389.00	1.10	11904.50
2471090	Vaudreuil-sur-le-	1359	1374.0	0.70	1.37	0.51	49.79	34.85	509.50	32.57	32475.18
2459020	Varennes	20994	27520.2	8.41	92.38	0.09	46.04	387.42	305.80	4.31	14467.85
2471040	Coteau-du-Lac	6842	8455.9	2.65	47.41	0.06	42.74	113.23	313.30	1.95	10933.10
2472025	Saint-Joseph-du-Lac	6195	7244.5	5.24	41.62	0.13	46.46	243.37	723.10	6.62	38032.11
2466058	Côte-Saint-Luc	32321	37142.0	4.49	6.95	0.65	48.90	219.39	120.80	11.80	2208.01
2473010	Sainte-Thérèse	26025	35303.6	8.43	9.58	0.88	49.08	413.56	238.70	47.21	12810.92
2457045	Saint-Mathieu-de-Beloeil	2624	3858.3	2.00	39.85	0.05	43.62	87.46	519.60	2.03	20966.40
2466092	L'Île-Dorval	5	5.0	0.03	0.18	0.15	51.54	1.40	5443.70	10.73	386280.00

2467020	Candiac	19876	25068.3	6.35	17.59	0.36	47.93	304.30	253.20	18.55	13016.22
2467035	Saint-Constant	24980	28482.8	9.29	56.82	0.16	47.83	444.62	326.30	8.91	17774.46
2466047	Montréal-Ouest	5085	5938.4	1.14	1.41	0.81	48.99	55.86	192.00	37.77	8967.96
2471055	Pointe-des-Cascades	1340	1387.1	0.57	2.78	0.21	42.87	24.65	414.40	7.60	15231.67
2457040	Beloeil	20783	26984.9	7.25	25.25	0.29	48.32	350.39	268.70	15.42	14428.61
2458037	Saint-Bruno-de-Montarville	26107	36753.4	12.45	44.02	0.28	47.95	596.96	338.70	15.62	18708.28
2459010	Sainte-Julie	30104	36443.5	10.75	49.83	0.22	46.46	499.45	295.00	10.46	14302.21
2467015	La Prairie	23357	28644.2	6.67	43.49	0.15	47.62	317.73	232.90	7.46	11326.37
2458033	Boucherville	40753	68800.7	20.61	70.80	0.29	47.83	985.72	299.50	15.59	16043.04
2473015	Blainville	53510	64101.5	23.57	55.37	0.43	48.73	1148.49	367.70	24.92	21525.54
2466097	Pointe-Claire	30790	55730.2	14.28	18.87	0.76	49.01	699.75	256.20	41.60	14085.58
2457030	Otterburn Park	8450	8843.9	3.68	5.63	0.65	47.84	176.24	416.60	36.81	23433.27
2472020	Pointe-Calumet	6396	6664.4	3.92	5.07	0.77	46.25	181.40	588.50	39.78	30262.80
2471070	Pincourt	14305	15592.4	4.77	7.53	0.63	46.60	222.49	306.20	31.29	15110.83
2471065	Notre-Dame-de-l'Île-Perrot	10620	11337.5	6.04	27.72	0.22	45.09	272.47	533.00	10.11	24718.80
2455057	Richelieu	5467	6984.1	2.64	32.52	0.08	45.60	120.37	378.00	3.83	17833.70
2465005	Laval	401553	523805.1	123.91	246.58	0.50	48.94	6063.61	236.60	26.66	12550.13
2457035	Mont-Saint-Hilaire	18200	22267.1	10.81	45.69	0.24	47.69	515.30	485.30	13.33	27351.93
2460020	Saint-Sulpice	3273	3513.6	2.30	36.35	0.06	43.91	100.99	654.60	2.65	27416.00
2473030	Bois-des-Filion	9485	11680.9	3.10	4.27	0.73	48.50	150.55	265.70	39.28	14359.01
2457010	Carignan	7966	9075.9	6.44	64.70	0.10	45.24	291.42	709.80	4.73	33719.19
02458012	Saint-Lambert	21555	26696.0	5.24	7.55	0.69	48.34	253.36	196.30	31.74	8976.52
2467055	Léry	2307	2473.9	3.13	10.52	0.30	45.89	143.86	1267.30	15.14	64382.56
2475005	Saint-Colomban	13080	13567.8	18.68	94.57	0.20	47.32	884.17	1377.00	11.20	78065.95

Table 6. Values of the urban sprawl metrics in 2016 for CSDs of Montreal CMA_{2011} delineation

CSDUID	**Name**	**Inhabitants**	**Inhabitants and jobs**	**urban areas (km^2)**	**Unit area (km^2)**	***PBA***	***DIS* (UPU/m^2)**	***TS* (MUPU)**	***LUP* (m^2/(inhb. or job))**	***WUP* (UPU/m^2)**	***WSPC* (UPU/ (inh. or job))**
2466023	Montréal	1704694	2579305.7	255.75	365.83	0.70	48.96	12520.54	99.20	5.24	743.20
2458007	Brossard	85721	110161.9	24.84	45.36	0.55	48.87	1213.77	225.50	28.29	11648.63
2470022	Beauharnois	12884	15590.3	8.21	69.56	0.12	43.55	357.40	526.40	4.73	21104.08
2467050	Châteauguay	47906	59512.0	20.02	37.23	0.54	47.99	961.01	336.50	29.75	18611.25
2467025	Delson	7457	11326.6	4.40	7.65	0.57	48.99	215.51	388.40	34.37	23213.62
2472010	Deux-Montagnes	17496	19023.5	5.88	6.15	0.96	48.34	284.13	309.00	53.15	17182.54
2457005	Chambly	29120	35818.3	10.77	27.53	0.39	47.49	511.28	300.60	20.50	15756.32
2466087	Dorval	18980	58304.4	16.04	20.88	0.77	48.91	784.66	275.20	42.96	15384.85
2471025	Saint-Zotique	7934	8710.5	3.95	25.18	0.16	42.01	166.01	453.70	5.33	15407.75
2466107	Beaconsfield	19324	21266.7	8.81	11.00	0.80	48.15	424.08	414.10	45.89	23736.19
2471033	Les Coteaux	5368	6025.1	3.31	11.71	0.28	43.77	145.05	550.00	11.62	22583.74

2472032	Oka	3824	4626.5	3.20	57.74	0.06	41.57	132.98	691.50	1.84	22963.66
2472005	Saint-Eustache	44008	61037.4	16.76	69.79	0.24	47.87	802.38	274.60	12.62	14429.68
2455065	Saint-Mathias-sur-Richelieu	4531	5085.2	3.89	50.11	0.08	45.88	178.42	764.80	3.90	38431.16
2467005	Saint-Mathieu	2156	2377.2	2.43	31.58	0.08	44.45	107.96	1021.70	3.44	45698.04
2467010	Saint-Philippe	6320	6746.5	2.32	62.05	0.04	47.39	110.14	344.50	2.00	18394.86
2459015	Saint-Amable	12167	13253.7	7.24	36.73	0.20	45.03	325.79	545.90	9.10	25218.92
2467045	Mercier	13115	14798.3	5.73	46.40	0.12	45.93	263.18	387.20	6.00	18813.02
2474005	Mirabel	50513	68212.4	39.24	486.38	0.08	45.35	1779.86	575.30	3.85	27451.93
2457025	McMasterville	5698	6564.6	2.15	3.40	0.63	47.37	102.07	328.20	33.56	17381.74
2464008	Terrebonne	111575	139294.3	49.64	154.92	0.32	47.19	2342.38	356.30	16.95	18851.42
2472015	Sainte-Marthe-sur-le-Lac	18074	19485.5	6.30	9.51	0.66	47.29	297.94	323.30	34.75	16959.93
2466102	Kirkland	20151	27679.7	7.46	9.64	0.77	49.47	368.99	269.50	44.30	15428.32
2467040	Saint-Isidore	2608	3264.8	2.27	51.93	0.04	43.39	98.62	696.30	1.75	27835.38
2467030	Sainte-Catherine	17047	20186.5	5.49	9.53	0.58	48.32	265.30	272.00	31.05	14658.64
2471100	Hudson	5185	6210.8	7.61	21.93	0.35	46.91	356.80	1224.60	19.06	67299.51
2466062	Hampstead	6973	7530.6	1.69	1.79	0.94	49.30	83.07	223.80	49.58	11785.01
2460040	L'Épiphanie	3200	3510.9	2.63	54.71	0.05	43.91	115.32	748.10	2.02	31477.72
2476025	Gore	1904	1992.7	1.98	97.50	0.02	38.03	75.27	993.30	0.49	23975.61
2452007	Lavaltrie	13657	15491.5	9.02	68.46	0.13	44.70	403.08	582.10	5.92	26161.57
2473020	Rosemère	13958	18853.4	8.83	10.69	0.83	49.20	434.47	468.40	50.82	28815.35
2472043	Saint-Placide	1686	1963.8	1.99	43.06	0.05	40.09	79.94	1015.30	1.34	29382.61
2473005	Boisbriand	26884	38946.3	11.90	27.69	0.43	48.64	578.63	305.40	24.27	17255.47
2464015	Mascouche	46692	54568.2	20.54	107.24	0.19	48.00	986.03	376.40	10.77	21165.70
2475017	Saint-Jérôme	74346	102440.4	38.04	91.59	0.42	47.90	1822.11	371.40	23.16	20706.92
2466127	Senneville	921	2450.8	0.87	7.48	0.12	47.21	41.08	355.00	6.16	18800.49
2460035	L'Épiphanie	5493	6170.5	2.04	2.34	0.87	40.27	82.09	330.40	23.90	9063.48
2473035	Sainte-Anne-des-Plaines	14421	17259.5	5.41	92.96	0.06	43.76	236.63	313.30	2.25	12118.58
2471083	Vaudreuil-Dorion	38117	51690.7	20.45	72.35	0.28	47.61	973.71	395.70	15.58	21806.89
2460005	Charlemagne	5913	6833.5	1.62	2.31	0.70	48.03	77.94	237.50	35.40	11966.69
2466142	Dollard-Des Ormeaux	48899	56789.5	12.82	15.20	0.84	49.28	631.95	225.80	44.59	11934.73
2466117	Sainte-Anne-de-Bellevue	4958	8803.2	3.26	10.57	0.31	48.03	156.65	370.50	17.34	20820.18
2471060	L'Île-Perrot	10756	12580.4	4.15	5.46	0.76	48.02	199.17	329.70	41.98	18219.70
2466112	Baie-D'Urfé	3823	7875.9	4.73	6.02	0.78	47.74	225.70	600.30	44.91	34327.45
2471105	Saint-Lazare	19889	21641.2	18.42	66.89	0.28	47.44	873.63	851.00	15.61	48248.41
2466072	Mont-Royal	20276	36923.1	6.63	7.66	0.87	49.52	328.38	179.60	38.83	8055.61
2457020	Saint-Basile-le-Grand	17059	19117.1	7.54	37.03	0.20	47.20	355.76	394.30	10.91	21132.78
2473025	Lorraine	9352	9902.9	4.56	6.02	0.76	48.65	222.00	460.80	45.18	27465.05
2460013	Repentigny	84285	101381.7	28.05	62.71	0.45	48.02	1346.99	276.70	23.78	14709.20
2471050	Les Cèdres	6777	7604.8	7.32	78.18	0.09	44.78	327.78	962.60	4.30	44205.56

2466032	Westmount	20312	33032.1	3.32	4.02	0.83	48.86	162.35	100.60	6.65	809.30
2466007	Montréal-Est	3850	8751.1	6.81	12.48	0.55	48.78	332.06	777.90	33.53	47817.18
2471075	Terrasse-Vaudreuil	1986	2194.0	0.91	1.03	0.88	48.17	43.77	414.10	50.47	23694.19
2471095	L'Île-Cadieux	126	126.0	0.19	0.57	0.33	52.01	9.84	1501.70	23.99	108526.19
2458227	Longueuil	239700	313676.4	66.38	115.54	0.57	48.85	3242.88	211.60	28.58	10527.20
2460028	L'Assomption	22429	26646.5	12.49	100.68	0.12	45.49	568.10	468.70	5.91	22330.13
2459025	Verchères	5835	6757.2	2.81	72.96	0.04	41.57	116.91	416.10	1.24	13388.68
2471090	Vaudreuil-sur-le-	1341	1466.0	0.91	1.37	0.67	48.78	44.50	622.20	40.66	37997.41
2459020	Varennes	21257	28918.1	8.83	92.38	0.10	46.06	406.95	305.50	4.53	14471.26
2471040	Coteau-du-Lac	7044	9382.9	3.07	47.41	0.06	43.04	132.23	327.50	2.35	11874.06
2472025	Saint-Joseph-du-Lac	6687	7680.4	5.56	41.62	0.13	46.64	259.33	724.00	7.13	38637.19
2466058	Côte-Saint-Luc	32448	37599.1	4.54	6.95	0.65	48.94	222.08	120.70	11.92	2203.35
2473010	Sainte-Thérèse	25989	35013.3	8.54	9.58	0.89	49.19	420.06	243.90	48.57	13289.26
2457045	Saint-Mathieu-de-Beloeil	2619	4305.8	2.20	39.85	0.06	44.66	98.23	510.90	2.46	22767.14
2466092	L'Île-Dorval	5	5.0	0.05	0.18	0.26	51.23	2.41	9407.30	18.32	659520.00
2467020	Candiac	21047	26887.8	7.16	17.59	0.41	48.36	346.05	266.10	21.83	14281.21
2467035	Saint-Constant	27359	31363.8	9.84	56.82	0.17	47.94	471.77	313.70	9.43	17083.77
2466047	Montréal-Ouest	5050	6028.2	1.18	1.41	0.84	49.02	57.96	196.10	39.96	9346.72
2471055	Pointe-des-Cascades	1481	1481.0	0.65	2.78	0.23	42.87	27.73	436.80	8.59	16124.38
2457040	Beloeil	22458	29022.0	9.05	25.25	0.36	48.38	437.76	311.80	20.03	17426.71
2458037	Saint-Bruno-de-Montarville	26394	37973.4	13.07	44.02	0.30	48.03	627.63	344.20	16.52	19150.50
2459010	Sainte-Julie	29881	36338.8	11.04	49.83	0.22	46.57	514.08	303.80	10.90	14946.76
2467015	La Prairie	24110	29693.2	7.45	43.49	0.17	48.13	358.74	251.00	8.89	13020.71
2458033	Boucherville	41671	70734.9	21.53	70.80	0.30	47.92	1031.73	304.40	16.44	16455.12
2473015	Blainville	56863	69345.2	26.09	55.37	0.47	48.91	1276.14	376.30	27.95	22317.21
2466097	Pointe-Claire	31380	56514.3	14.44	18.87	0.76	49.02	707.69	255.40	42.04	14037.05
2457030	Otterburn Park	8421	8910.6	3.73	5.63	0.66	47.89	178.68	418.80	37.41	23636.88
2472020	Pointe-Calumet	6428	6727.1	3.93	5.07	0.78	46.49	182.50	583.50	40.54	30553.47
2471070	Pincourt	14558	15995.2	5.78	7.53	0.77	46.72	269.94	361.20	39.28	18491.64
2471065	Notre-Dame-de-l'Île-Perrot	10654	11466.6	6.82	27.72	0.25	45.01	306.77	594.40	11.38	27510.74
2455057	Richelieu	5236	6892.3	2.67	32.52	0.08	45.83	122.19	386.80	3.95	18637.32
2465005	Laval	422993	548642.3	129.71	246.58	0.53	49.00	6355.71	236.40	28.00	12584.23
2457035	Mont-Saint-Hilaire	18585	22487.4	12.01	45.69	0.26	47.80	574.08	534.10	15.01	30497.33
2460020	Saint-Sulpice	3439	3759.2	2.65	36.35	0.07	43.98	116.46	704.40	3.09	29879.18
2473030	Bois-des-Filion	9636	11676.8	3.28	4.27	0.77	48.78	160.19	281.30	42.92	15695.14
2457010	Carignan	9462	10396.1	6.97	64.70	0.11	45.32	316.11	670.90	5.15	32050.96
2458012	Saint-Lambert	21861	27447.7	5.30	7.55	0.70	48.37	256.35	193.10	31.71	8722.43
2467055	Léry	2318	2456.7	3.14	10.52	0.30	45.99	144.61	1280.10	15.31	65560.78
2475005	Saint-Colomban	16019	16665.4	21.22	94.57	0.22	47.68	1011.64	1273.10	13.01	73827.04

3.3.3 Analysis of reference scenario for 2070

3.3.3.1 Scenario 1A: "Business as usual"

Available data from 1951 to 2016 indicate a steady increase in land uptake per person, with slope variations. According to Figure 24, the highest increase was seen between 1996 and 2011, with a slope of 3.37 $m^2/$ ((inhabitant or job) · year) while the lower increase was observed between 2011 and 2016, with a slope of 1.2 $m^2/$ ((inhabitant or job) · year). When predicting potential future trends, it is not prudent to rely solely on the most recent five years due to data limitations and a short observation period. But it is necessary to consider a longer time span. The predictions should not rely only on the most pessimistic trend, either, which might have changed. As such, in this study, the linear increase between 1971 and 2016 was adopted as the most reliable option, with a slope of 2.36 $m^2/$ ((inhabitant or jobs) · year). It is noteworthy that the average slope between the strongest and the weakest trends is 2.28 $m^2/$ ((inhabitant or job) · year), which is a small difference, further strengthening the chosen time period. *LUP* increased from 111.5 to 217.9 $m^2/$ (inhabitant or job) between 1971 and 2016. According to a liner extrapolation, it would increase to 345.56 m^2 / (inhabitant or job) in 2070. Accordingly, from 2016 to 2070, built-up area is projected to increase from 1207.11 km^2 by about 100 % to 2425.03 km^2. Accordingly, dispersion is projected to increase from 47.922 UPU/m^2 to 49.939 UPU/m^2 from 2016 to 2070, and the value of *WUP* will increase from 13.46 UPU/m^2 by 159.51 % to 34.93 UPU/m^2. The *WSPC* value is projected to increase by 104.56%, from 10,441.37 in 2016 to 21,359.67 UPU/ (inhab. or job) in 2070 (Table M.1 in Appendix M and Figure 14).

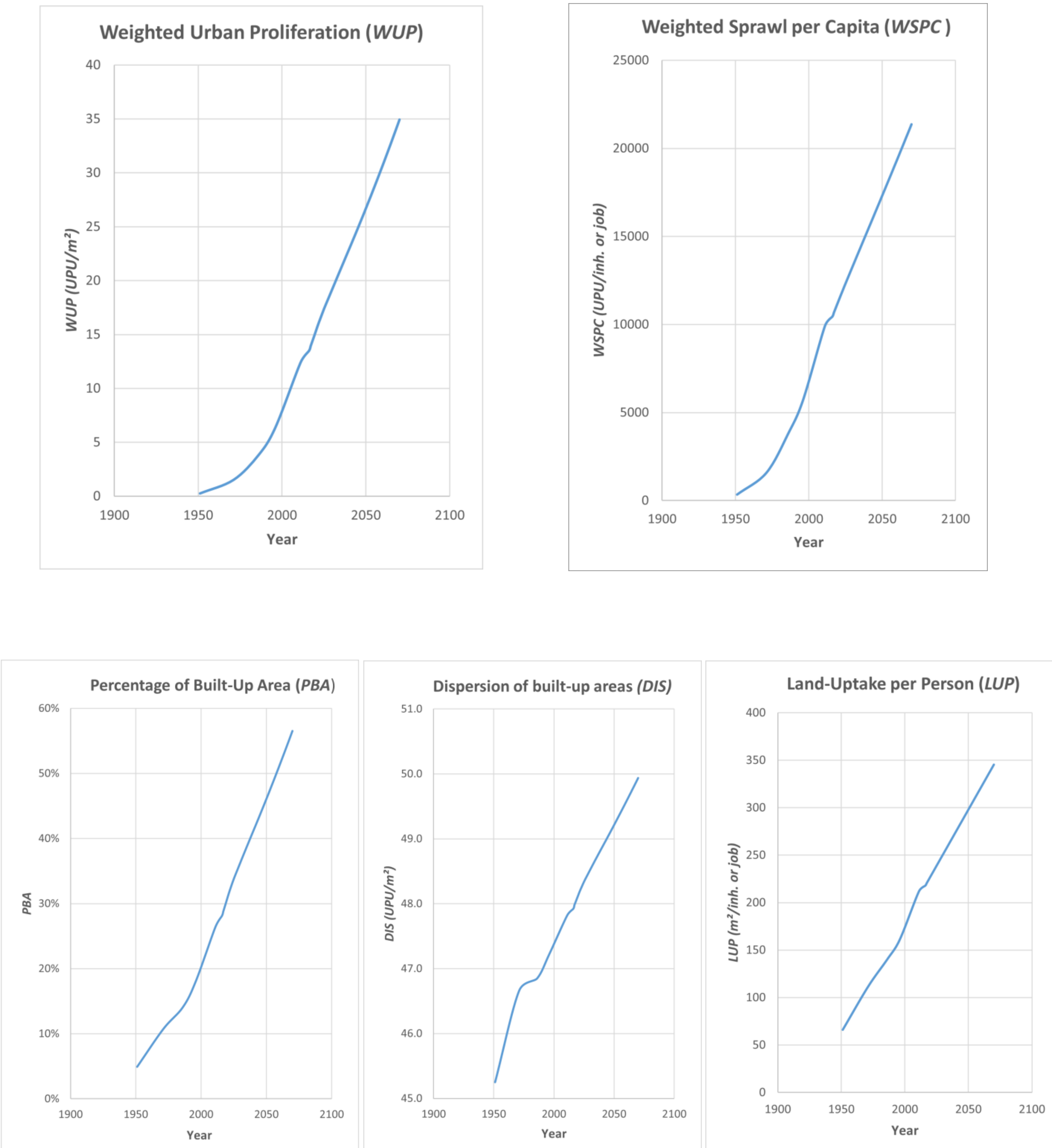


Figure 14 Change in *WUP*, *WSPC*; DIS*, PBA* and *LUP* over time (1951-2070) in sceario1A- "Business as Usual".

3.3.3.2 Scenario 1B: "Half-trend"

According to the half-trend scenario, land uptake is projected to increase to 281.73 m^2/(inhabitant or job) by the year 2070. The total amount of built-up area is expected to increase from 1207.11 km^2 in 2016 to 1977.10 km^2 in 2070 (63.8% increase). Over the same period, the dispersion is projected to increase from 47.922 UPU/m^2 to 49.217 UPU/m^2. Consequently, the value of the *WUP* is expected to rise from 13.46 UPU/m^2 by 95.84 % to 26.36 UPU/m^2. The *WSPC* value is expected to increase by 55% to 16,122.71 UPU/(inhab. or job) in 2070.The results for scenario 1B from 1951 to 2070 are presented in Figure 15 and Table M.2 in Appendix M.

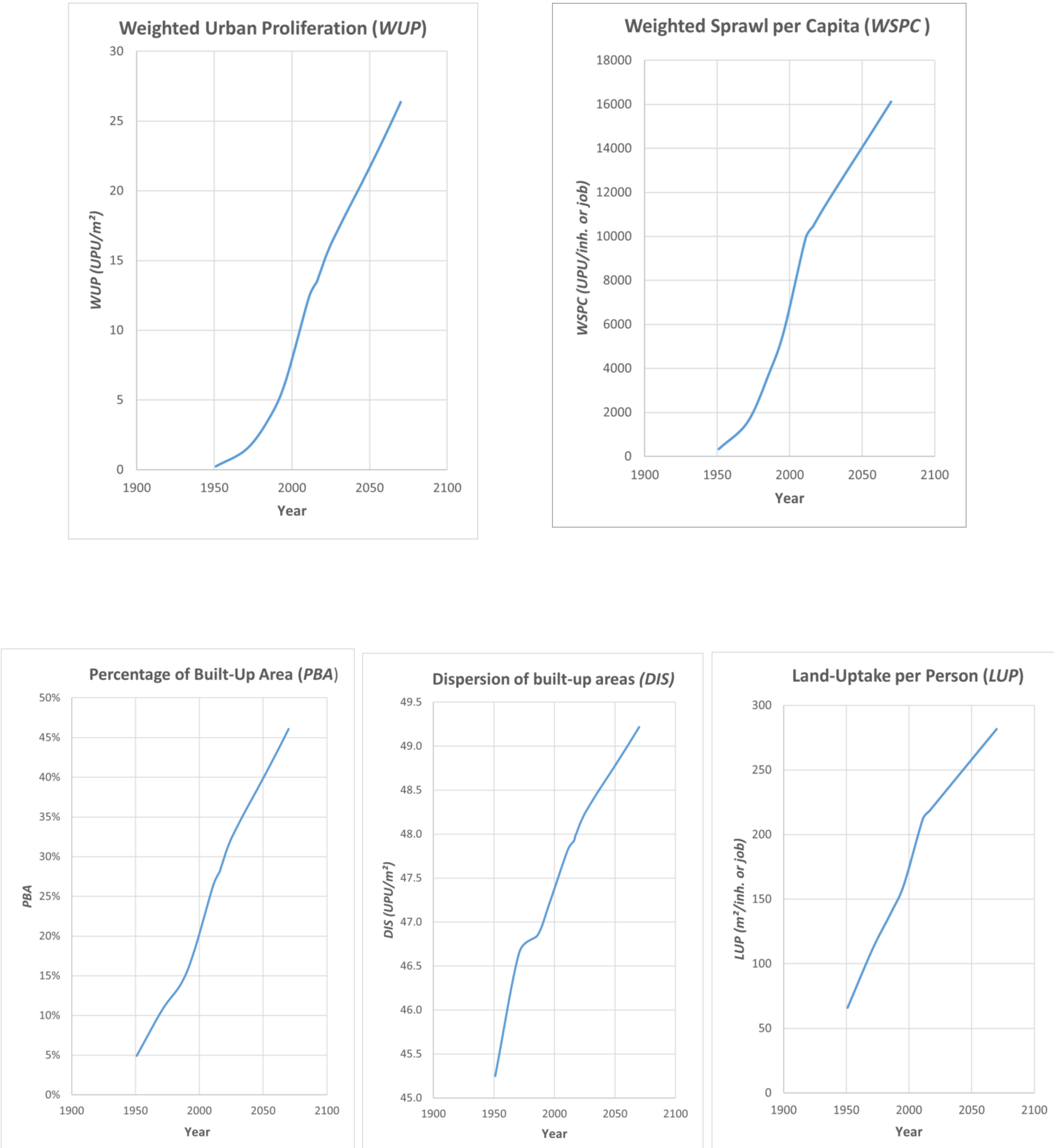


Figure 15 Change in *WUP*, *WSPC*, *DIS*, *PBA* and *LUP* over time (1951-2070) in sceario1B- “Half trend”

3.3.3.3 Scenario 2. "Constant *LUP*"

Land uptake per inhabitant or workplace remains at the value of 217.90 m^2/ (inhabitant or job) as it was in 2016. This results in an increase of built-up area by 26.7 % to 1529.17 km² in 2070. Dispersion will increase to 48.477 UPU/m². This results in a value of 17.66 UPU/m² for *WUP* and a value of 10801.12 UPU/ (inh. or job) for *WSPC* to in 2070 (Figure 16 and Table M.3 in Appendix M).

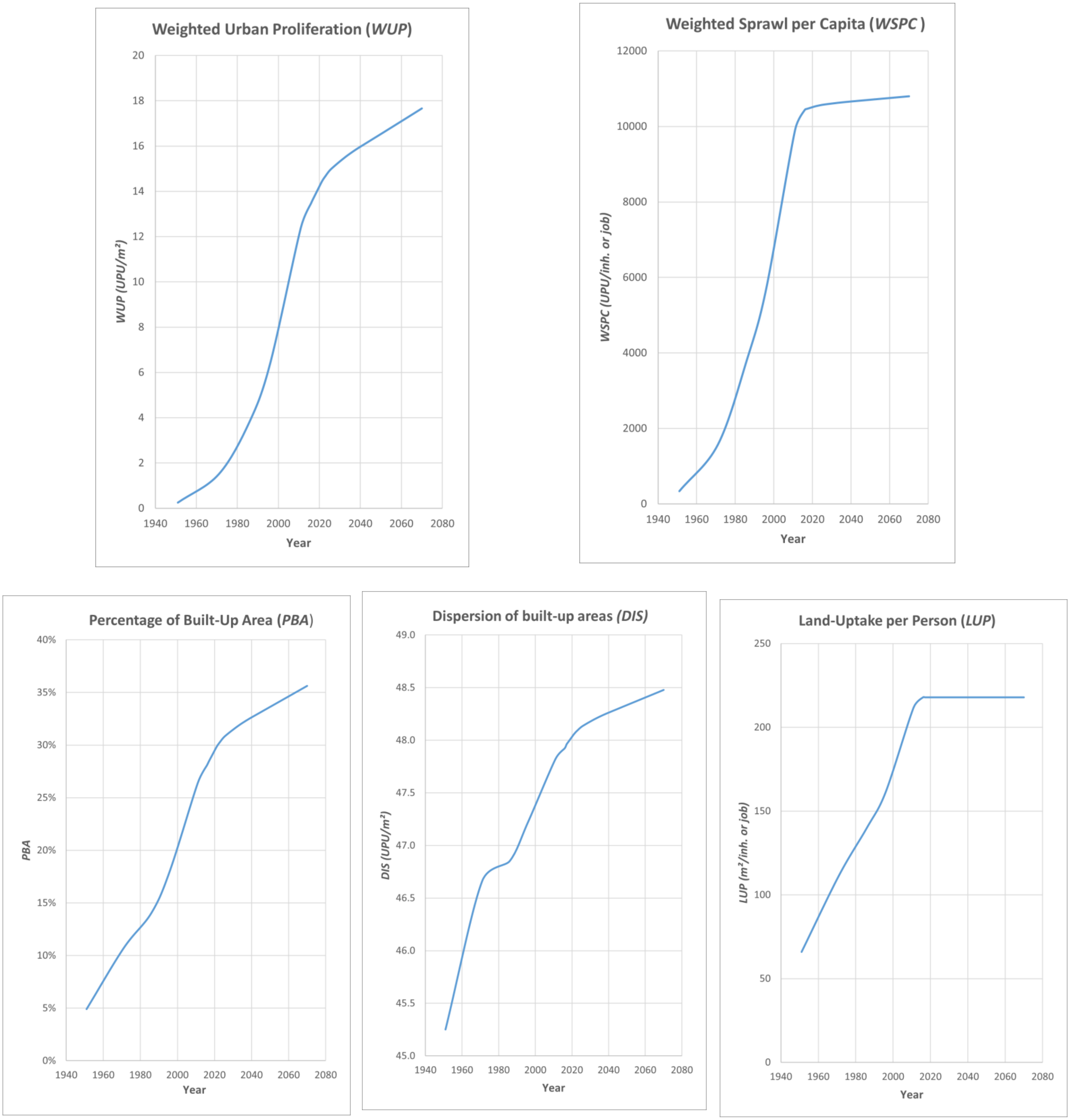


Figure 16 Change in *WUP*, *WSPC*, *DIS*, *PBA* and *LUP* over time (1951-2070) in Scenario 2- "Constant *LUP*"

3.3.3.4 Scenario 3: "Same increase as population"

The calculations for scenario 3 indicate a 26.67% increase in urban sprawl, resulting in a value of *WUP* = 17.05 UPU/m². This increase in value of *WUP* corresponds to an increase in dispersion to increase up to approximately 48.426 UPU/m². To attain this lower level of urban sprawl than in scenario 2, the land uptake per person must be limited to around 213.54 m² per inhabitant or job. The *WSPC* value will remain constant at 10,441.37 UPU/ (inb. or job) in 2016 through 2070, because the rates of change in the value of *WUP* and inhabitants + jobs are the same ($WSPC = WUP \cdot A_{\text{reporting unit}} / N_{\text{inhabitantsor jobs}}$) (Figure 17 and Table M.4 in Appendix M).

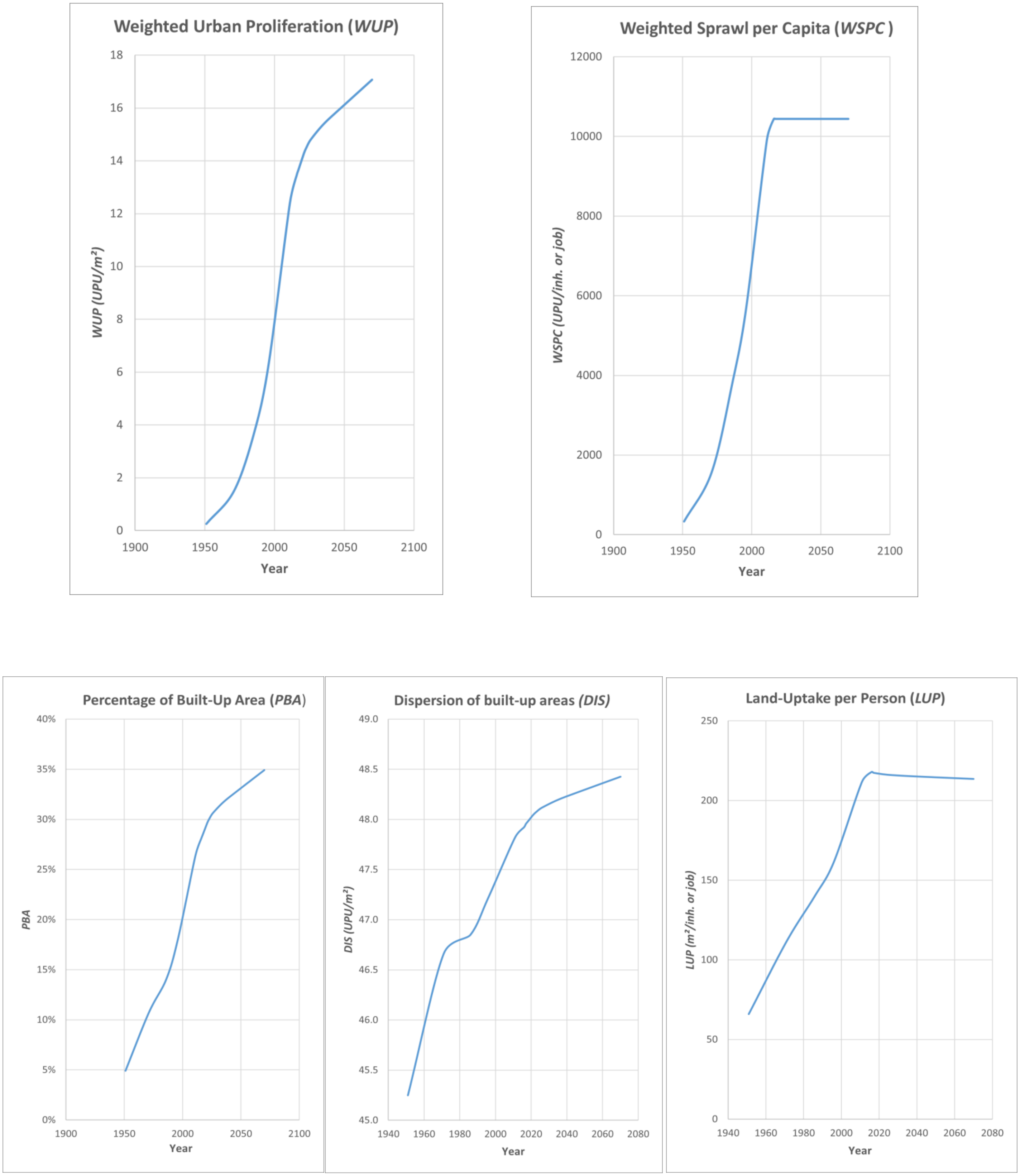


Figure 17 Change in *WUP*, *DIS, PBA* and *LUP* over time (1951-2070) in scenario 3- “Same increase as population”.

3.3.3.5 Scenario 4. “Half increase as population”

In Scenario 4, urban sprawl is expected to increase by 12.56%, with a value of 15.15 UPU/m² in 2070. Subsequently, the *WSPC* value is expected to decrease by 11.13% and reach a value of 9279.29 UPU/ (inb. or job). The corresponding values for dispersion and land uptake per person are estimated to be 48.269 UPU/m² and 200.25 m²/ (inhabitant or job) (Figure 18 and Table M.5 in Appendix M).

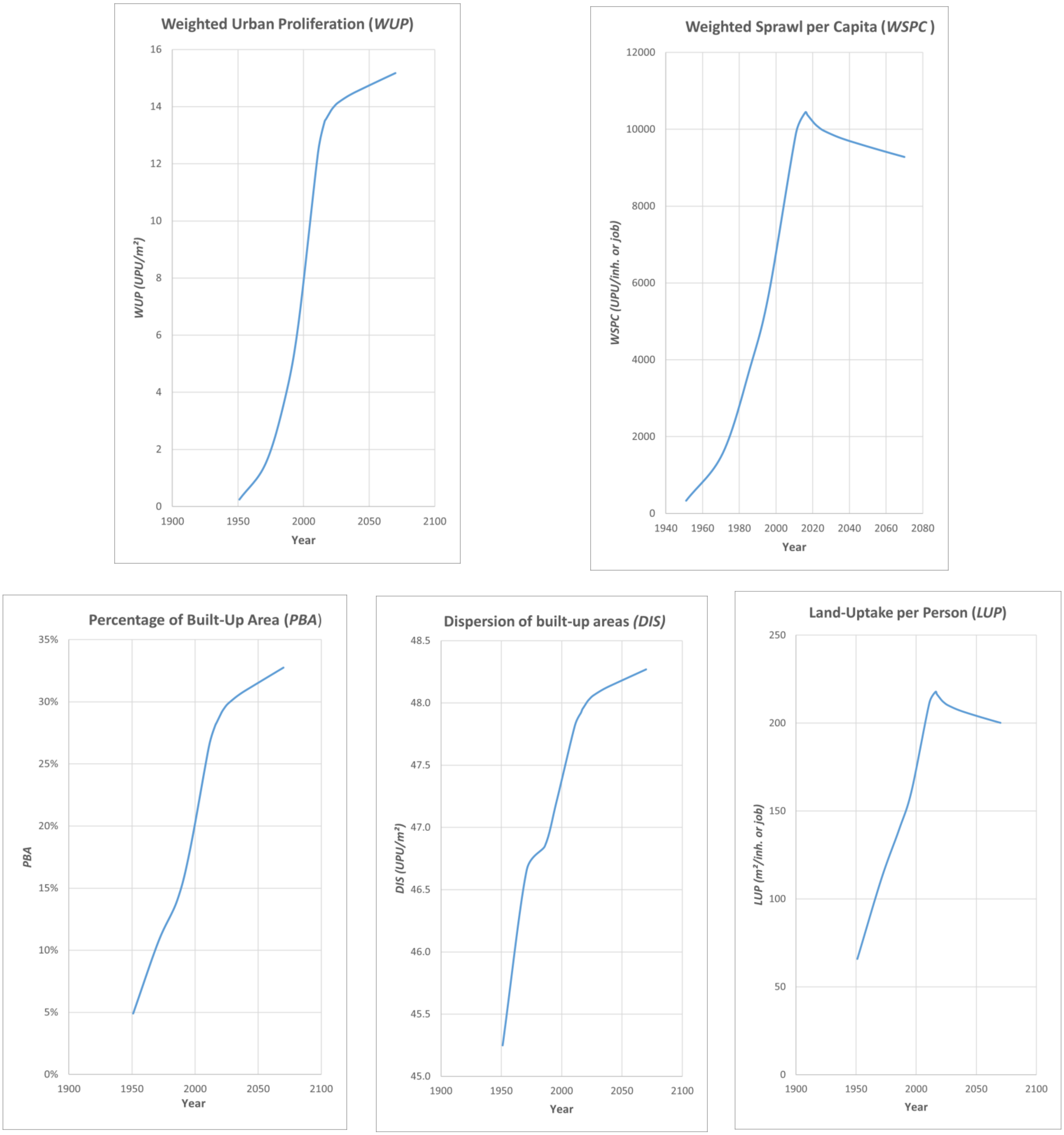


Figure 18 Change in *WUP*, *WSPC*, *DIS, PBA* and *LUP* over time (1951-2070) in scenario 4- "Half increase as population"

3.3.3.6 Scenario 5: "Constant urban sprawl"

Under the constant urban sprawl scenario, the built-up area can increase to a maximum of 116.96 km^2 (+9.67%) up to a total amount of 1324.07 km^2 in 2070. This would correspond to a value of dispersion of 48.132 UPU/m^2. The land uptake per inhabitant or job in this scenario would be correspondingly lower than in Scenario 4, at around 188.67 m^2 per inhabitant or job. The value of *WSPC* is expected to be 8,243.65 UPU/(inb. or job) with an approximate 21% decrease (Figure 19 and Table M.6 in Appendix M).

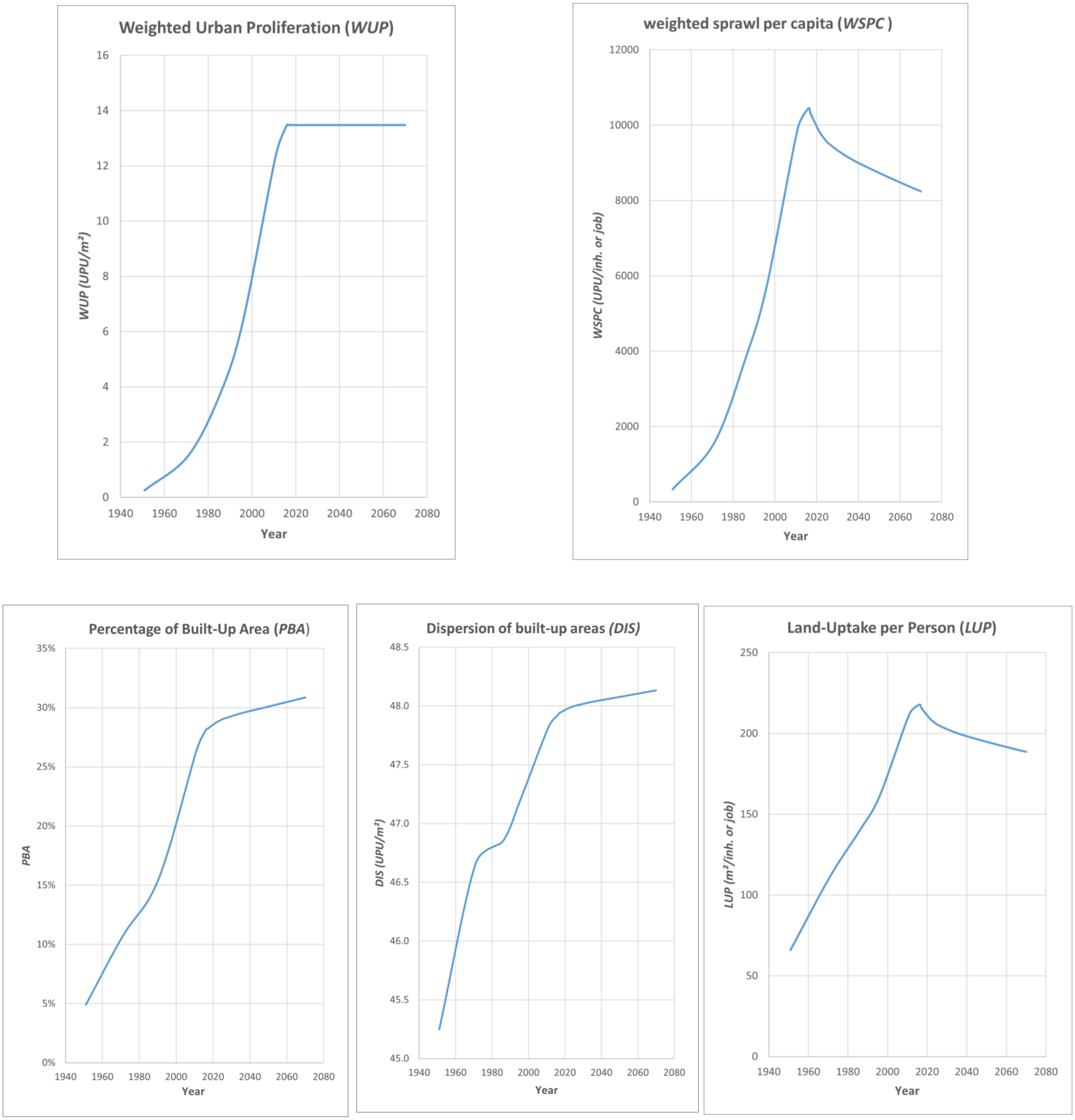


Figure 19 Change in *WUP*, *WSPC*, *DIS, PBA* and *LUP* over time (1951-2070) in scenario 5- "Constant urban sprawl"

3.3.3.7 Scenario 6: "Constant built-up area"

Scenario 6 leads to a decrease in the urban sprawl value by 22.81 % resulting in *WUP* = 10.96 UPU/m^2, while the value of dispersion remains constant. The land uptake per person in this scenario would be correspondingly lower than in Scenario 5, at around 172.01 m^2 per inhabitant or job. The *WSPC* value is projected to decrease to 6,694.78 UPU/(inb. or job) (Table M.7 in Appendix M and Figure 20).

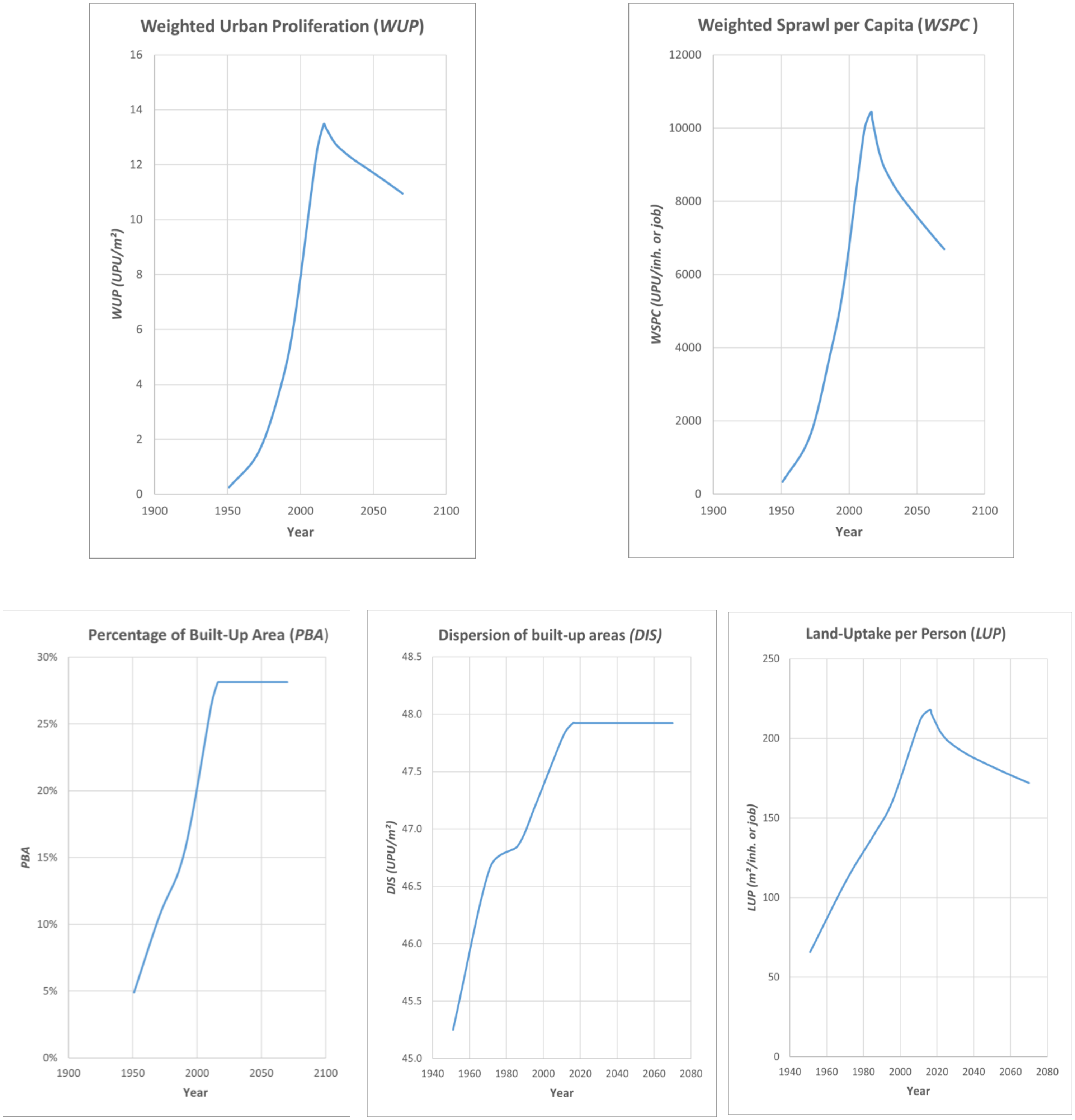


Figure 20 Change in *WUP*, *WSPC*, *DIS, PBA* and *LUP* over time (1951-2070) in scenario 6-"Constant built-up area"

3.3.4 Scenarios for Montreal's CSDs

With all the information at hand, we calculated all values for scenarios 4, 6, and 7 for 86 CSDs, replicating the analysis that was done at the CMA level. The relationship between *DIS* and *PBA* across all CSDs is explained in Appendix K.

The overview of results of the calculation of *WUP* and its components for these three scenarios are presented in Table 7. For example, in the CSD of Montreal, in Scenario 4, urban sprawl is projected to increase by 6.2%, reaching a value of 5.56 UPU/m² in 2070. The corresponding values for dispersion and land uptake per capita are estimated at approximately 49.166 UPU/m² and 98.08 m²/ (inhabitant or job). In Scenario 5, the built-up area may expand by a maximum of 26.86 km² (+10.5%) to a total amount of 282.611 km² by 2070. This results in a dispersion value of 49.15 UPU/m², with land uptake per inhabitant or job estimated at 97.22 m². Scenario 6 would lead to a decrease in urban sprawl by 51.32%, resulting in a value of 2.46 UPU/m². The dispersion value remains constant. In this scenario, land uptake per person is correspondingly lower than in scenario 5, at around 88 m² per inhabitant or job.

In another CSD, Longueuil, under scenario 4, urban sprawl is projected to increase by 17.8%, reaching a value of 33.69 UPU/m² in 2070. The corresponding values for dispersion and land uptake per capita are estimated at 49.28 UPU/m² and 190.36 m²/ (inhabitant or job). In Scenario 5, the built-up area can expand by 15.6% to a total of 76.74 km² by 2070, resulting in a dispersion value of 49.13 UPU/m². Land uptake per inhabitant or job in this scenario is estimated at 176.26 m². Scenario 6 leads to a decrease in urban sprawl by 31.5%, resulting in a value of 19.59 UPU/m², with the dispersion value remaining constant. In this scenario, land uptake per person is correspondingly lower than in scenario 5, at around 152.45 m² per inhabitant or job.

Table 7. Urban sprawl metrics values for scenarios 4, 5 and 6 for Montreal CSDs in 2070

	Scenario 4					**Scenario 5**					**Scenario 6**				
CSD Name	***PBA***	***LUP*** (m^2/ (inh. or Job))	***DIS*** (UPU/ m^2	***WUP*** (UPU/m^2)	***WSPC*** (UPU/ (inb. or job))	***PBA***	***LUP*** (m^2/ (inh. or Job))	***DIS*** (UPU/ m^2	***WUP*** (UPU/m^2)	***WSPC*** (UPU/ (inb. or job))	***PBA***	***LUP*** (m^2/ (inh. or Job))	***DIS*** (UPU/ m^2	***WUP*** (UPU/m^2)	***WSPC*** (UPU/ (inb. or job))
Montreal	0.78	98.08	49.17	5.56	699.72	0.77	97.22	49.15	5.24	659.45	0.70	87.98	48.96	2.55	320.91
Brossard	0.68	200.59	49.29	33.48	9842.79	0.63	184.22	49.13	28.29	8316.98	0.55	160.99	48.87	20.53	6035.62
Beauharnois	0.15	403.43	43.98	6.05	16545.22	0.12	334.84	43.62	4.73	12935.36	0.12	322.65	43.55	4.50	12306.36
Châteauguay	0.64	288.84	48.33	35.03	15822.80	0.57	257.26	48.10	29.75	13437.86	0.54	242.93	47.99	27.30	12331.21
Delson	0.69	325.68	49.36	41.26	19371.48	0.60	283.48	49.09	34.37	16136.64	0.57	269.86	48.99	32.11	15075.57
Deux-Montagnes	1.00	265.62	48.55	54.23	15566.13	0.99	262.75	48.41	53.15	14084.78	0.96	253.09	48.34	50.33	13337.47
Chambly	0.51	245.35	47.99	25.86	12507.96	0.44	212.74	47.72	20.50	9915.43	0.39	189.15	47.49	16.41	7937.18
Dorval	0.79	271.10	48.97	26.79	9166.50	0.78	265.94	48.93	0.49	167.66	0.77	262.86	48.91	42.37	14497.37
Saint-Zotique	0.23	300.02	42.74	7.94	10393.61	0.18	231.20	42.24	5.33	6977.07	0.16	205.45	42.01	4.32	5654.96
Beaconsfield	0.84	394.94	48.24	48.09	22657.11	0.81	380.17	48.17	45.89	21620.60	0.80	377.11	48.15	45.43	21403.88
Les Coteaux	0.35	428.65	44.17	14.61	17999.51	0.29	359.30	43.83	11.62	14315.84	0.28	348.57	43.77	11.16	13749.12
Oka	0.07	530.88	41.96	2.33	18163.94	0.06	440.57	41.60	1.84	14344.06	0.06	431.92	41.57	1.79	13954.27
Saint-Eustache	0.27	251.82	48.10	13.96	13047.06	0.25	235.74	47.97	12.62	11794.69	0.24	224.46	47.87	11.66	10897.47
Saint-Mathias-sur-Richelieu	0.08	749.70	45.91	3.97	37742.85	0.08	738.40	45.88	3.90	37077.36	0.08	737.79	45.88	3.90	37077.36
Saint-Mathieu	0.09	793.31	44.83	4.30	36491.19	0.08	658.67	44.47	3.44	29192.96	0.08	652.67	44.45	3.40	28853.50
Saint-Philippe	0.06	236.05	48.29	3.06	12054.31	0.05	186.21	47.83	2.00	7878.63	0.04	147.55	47.39	1.09	4293.86
Saint-Amable	0.25	408.20	45.51	11.93	19253.84	0.21	331.17	45.10	9.10	14686.50	0.20	317.90	45.03	8.61	13895.69
Mercier	0.17	281.23	46.58	8.33	13594.02	0.14	226.76	46.16	6.00	9791.61	0.12	201.51	45.93	4.87	7947.53
Mirabel	0.11	388.05	46.02	5.57	18989.03	0.09	293.26	45.48	3.85	13125.27	0.08	275.07	45.35	3.51	11966.16
McMasterville	0.67	313.18	47.47	35.24	16532.02	0.64	301.90	47.40	33.56	15743.89	0.63	297.63	47.37	32.92	15443.65
Terrebonne	0.38	305.03	47.51	19.91	16064.18	0.34	271.49	47.29	16.95	13675.93	0.32	258.50	47.19	15.79	12740.00
Sainte-Marthe-sur-le-Lac	0.94	242.97	47.98	47.93	12326.05	0.78	200.86	47.61	34.75	8936.58	0.66	170.29	47.29	24.40	6274.89
Kirkland	0.77	287.08	49.47	42.92	15926.72	0.77	287.08	49.47	44.30	16438.81	0.77	287.08	49.47	45.08	16728.25
Saint-Isidore	0.05	558.90	43.72	2.13	22885.58	0.04	477.49	43.42	1.75	18802.71	0.04	470.37	43.39	1.72	18480.38
Sainte-Catherine	0.17	281.23	46.58	8.33	2791.24	0.14	226.76	46.16	6.00	2010.50	0.12	201.51	45.93	4.87	1631.85
Hudson	0.36	1282.44	46.98	5.07	18067.43	0.35	1236.98	46.91	19.06	67922.12	0.35	1235.79	46.91	19.07	67957.76
Hampstead	1.00	199.58	49.41	49.18	10799.74	1.00	199.58	49.41	49.18	9895.60	0.94	187.99	49.30	43.75	8732.00
Gore	0.03	737.67	38.48	0.63	18091.83	0.02	590.36	38.05	0.49	14071.42	0.02	582.96	38.03	0.48	13784.25
Lavaltrie	0.16	455.22	45.09	7.43	20922.92	0.14	381.76	44.72	5.92	16670.75	0.13	370.94	44.70	5.72	16107.55
Rosemere	0.89	435.04	49.34	54.64	26789.13	0.83	409.35	49.22	50.82	24916.24	0.83	405.17	49.20	50.20	24612.26
Saint-Placide	0.05	889.35	40.28	1.50	528858.48	0.05	807.88	40.10	1.34	23288.54	0.05	804.74	40.09	1.33	23114.75
Boisbriand	0.49	272.56	48.91	27.57	15206.13	0.45	249.52	48.74	24.27	13386.03	0.43	236.92	48.64	22.43	12371.18
Mascouche	0.24	302.97	48.45	13.50	16901.17	0.21	257.47	48.14	10.77	13483.38	0.19	239.82	48.00	9.68	12118.77
Saint-Jérôme	0.52	302.51	48.32	28.68	16745.90	0.44	259.39	48.03	23.16	13522.84	0.42	242.54	47.90	20.95	12232.45
Senneville	0.13	325.48	47.39	6.73	17202.91	0.12	304.38	47.26	6.16	15745.90	0.12	297.35	47.21	5.97	15260.24
Sainte-Anne-des-Plaines	0.07	259.72	44.16	2.74	9939.50	0.06	229.37	43.92	2.25	8162.00	0.06	211.01	43.76	1.95	7073.73
Vaudreuil-Dorion	0.37	303.27	48.15	20.49	16616.94	0.37	303.27	48.15	15.58	12635.04	0.28	229.24	47.61	13.64	11061.74
Charlemagne	0.77	225.02	48.20	37.96	11164.46	0.73	215.86	48.12	35.40	10411.54	0.70	206.58	48.03	32.76	9635.08
Dollard-Des Ormeaux	0.85	231.53	49.30	44.29	12015.66	0.85	230.26	49.29	44.59	12097.05	0.84	228.92	49.28	44.90	12181.15
Sainte-Anne-de-Bellevue	0.32	362.14	48.08	17.75	20362.10	0.31	355.58	48.04	17.34	19891.77	0.31	353.87	48.03	17.24	19777.05

L'Île-Perrot	0.85	298.06	48.24	46.74	16356.81	0.79	275.56	48.08	41.98	14691.03	0.76	266.03	48.02	39.93	13973.63
Baie-D'Urfé	0.80	607.15	47.77	44.97	34306.08	0.79	599.44	47.74	44.91	34260.31	0.78	598.77	47.74	44.91	34260.31
Saint-Lazare	0.34	665.51	47.84	19.60	38475.70	0.28	547.76	47.46	15.61	30643.15	0.28	540.48	47.44	15.36	30152.38
Mont-Royal	0.96	173.03	49.72	41.69	7504.55	0.93	167.98	49.67	38.83	6989.73	0.87	155.86	49.52	31.84	5731.47
Saint-Basile-le-Grand	0.21	378.65	47.28	11.36	20311.84	0.21	366.67	47.22	10.91	19507.23	0.20	363.91	47.20	10.81	19328.43
Lorraine	0.85	408.73	48.87	50.83	24408.75	0.77	371.06	48.68	45.18	21695.60	0.76	364.11	48.65	44.13	21191.38
Repentigny	0.49	259.45	48.18	25.61	13660.47	0.46	246.80	48.09	23.78	12684.34	0.45	238.61	48.02	22.58	12044.26
Les Cèdres	0.11	795.02	45.06	5.10	37324.85	0.09	690.07	44.79	4.30	31469.97	0.09	685.29	44.78	4.27	31250.41
Westmount	0.83	119.06	48.86	6.12	880.20	0.83	119.03	48.86	6.65	956.43	0.83	118.73	48.86	14.13	2032.23
Montréal-Est	0.61	687.01	48.99	37.69	42560.43	0.55	620.19	48.79	33.53	37862.86	0.55	616.09	48.78	33.28	37580.55
Terrasse-Vaudreuil	0.88	425.79	48.18	49.92	24040.36	0.88	423.82	48.17	50.47	24305.23	0.88	423.44	48.17	50.58	24358.20
Longueuil	0.72	190.36	49.28	33.69	8940.10	0.66	176.26	49.13	28.58	7584.09	0.57	152.45	48.85	19.59	5198.47
L'Assomption	0.15	381.71	45.85	7.18	18381.09	0.13	328.62	45.56	5.91	15129.84	0.12	317.53	45.49	5.64	14438.63
Verchères	0.04	421.15	41.58	1.24	13509.87	0.04	420.12	41.58	1.24	13509.87	0.04	419.94	41.57	1.24	13509.87
Vaudreuil-sur-le-Lac	0.69	600.08	48.84	42.07	36694.55	0.67	582.49	48.79	40.66	35464.71	0.67	581.03	48.78	40.54	35360.05
Varennes	0.10	296.73	46.12	4.67	14033.88	0.10	290.26	46.08	4.53	13613.16	0.10	287.38	46.06	4.47	13432.86
Coteau-du-Lac	0.10	296.73	46.12	4.67	7202.42	0.10	290.26	46.08	4.53	6986.50	0.10	287.38	46.06	4.47	6893.97
Saint-Joseph-du-Lac	0.16	571.04	47.03	8.87	31049.23	0.14	475.65	46.67	7.13	24958.40	0.13	467.68	46.64	6.98	24433.33
Cote-Saint-Luc	0.79	117.51	49.30	13.28	1980.23	0.77	115.04	49.26	11.92	1777.43	0.65	97.33	48.94	4.41	657.59
Sainte-Thérèse	0.95	233.66	49.32	12.20	2991.36	0.92	225.73	49.25	48.57	11909.06	0.89	218.55	49.19	46.05	11291.17
Saint-Mathieu-de-Beloeil	0.06	476.43	44.77	2.62	21331.36	0.06	452.54	44.67	2.46	20028.68	0.06	449.39	44.66	2.44	19865.84
Candiac	0.50	231.37	48.76	25.94	12032.91	0.45	208.80	48.56	21.83	10126.39	0.41	188.70	48.36	18.00	8349.75
Saint-Constant	0.23	249.47	48.50	12.23	13197.47	0.20	212.28	48.19	9.43	10175.98	0.17	186.88	47.94	7.40	7985.39
Montreal-Ouest	0.92	188.93	49.19	42.50	8766.89	0.89	183.42	49.13	39.96	8242.94	0.84	173.46	49.02	35.29	7279.61
Pointe-des-Cascades	0.34	288.95	43.62	12.86	10837.84	0.26	223.20	43.12	8.59	7239.27	0.23	195.83	42.87	6.73	5671.75
Beloeil	0.45	261.18	48.80	24.44	14289.00	0.39	229.04	48.55	20.03	11710.67	0.36	209.57	48.38	17.24	10079.48
Saint-Bruno-de-Montarville	0.32	323.57	48.15	17.61	17964.73	0.30	308.15	48.06	16.52	16852.77	0.30	302.84	48.03	16.14	16465.12
Sainte-Julie	0.23	293.46	46.64	11.31	14412.50	0.22	285.80	46.59	10.90	13890.03	0.22	282.29	46.57	10.71	13647.91
La Prairie	0.22	217.19	48.58	10.72	10805.96	0.19	195.87	48.38	8.89	8961.29	0.17	172.74	48.13	6.79	6844.45
Boucherville	0.32	288.27	48.04	17.44	15511.21	0.31	276.22	47.96	16.44	14621.81	0.30	270.46	47.92	15.96	14194.89
Blainville	0.61	296.73	49.42	35.94	17383.03	0.51	247.95	49.07	27.95	13518.52	0.47	227.89	48.91	24.53	11864.38
Pointe-Claire	0.92	226.47	49.38	49.02	12049.86	0.84	206.89	49.21	42.04	10334.07	0.76	188.04	49.02	35.02	8608.44
Otterburn Park	0.67	412.73	47.91	37.95	23306.83	0.66	407.95	47.89	37.41	22975.19	0.66	407.05	47.89	37.31	22913.77
Pointe-Calumet	0.82	547.61	46.59	43.00	28787.61	0.78	521.43	46.50	40.54	27140.69	0.78	518.86	46.49	40.30	26980.02
Pincourt	0.82	337.04	46.85	42.12	17261.73	0.78	319.62	46.75	39.28	16097.84	0.77	314.28	46.72	38.41	15741.29
Notre-Dame-de-l'Île-Perrot	0.28	516.70	45.23	12.94	24234.34	0.25	465.87	45.03	11.38	21312.74	0.25	460.45	45.01	11.22	21013.08
Richelieu	0.09	337.94	46.08	4.52	16326.18	0.08	305.57	45.89	3.95	14267.35	0.08	296.12	45.83	3.78	13653.31
Laval	0.62	215.09	49.31	31.82	11078.74	0.58	200.23	49.17	28.00	9748.74	0.53	183.15	49.00	23.44	8161.09
Mont-Saint-Hilaire	0.27	514.15	47.93	15.50	29565.21	0.26	501.46	47.80	15.01	28630.57	0.26	501.46	47.80	14.96	28535.20
Saint-Sulpice	0.07	703.61	43.99	3.09	29790.65	0.07	702.42	43.98	3.09	29790.65	0.07	702.34	43.98	3.09	29790.65
Bois-des-Filion	0.94	243.66	49.16	50.91	13250.69	0.84	218.84	48.95	42.92	11171.08	0.77	200.02	48.78	36.59	9523.53
Carignan	0.16	409.04	46.14	8.18	20329.50	0.12	288.18	45.46	5.15	12799.14	0.11	267.92	45.32	4.64	11531.65

Saint-Lambert	0.81	181.74	48.65	35.13	7876.80	0.81	181.74	48.65	31.71	7109.97	0.70	157.32	48.37	24.62	5520.26
Léry	0.32	1192.99	46.09	16.30	61588.57	0.30	1130.53	45.99	15.31	57847.92	0.30	1128.96	45.99	15.28	57734.56
Saint-Colomban	0.31	855.68	48.33	18.78	51357.92	0.23	622.27	47.71	13.01	35578.62	0.22	613.48	47.68	12.80	35004.33
L'Épiphanie	0.09	429.27	42.52	3.22	15188.85	0.08	393.86	42.36	2.88	13585.06	0.08	386.14	42.32	2.81	13254.86

3.3.5 Targets and limits for Montreal CMA

For the Montreal CMA_{2011} in the year 2070, we are proposing a specific target value of 12.218 UPU/m^2 between scenario 5 and scenario 6. The no-deterioration value corresponds to Scenario 5, which is 13.48 UPU/m^2. As a limit value, we propose a value that falls between the target value and the no deterioration value, which is 12.849 UPU/m^2. The warning value is calculated midway between the no-deterioration (scenario 5) and Scenario 4 at 14.327 UPU/m^2. Table 8 displays the target and limit values along with values for the three components of *WUP*. In each scenario, the interplay of the three components must be considered in a way that ensures the overall *WUP* value either matches the target value or at least stays within the established limit. The values assigned to these components in the Table 8 serve to indicate the approximate values, allowing the overall *WUP* value to align with the target or remain within the specified limits. Such an interplay of the components also applies to the warning value. If a no-deterioration objective is chosen, the value of *WUP* should be set at 13.48 UPU/m^2. For instance, if the dispersion increases beyond 48.13 UPU/m^2, it is necessary to reduce the *LUP* to a level less than 188.67 m^2 per inhabitant or job to compensate for the higher contribution of dispersion to urban sprawl.

Table 8. Proposed values for the target, limit, no-deterioration, and warning values for urban sprawl in the Montreal CMA_{2011}

	2016	Scenario 4	Warning	No deterioration	Limit	Target	Scenario 6
WUP (UPU/m^2)	13.480	15.173	14.38	13.48	12.85	12.22	10.950
Built-up areas(km^2)	1207.11	1405.325	1368.050	1324.07	1295.174	1265.576	1207.11
PBA	0.281	0.327	0.319	0.308	0.302	0.295	0.281
LUP (m^2/inhabitant or job)	217.90	200.25	194.94	188.67	184.56	180.34	172.01
DIS (UPU/m^2)	47.920	48.269	48.207	48.132	48.084	48.034	47.920
Inhabitants and jobs	5540650.6	7017763.3	7017763.3	7017763.3	7017763.3	7017763.3	7017763.3

3.3.6 Targets and limits for the CSDs

Table 9 presents target and limit values, as well as values denoting the no-deterioration and warning thresholds at the CSD level. The methodology used for the CSDs is consistent with that applied to the Montreal CMA.

Table 9. Proposed values (*WUP*) for target, limit, no-deterioration, and warning values for urban sprawl for all CSDs in the Montreal CMA_{2011} for 2070

CSDUID	CSD name	*WUP* in 2016	Scenario 4	Warning value	No deterioration	Limit	Target	*WUP* for Scenario 6
2466023	Montreal	5.24	5.56	5.4	5.24	4.5675	3.895	2.55
2458007	Brossard	28.29	33.48	30.885	28.29	26.35	24.41	20.53
2470022	Beauharnois	4.73	6.05	5.39	4.73	4.6725	4.615	4.5
2467050	Châteauguay	29.75	35.03	32.39	29.75	29.1375	28.525	27.3
2467025	Delson	34.37	41.26	37.815	34.37	33.805	33.24	32.11
2472010	Deux-Montagnes	53.15	58.74	53.69	53.15	52.445	51.74	50.33
2457005	Chambly	20.50	25.86	23.18	20.5	19.4775	18.455	16.41
2466087	Dorval	42.96	26.79	13.64	0.49	10.96	21.43	42.37
2471025	Saint-Zotique	5.33	7.94	6.635	5.33	5.0775	4.825	4.32
2466107	Beaconsfield	45.89	48.09	46.99	45.89	45.775	45.66	45.43
2471033	Les Coteaux	11.62	14.61	13.115	11.62	11.505	11.39	11.16
2472032	Oka	1.84	2.33	2.085	1.84	1.8275	1.815	1.79
2472005	Saint-Eustache	12.62	13.96	13.29	12.62	12.38	12.14	11.66
2455065	Saint-Mathias-sur-Richelieu	3.90	3.97	3.935	3.9	3.9	3.9	3.9
2467005	Saint-Mathieu	3.44	4.3	3.87	3.44	3.43	3.42	3.4
2467010	Saint-Philippe	2.00	3.06	2.53	2	1.7725	1.545	1.09
2459015	Saint-Amable	9.10	11.93	10.515	9.1	8.9775	8.855	8.61
2467045	Mercier	6.00	8.33	7.165	6	5.7175	5.435	4.87
2474005	Mirabel	3.85	5.57	4.71	3.85	3.765	3.68	3.51
2457025	McMasterville	33.56	35.24	34.4	33.56	33.4	33.24	32.92
2464008	Terrebonne	16.95	19.91	18.43	16.95	16.66	16.37	15.79
2472015	Sainte-Marthe-sur-le-Lac	34.75	47.93	41.34	34.75	32.1625	29.575	24.4
2466102	Kirkland	44.30	42.92	43.61	44.3	44.495	44.69	45.08
2467040	Saint-Isidore	1.75	2.13	1.94	1.75	1.7425	1.735	1.72
2467030	Sainte-Catherine	31.05	8.33	7.165	6	5.7175	5.435	4.87
2471100	Hudson	19.06	5.07	12.065	19.06	19.0625	19.065	19.07
2466062	Hampstead	49.58	54.11	49.18	49.18	47.82	46.46	43.75
2476025	Gore	0.49	0.63	0.56	0.49	0.4875	0.485	0.48
2452007	Lavaltrie	5.92	7.43	6.675	5.92	5.87	5.82	5.72

2473020	Rosemere	50.82	54.64	52.73	50.82	50.665	50.51	50.2
2472043	Saint-Placide	1.34	1.50	1.42	1.34	1.338	1.335	1.33
2473005	Boisbriand	24.27	27.57	25.92	24.27	23.81	23.35	22.43
2464015	Mascouche	10.77	13.5	12.135	10.77	10.4975	10.225	9.68
2475017	Saint-Jérôme	23.16	28.68	25.92	23.16	22.6075	22.055	20.95
2466127	Senneville	6.16	6.73	6.445	6.16	6.1125	6.065	5.97
2473035	Sainte-Anne-des-Plaines	2.25	2.74	2.495	2.25	2.175	2.1	1.95
2471083	Vaudreuil-Dorion	15.58	20.49	18.035	15.58	15.095	14.61	13.64
2460005	Charlemagne	35.40	37.96	36.68	35.4	34.74	34.08	32.76
2466142	Dollard-Des Ormeaux	44.59	44.29	44.44	44.59	44.6675	44.745	44.9
2466117	Sainte-Anne-de-Bellevue	17.34	17.75	17.545	17.34	17.315	17.29	17.24
2471060	L'Île-Perrot	41.98	46.74	44.36	41.98	41.4675	40.955	39.93
2466112	Baie-D'Urfé	44.91	44.97	44.94	44.91	44.91	44.91	44.91
2471105	Saint-Lazare	15.61	19.6	17.605	15.61	15.5475	15.485	15.36
2466072	Mont-Royal	38.83	41.69	40.26	38.83	37.0825	35.335	31.84
2457020	Saint-Basile-le-Grand	10.91	11.36	11.135	10.91	10.885	10.86	10.81
2473025	Lorraine	45.18	50.83	48.005	45.18	44.9175	44.655	44.13
2460013	Repentigny	23.78	25.61	24.695	23.78	23.48	23.18	22.58
2471050	Les Cèdres	4.30	5.1	4.7	4.3	4.2925	4.285	4.27
2466032	Westmount	6.65	6.12	6.385	6.65	8.52	10.39	14.13
2466007	Montréal-Est	33.53	37.69	35.61	33.53	33.4675	33.405	33.28
2471075	Terrasse-Vaudreuil	50.47	49.92	50.195	50.47	50.4975	50.525	50.58
2458227	Longueuil	28.58	33.69	31.135	28.58	26.3325	24.085	19.59
2460028	L'Assomption	5.91	7.18	6.545	5.91	5.8425	5.775	5.64
2459025	Verchères	1.24	1.24	1.24	1.24	1.24	1.24	1.24
2471090	Vaudreuil-sur-le-Lac	40.66	42.07	41.365	40.66	40.63	40.6	40.54
2459020	Varennes	4.53	4.67	4.6	4.53	4.515	4.5	4.47
2471040	Coteau-du-Lac	2.35	4.67	4.6	4.53	4.515	4.5	4.47
2472025	Saint-Joseph-du-Lac	7.13	8.87	8	7.13	7.0925	7.055	6.98
2466058	Cote-Saint-Luc	11.92	13.28	12.6	11.92	10.0425	8.165	4.41
2473010	Sainte-Thérèse	48.57	12.2	30.385	48.57	47.94	47.31	46.05
2457045	Saint-Mathieu-de-Beloeil	2.46	2.62	2.54	2.46	2.455	2.45	2.44
2467020	Candiac	21.83	25.94	23.885	21.83	20.8725	19.915	18
2467035	Saint-Constant	9.43	12.23	10.83	9.43	8.9225	8.415	7.4
2466047	Montreal-Ouest	39.96	42.5	41.23	39.96	38.7925	37.625	35.29
2471055	Pointe-des-Cascades	8.59	12.86	10.725	8.59	8.125	7.66	6.73
2457040	Beloeil	20.03	24.44	22.235	20.03	19.3325	18.635	17.24

2458037	Saint-Bruno-de-Montarville	16.52	17.61	17.065	16.52	16.425	16.33	16.14
2459010	Sainte-Julie	10.90	11.31	11.105	10.9	10.8525	10.805	10.71
2467015	La Prairie	8.89	10.72	9.805	8.89	8.365	7.84	6.79
2458033	Boucherville	16.44	17.44	16.94	16.44	16.32	16.2	15.96
2473015	Blainville	27.95	35.94	31.945	27.95	27.095	26.24	24.53
2466097	Pointe-Claire	42.04	49.02	45.53	42.04	40.285	38.53	35.02
2457030	Otterburn Park	37.41	37.95	37.68	37.41	37.385	37.36	37.31
2472020	Pointe-Calumet	40.54	43	41.77	40.54	40.48	40.42	40.3
2471070	Pincourt	39.28	42.12	40.7	39.28	39.0625	38.845	38.41
2471065	Notre-Dame-de-l'Île-Perrot	11.38	12.94	12.16	11.38	11.34	11.3	11.22
2455057	Richelieu	3.95	4.52	4.235	3.95	3.9075	3.865	3.78
2465005	Laval	28.00	31.82	29.91	28	26.86	25.72	23.44
2457035	Mont-Saint-Hilaire	15.01	15.5	15.255	15.01	14.9975	14.985	14.96
2460020	Saint-Sulpice	3.09	3.09	3.09	3.09	3.09	3.09	3.09
2473030	Bois-des-Filion	42.92	50.91	46.915	42.92	41.3375	39.755	36.59
2457010	Carignan	5.15	8.18	6.665	5.15	5.0225	4.895	4.64
2458012	Saint-Lambert	31.71	35.13	33.42	31.71	29.9375	28.165	24.62
2467055	Léry	15.31	16.3	15.805	15.31	15.3025	15.295	15.28
2475005	Saint-Colomban	13.01	18.78	15.895	13.01	12.9575	12.905	12.8
2460037	L'Épiphanie	2.88	3.22	3.05	2.88	2.8625	2.845	2.81

3.4 Results

3.4.1 Greenbelt scenarios for the Montreal CMA

Table 10 and Figure 21 present the results of urban sprawl calculations for all four proposed greenbelt scenarios in the Montreal CMA for 2070.

Table 10. Value of the urban sprawl metrics for the greenbelt scenarios for the Montreal CMA_{2011} in 2070

Greenbelt Scenarios	**Inhabitants and jobs**	**Reporting unit area (km^2)**	**Built-up area (km^2)**	***PBA***	***DIS* (UPU/m^2)**	***TS* (MUPU)**	***UP* (UPU/m^2)**	***LUP* (m^2/(inh. or job))**	***WUP* (UPU/m^2)**
SC1	7017763.3	4291.69	1943.19	0.45	48.36	93979.68	21.90	276.9	24.58
SC2	7017763.3	4291.69	1781.00	0.41	48.26	85955.69	20.03	253.8	21.79
SC3	7017763.3	4291.69	1865.18	0.43	48.32	90128.94	21.00	265.8	23.26
SC4	7017763.3	4291.69	1703.01	0.39	48.21	82105.82	19.13	242.7	20.41

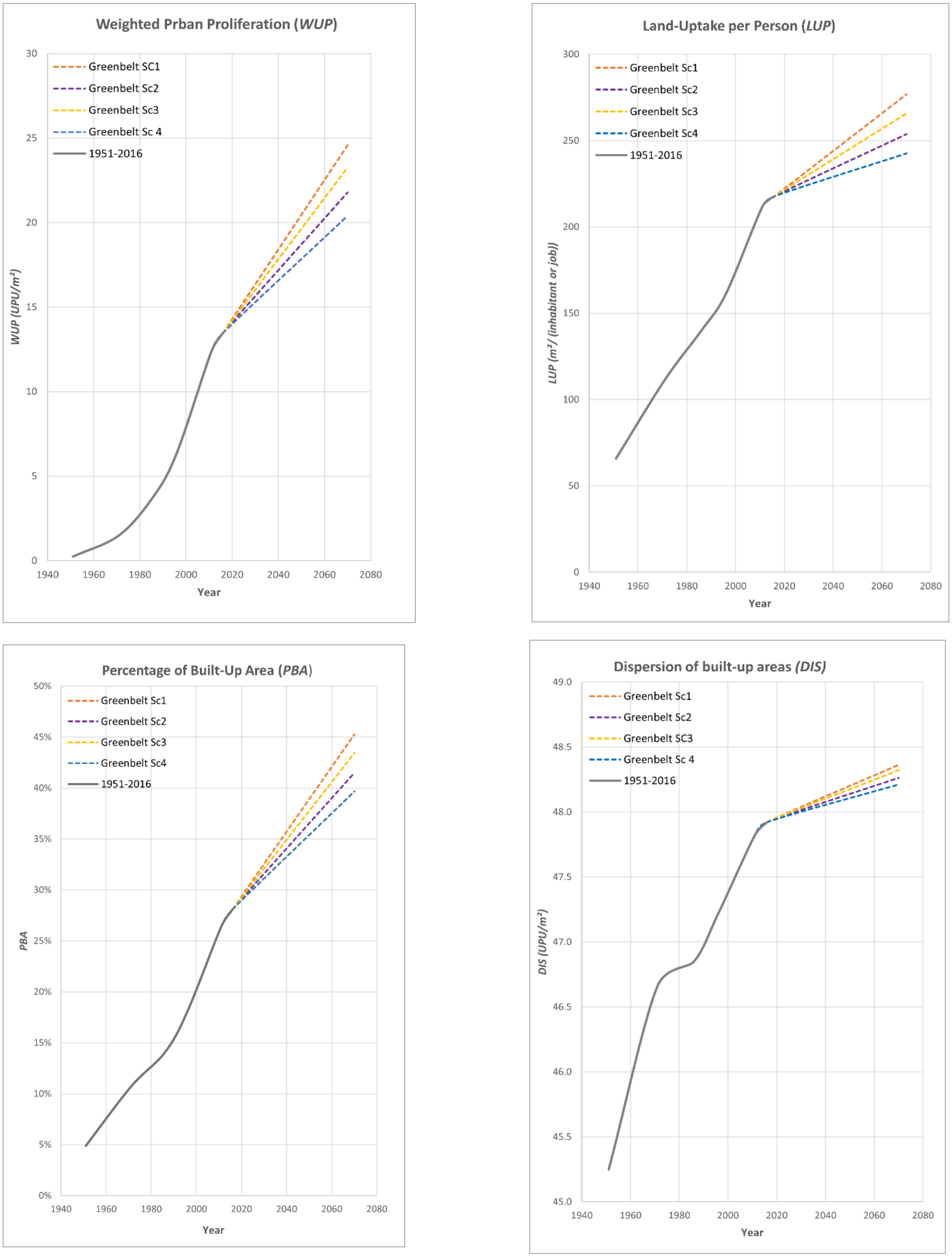


Figure 21 Change in *WUP*, *DIS, PBA* and *LUP* between 1951 and 2070 for the four greenbelts scenarios

3.4.1.1 Greenbelt scenario 1

In greenbelt scenario 1, the built-up area is expected to increase from 1,207.11 km^2 in 2016 to 1,943.19 km^2 in 2070, representing a substantial 61% increase compared to the 2016. This expansion is accompanied by an 82.38% increase in the value of the *WUP* between 2016 and 2070, resulting in a value of 24.58 UPU/m^2 in 2070. This substantial increase in the value of *WUP* is accompanied by an increase in dispersion, expected to reach 48.36 UPU/m^2. The *LUP* is projected to rise to around 276.9 square meters per inhabitant or job.

3.4.1.2 Greenbelt scenario 2

In greenbelt scenario 2, the projected land uptake is set to increase to 253.8 m^2 per inhabitant or job by the year 2070. Additionally, the built-up area is assumed to grow from 1207.11 km^2 in 2016 to 1781 km^2 in 2070, a 48% increase. Over the same period, dispersion is expected to rise from 47.92 UPU/m^2 to 48.26 UPU/m^2. As a result, the value of the *WUP* is projected to increase from 13.48 UPU/m^2 to 21.79 UPU/m^2.

3.4.1.3 Greenbelt scenario 3

In greenbelt scenario 3, urban sprawl increases by 72 %, resulting in a value of *WUP* = 23.26 UPU/m^2. The *DIS* value is projected to rise to 48.32 UPU/m^2. The built-up areas would increase to 1865.18 km^2, which represents a 54.52 % increase. The land uptake per person in this scenario would be 265.8 m^2 per inhabitant or job, marking a 22 % increase compared to 2016.

3.4.1.4 Greenbelt scenario 4

In greenbelt scenario 4, the projected *LUP* is expected to increase to 242.7 m² per inhabitant or job by the year 2070, representing an 11.38 % increase. Additionally, the built-up area is assumed to expand from 1207.11 km² in 2016 to 1703.01 km² in 2070, marking a 41.1% increase. Over the same period, dispersion is anticipated to rise to 48.21 UPU/m². Consequently, the value of the *WUP* is projected to increase from 13.48 UPU/m² to 20.41 UPU/m².

3.4.2 Greenbelt scenarios for the CSDs within the Montreal CMA

All four greenbelt scenarios have also been calculated at the CSD level.

3.4.2.1 Greenbelt scenario 1

Table 11 displays the results for greenbelt Scenario 1. As scenarios 2 to 4 are based on changes in three specific CSDs, Table 12, 13 and 14 present the values of the *WUP* metrics for the CSDs that have been affected by these scenarios. For all other CSDs, the results remain consistent with Scenario 1.

Table 11. Values of urban sprawl metrics for greenbelt scenario 1 for Montreal's CSDs in 2070

CSDUID	CSD name	Inhabitants	Jobs	Inhabitants and jobs	Unit area (km^2)	Urban area (km^2)	*PBA*	*LUP* (m^2/(inb. or job))	*DIS* (UPU/m^2)	*WUP* (UPU/m^2)
2466023	Montreal	1704694	1202241.2	2906935.2	365.834	318.394	0.870	109.5	49.189	10.848
2458007	Brossard	85721	68553.8	154274.8	45.355	29.780	0.657	193	49.058	30.843
2470022	Beauharnois	12884	12552.8	25436.8	69.563	25.675	0.369	1009.4	46.309	19.336
2467050	Châteauguay	47906	34523.8	82429.8	37.233	25.735	0.691	312.2	48.076	37.931
2467025	Delson	7457	8843.8	16300.8	7.653	7.430	0.971	455.8	48.560	57.503
2472010	Deux-Montagnes	17496	5726.8	23222.8	6.154	6.080	0.988	261.8	48.596	53.469
2457005	Chambly	29120	27797.9	56917.9	27.530	13.032	0.473	229	47.636	22.867
2466087	Dorval	18980	42055.2	61035.2	20.884	18.462	0.884	302.5	49.101	51.139
2471025	Saint-Zotique	7934	11300.3	19234.3	25.178	10.437	0.415	542.6	45.469	19.893
2466107	Beaconsfield	19324	4030.5	23354.5	11.003	10.194	0.926	436.5	48.688	55.090
2471033	Les Coteaux	5368	4139.0	9507.0	11.713	4.789	0.409	503.8	47.355	22.599

2472032	Oka	3824	3583.1	7407.1	57.743	6.449	0.112	870.7	42.119	3.944
2472005	Saint-Eustache	44008	30661.9	74669.9	69.787	21.652	0.310	290	48.010	16.684
2455065	Saint-Mathias-sur-Richelieu	4531	740.3	5271.3	50.115	4.029	0.080	764.3	46.300	4.184
2467005	Saint-Mathieu	2156	1565.1	3721.1	31.578	2.553	0.081	686	44.915	3.731
2467010	Saint-Philippe	6320	9432.5	15752.5	62.054	5.130	0.083	325.6	47.034	4.265
2459015	Saint-Amable	12167	10594.4	22761.4	36.735	7.652	0.208	336.2	46.025	10.006
2467045	Mercier	13115	15317.2	28432.2	46.400	6.528	0.141	229.6	46.269	6.167
2474005	Mirabel	50513	92155.9	142668.9	486.381	68.583	0.141	480.7	46.657	7.391
2457025	McMasterville	5698	1542.0	7240.0	3.396	2.655	0.782	366.6	47.738	43.068
2464008	Terrebonne	111575	80436.9	192011.9	154.923	89.723	0.579	467.3	48.026	33.278
2472015	Sainte-Marthe-sur-le-Lac	18074	18920.3	36994.3	9.514	8.253	0.868	223.1	48.074	42.528
2466102	Kirkland	20151	5829.7	25980.7	9.641	9.397	0.975	361.7	49.523	59.413
2467040	Saint-Isidore	2608	2224.7	4832.7	51.925	3.011	0.058	623.1	43.183	2.260
2467030	Sainte-Catherine	17047	11385.2	28432.2	9.527	8.735	0.917	307.2	48.277	50.770
2471100	Hudson	5185	969.7	6154.7	21.933	9.830	0.448	1597.2	47.824	26.299
2466062	Hampstead	6973	1991.4	8964.4	1.789	1.690	0.945	188.5	49.657	44.813
2476025	Gore	1904	1491.3	3395.3	97.503	93.100	0.955	27397.3	48.969	60.380
2452007	Lavaltrie	13657	10653.6	24310.6	68.459	12.648	0.185	520.3	44.622	8.204
2473020	Rosemere	13958	7837.2	21795.2	10.686	9.854	0.922	452.1	49.549	57.584
2472043	Saint-Placide	1686	791.8	2477.8	43.062	3.685	0.086	1487.2	42.330	3.112
2473005	Boisbriand	26884	23325.4	50209.4	27.693	15.764	0.569	314	48.714	32.478
2464015	Mascouche	46692	38966.4	85658.4	107.239	31.254	0.291	364.9	48.275	16.600
2475017	Saint-Jérôme	74346	82508.1	156854.1	91.585	76.504	0.835	487.7	48.633	49.925
2466127	Senneville	921	2005.1	2926.1	7.480	1.828	0.244	624.8	45.686	12.023
2473035	Sainte-Anne-des-Plaines	14421	11205.3	25626.3	92.961	9.041	0.097	352.8	44.346	4.062
2471083	Vaudreuil-Dorion	38117	51102.2	89219.2	72.355	32.124	0.444	360.1	47.907	24.674
2460005	Charlemagne	5913	1942.2	7855.2	2.310	2.124	0.919	270.4	49.220	52.029
2466142	Dollard-Des Ormeaux	48899	7123.4	56022.4	15.199	13.661	0.899	243.8	49.511	49.801
2466117	Sainte-Anne-de-Bellevue	4958	4258.4	9216.4	10.573	5.864	0.555	636.2	48.395	33.127
2471060	L'Île-Perrot	10756	4836.9	15592.9	5.457	5.375	0.985	344.7	48.188	55.373
2466112	Baie-D'Urfé	3823	4072.6	7895.6	6.023	5.974	0.992	756.6	48.171	58.778
2471105	Saint-Lazare	19889	14186.7	34075.7	66.892	38.729	0.579	1136.5	48.278	34.815
2466072	Mont-Royal	20276	22268.8	42544.8	7.658	7.389	0.965	173.7	49.569	41.713
2457020	Saint-Basile-le-Grand	17059	3653.2	20712.2	37.034	9.486	0.256	458	47.537	14.240
2473025	Lorraine	9352	3181.0	12533.0	6.018	5.405	0.898	431.3	49.453	55.593
2460013	Repentigny	84285	33271.6	117556.6	62.705	33.842	0.540	287.9	48.423	29.709
2471050	Les Cèdres	6777	3904.8	10681.8	78.176	10.346	0.132	968.6	45.936	6.725
2466032	Westmount	20312	7673.2	27985.2	4.025	3.629	0.902	129.7	49.250	21.245
2466007	Montréal-Est	3850	7199.6	11049.6	12.478	12.370	0.991	1119.6	49.148	62.623

2471075	Terrasse-Vaudreuil	1986	159.6	2145.6	1.033	1.006	0.974	468.8	47.780	55.089
2458227	Longueuil	239700	195714.7	435414.7	115.543	83.887	0.726	192.7	49.073	34.076
2460028	L'Assomption	22429	16900.4	39329.4	100.685	14.325	0.142	364.2	45.699	6.732
2459025	Verchères	5835	861.4	6696.4	72.957	4.277	0.059	638.7	43.493	2.358
2471090	Vaudreuil-sur-le-Lac	1341	228.9	1569.9	1.369	1.354	0.989	862.4	47.464	56.169
2459020	Varennes	21257	9484.5	30741.5	92.382	86.364	0.935	2809	48.827	58.457
2471040	Coteau-du-Lac	7044	23697.5	30741.5	47.412	13.310	0.281	433	46.236	14.132
2472025	Saint-Joseph-du-Lac	6687	5201.9	11888.9	41.617	8.617	0.207	724.7	47.264	11.551
2466058	Cote-Saint-Luc	32448	14175.4	46623.4	6.952	6.388	0.919	137	49.443	25.524
2473010	Sainte-Thérèse	25989	13087.2	39076.2	9.581	9.502	0.992	243.2	49.325	54.363
2457045	Saint-Mathieu-de-Beloeil	2619	2275.6	4894.6	39.851	3.554	0.089	726.1	46.861	4.835
2467020	Candiac	21047	16871.4	37918.4	17.589	11.770	0.669	310.4	48.930	38.556
2467035	Saint-Constant	27359	25298.4	52657.4	56.823	12.360	0.218	234.7	48.210	11.028
2466047	Montreal-Ouest	5050	1766.3	6816.3	1.406	1.349	0.959	197.9	49.634	47.412
2471055	Pointe-des-Cascades	1481	1822.3	3303.3	2.784	2.244	0.806	679.3	46.582	42.712
2457040	Beloeil	22458	20722.4	43180.4	25.246	11.510	0.456	266.5	48.348	24.456
2458037	Saint-Bruno-de-Montarville	26394	16758.5	43152.5	44.022	21.534	0.489	499	48.284	28.684
2459010	Sainte-Julie	29881	9224.9	39105.9	49.833	14.615	0.293	373.7	47.514	15.962
2467015	La Prairie	24110	19035.8	43145.8	43.492	14.403	0.331	333.8	48.583	18.961
2458033	Boucherville	41671	37932.8	79603.8	70.800	30.334	0.428	381.1	48.095	24.265
2473015	Blainville	56863	57626.2	114489.2	55.375	46.704	0.843	407.9	49.161	51.159
2466097	Pointe-Claire	31380	45392.7	76772.7	18.872	17.586	0.932	229.1	49.059	49.029
2457030	Otterburn Park	8421	745.9	9166.9	5.630	4.608	0.819	502.7	48.051	47.334
2472020	Pointe-Calumet	6428	1137.8	7565.8	5.065	4.013	0.792	530.4	47.162	43.337
2471070	Pincourt	14558	3827.6	18385.6	7.535	6.979	0.926	379.6	47.339	49.909
2471065	Notre-Dame-de-l'Île-Perrot	10654	4148.3	14802.3	27.722	9.285	0.335	627.3	46.138	17.098
2455057	Richelieu	5236	3768.1	9004.1	32.523	2.882	0.089	320.1	46.020	4.219
2465005	Laval	422993	285214.9	708207.9	246.576	175.418	0.711	247.7	49.120	38.865
2457035	Mont-Saint-Hilaire	18585	5366.2	23951.2	45.685	14.885	0.326	621.5	47.693	18.610
2460020	Saint-Sulpice	3439	330.9	3769.9	36.346	3.357	0.092	890.5	45.716	4.602
2473030	Bois-des-Filion	9636	6783.9	16419.9	4.274	4.084	0.956	248.8	49.119	52.292
2457010	Carignan	9462	16571.3	26033.3	64.700	10.258	0.159	394	44.907	7.069
2458012	Saint-Lambert	21861	11826.8	33687.8	7.553	6.368	0.843	189	48.858	38.446
2467055	Léry	2318	467.4	2785.4	10.524	5.869	0.558	2107	46.144	29.059
2475005	Saint-Colomban	16019	18563.2	34582.2	94.572	91.791	0.971	2653.9	49.187	61.875
2460037	L'Épiphanie	8693	3402.6	12095.6	57.055	16.107	0.282	1331.6	45.363	13.734

3.4.2.2 Greenbelt scenario 2

In greenbelt scenario 2, significant open areas in the two CSDs of Gore and Saint Colomban were incorporated into the greenbelt. This had a substantial impact on the *WUP* values for these two CSDs and their components. Furthermore, there are some adjacent CSDs, namely Mirabel and Saint-Jérôme, which have been positively affected by the changes in Gore and Saint Colomban (because they are within the horizon of perception = 2km (Appendix A)). The value of *DIS* was slightly lower, resulting in a minor decrease in the *WUP* value for Mirabel and Saint-Jérôme (Table 12).

In Saint-Colomban, the built-up areas were reduced by 76.87 %, decreasing from 91.791 km² in greenbelt scenario 1 to 21.23 km² in greenbelt scenario 2. This resulted in a 78.5 % reduction in the *WUP* value, reducing from 61.87 UPU/m^2 in scenario 1 to 13.73 UPU/m^2. The value of *DIS* was reduced to 48.244 UPU/m². The *LUP* has decreased to 614 m² per inhabitant or job, reflecting a reduction by 76.86 %.

For the CSD of Gore, the built-up areas were significantly reduced to 1.97 km², indicating a substantial reduction of 97.88 % compared to scenario 1, which was 93.1 km². This considerable reduction has led to a significant decrease in the *WUP* value, dropping from 60.38 UPU/m^2 in scenario 1 to just 0.47 UPU/m^2, representing a 99 % reduction. The land uptake per inhabitant or job has also seen a significant decrease, now at 580.5 m², signifying a reduction of 97.88 %. The value of dispersion was notably lower at 37.972 UPU/m^2.

Table 12. Values of the urban sprawl metrics values for the CSDs that have been affected by scenario 2 compared to scenario 1

CSDUID	CSD name	Inhabitants	Jobs	Inhabitants and jobs	Unit area (km^2)	Urban area (km^2)	*PBA*	*LUP* (m^2/(inb. or job))	*DIS* (UPU/m^2)	*WUP* (UPU/m^2)
2475005	Saint-Colomban	16019	18563.2	34582.2	94.572	21.233	0.225	614.0	48.244	13.272
2476025	Gore	1904	1491.3	3395.3	97.503	1.971	0.020	580.5	37.972	0.474
2474005	Mirabel	50513	92155.9	142668.9	486.381	68.583	0.141	480.7	46.390	7.241
2475017	Saint-Jérôme	74346	82508.1	156854.1	91.585	76.504	0.835	487.6	48.554	49.685

3.4.2.3 Greenbelt scenario 3

In greenbelt scenario 3, the considerable open areas within the CSD of Varennes were included in the greenbelt, resulting in notable changes in urban sprawl results for this CSD. Additionally, several nearby CSDs have been affected by the changes in Varennes (Montreal, Saint-Amable, Verchères, Sainte-Julie, and Boucherville) as detailed in Table 13.

In Varennes, the urban areas have undergone a significant reduction of 89.76 %, decreasing from 86.36 km² in greenbelt scenario 1 to 8.36 km². This substantial change resulted in a 92.26 % reduction in the value *WUP*, changing from 58.46 UPU/m^2 in scenario 1 to 4.52 UPU/m^2. The value of *DIS* was reduced to 46.21 UPU/m². Furthermore, the *LUP* has decreased to 287.4 m²/(inh. or job) 89.76 % lower than its value in greenbelt scenario (2809 m²/(inh. or job)).

Table 13. Values of urban sprawl metrics for CSDs that are affected by scenario 3

CSDUID	CSD name	Inhabitants	Jobs	Inhabitants and jobs	Unit area (km^2)	Urban area (km^2)	*PBA*	*LUP* (m^2/inb. or job)	*DIS* (UPU/m^2)	*WUP* (UPU/m^2)
2459020	Varennes	21257	9484.5	30741.5	92.382	8.836	0.096	287.4	46.212	4.519
2466023	Montreal	1704694	1202241.2	2906935.2	365.834	318.394	0.870	109.5	49.186	10.846
2459015	Saint-Amable	12167	10594.4	22761.4	36.735	7.652	0.208	336.2	45.159	9.301
2459025	Verchères	5835	861.4	6696.4	72.957	4.277	0.059	638.7	43.1513	2.12644
2459010	Sainte-Julie	29881	9224.9	39105.9	49.833	14.615	0.293	373.7	47.128	15.538
2458033	Boucherville	41671	37932.8	79603.8	70.800	30.334	0.428	381.1	48.005	24.129

3.4.2.4 Greenbelt scenario 4

Since greenbelt scenario 4 is a combination of all three greenbelt scenarios, urban sprawl in all CSDs mentioned in greenbelt scenarios 2 and 3 have different values than in greenbelt scenario 1. Their values are the same as those mentioned in greenbelt scenarios 2 and 3 (Table 14). They are far enough apart (> 2 km) so no CSD is affected by both.

Table 14. Values of urban sprawl metrics for CSDs that are affected by Scenario 4

CSDUID	CSD name	Inhabitants	Jobs	Inhabitants and jobs	Unit area (km^2)	Urban area (km^2)	*PBA*	*LUP* (m^2/(inb. or job))	*DIS* (UPU/m^2)	*WUP* (UPU/m^2)
2475005	Saint-Colomban	16019	18563.2	34582.2	94.572	21.233	0.225	614.0	48.244	13.272
2476025	Gore	1904	1491.3	3395.3	97.503	1.971	0.020	580.5	37.972	0.474
2459020	Varennes	21257	9484.5	30741.5	92.382	8.836	0.096	287.4	46.212	4.519
2466023	Montreal	1704694	1202241.2	2906935.2	365.834	318.394	0.870	109.5	49.186	10.846
2459015	Saint-Amable	12167	10594.4	22761.4	36.735	7.652	0.208	336.2	45.159	9.301
2459025	Verchères	5835	861.4	6696.4	72.957	4.277	0.059	638.7	43.1513	2.12644
2459010	Sainte-Julie	29881	9224.9	39105.9	49.833	14.615	0.293	373.7	47.128	15.538
2458033	Boucherville	41671	37932.8	79603.8	70.800	30.334	0.428	381.1	48.005	24.129
2474005	Mirabel	50513	92155.9	142668.9	486.381	68.583	0.141	480.7	46.390	7.241
2475017	Saint-Jérôme	74346	82508.1	156854.1	91.585	76.504	0.835	487.6	48.554	49.685

3.5 Discussion

3.5.1. Urban sprawl in 2011 and 2016

3.5.1.1 Montreal CMA

The increase in urban sprawl in the Montreal CMA_{2011} from 12.4 to 13.48 UPU/m^2 between 2011 and 2016 can be attributed to several factors: growth in built-up areas (6.4%), a 2.8% increase in *LUP*, and a slight rise in dispersion. The population and job count also witnessed growth, with an increase of 176,766 people and jobs, representing a 3.3% rise.

3.5.1.2 Montreal's CSDs

Urban sprawl increased in most CSDs, although there were a few exceptions (Figure 22). Some CSDs experienced a decline in population, yet *PBA* continued to rise in those areas. Therefore, *LUP* and *WUP* increased accordingly. For example, in Kirkland, the number of inhabitants decreased by 1,102 and the number of inhabitants and jobs decreased by 1,097. However, the value of *WUP* increased by 2%, and all components (*PBA*, *DIS*, and *LUP*) increased as well.

CSDs with highest *WUP* values among all CSDs in both years, such as Deux-Montagnes, Rosemère, and Terrasse-Vaudreuil, had values exceeding 50 UPU/m^2. In addition, some CSDs had a significant relative increase in *WUP* compared to 2011. Notably, Saint-Zotique, Beloeil, and Vaudreuil-Dorion showed increases of 39%, 30%, and 30%, respectively. In these CSDs, an increase in all three components led to a rise in their *WUP* value. In most CSDs, value of *WSPC* increased between 2011 and 2016. However, there are certain CSDs, such as Saint-Mathieu, Mirabel, Saint-Isidore, Gore, Senneville, Baie-D'Urfé, Carignan, and Saint-Colomban, where the *WSPC* decreased, primarily as a result of a reduction in their values of *LUP*. In most cases, the reason for this phenomenon is that, in these CSDs, *PBA* increased only by less than 1 percentage point. Consequently, the increase in inhabitants and jobs resulted in a densification. In the case of Baie-D'Urfé, despite a decrease in the number of inhabitants, the total number of inhabitants and jobs increased, contributing to a decrease in *LUP* and there was no significant increase in *PBA*. The densification in this area is primarily related to the presence of industrial parks, attracting more individuals seeking employment opportunities. In Senneville, a similar process occurred where there was no increase in inhabitants and *PBA*, yet there was an increase in the total number of inhabitants and jobs by 179.

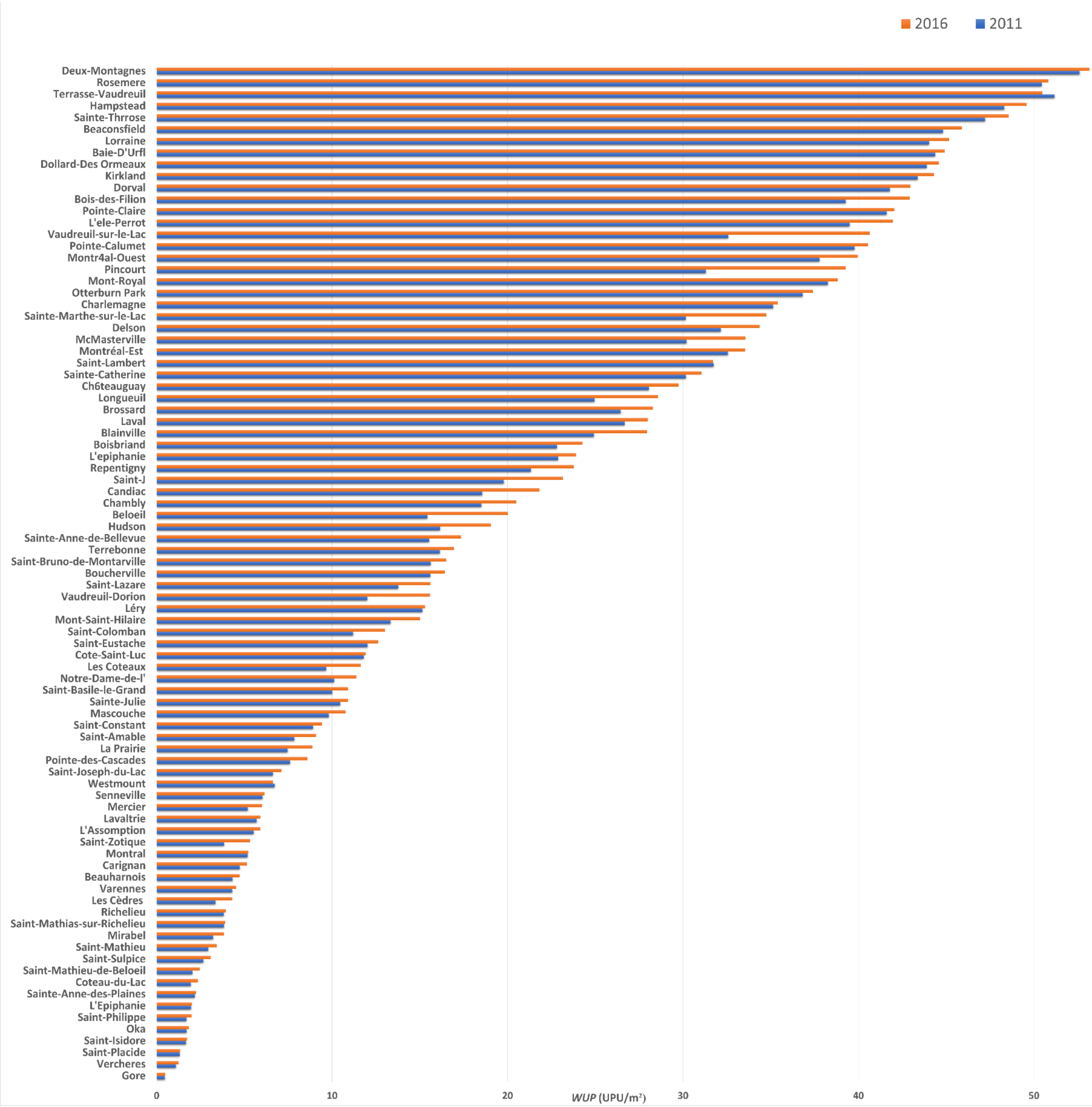


Figure 22 Urban sprawl (WUP) in the Montreal CMA_{2011} at CSD level in 2011 and 2016

3.5.2 Rise in urban sprawl between 1951 and 2016 in the Montreal CMA

In order to facilitate comparisons over time, and based on past research and data availability, this study uses the Montreal CMA boundaries of 2011. The trend of a continuous increase in urban sprawl in Montreal since 1951 until 2011 (Nazarnia et al., 2016) has continued until 2016. Urban sprawl in Montreal CMA_{2011} increased sharply between 1996 and 2011 and while the rate of increase slowed somewhat between 2011 to 2016, sprawl still continued to increase considerably. The increase in urban sprawl is primarily explained by a substantial increase in the total amount of built-up areas, their high dispersion, and a relentless rise in land uptake per inhabitant or job (Figure 24).

An important observation is that the relative increase in the amount of built-up areas over the three decades 1986-2016, a remarkable 100% increase, was four times greater than the relative growth in the number of inhabitants, which saw a 25% increase (Figure 23). The rise in the value of *WUP* was even more significant, with an increase ten times larger (252%) than in the number of inhabitants. This striking difference demonstrates the substantial changes in the urban landscape over this period, emphasizing the high expansion and transformation of urban areas compared to the much lower increase in population. Planning strategies have obviously been ineffective at controlling urban sprawl in the Montreal CMA.

The boundaries of the CMA have undergone various changes between 1951 and 2011, with the CMA expanding over time. As a result, certain areas included within the 2011 delineation of the CMA were not encompassed within the 1951, 1971, 1986, and 1996 CMA delineations. Therefore, Nazarnia et al. (2016), utilized an average value of weighted urban proliferation (*WUP*) for the 2011 delineation, as a proxy for those points in time. This average value lies between the

$WUP_{\max}$ and $WUP_{\min}$ values that they considered in their assumptions (see Nazarnia et al. (2016) for detailed explanation). The error bars on the Figure 24 illustrate the potential margin of error for this average value. The dashed line representing the Montreal CMA_{2016} indicates that, although the *WUP* value was slightly lower compared to the CMA_{2011}, the total sprawl (*TS*) is higher. The lower value of *WUP* results from lower values of *PBA* in the two CSDs that were added ($PBA_{Saint\text{-}Jean\text{-}sur\text{-}Richelieu}$ = 20%, $PBA_{Saint\text{-}Lin\text{–}Laurentides}$ = 6%) and their lower *WUP* values ($WUP_{Saint\text{-}Jean\text{-}sur\text{-}Richelieu}$ =10.94 UPU/m^2, $WUP_{Saint\text{-}Lin\text{–}Laurentides}$ = 2.08 UPU/m^2) than the value of *WUP* of CMA_{2011} in 2016 (13.48 UPU/m^2).

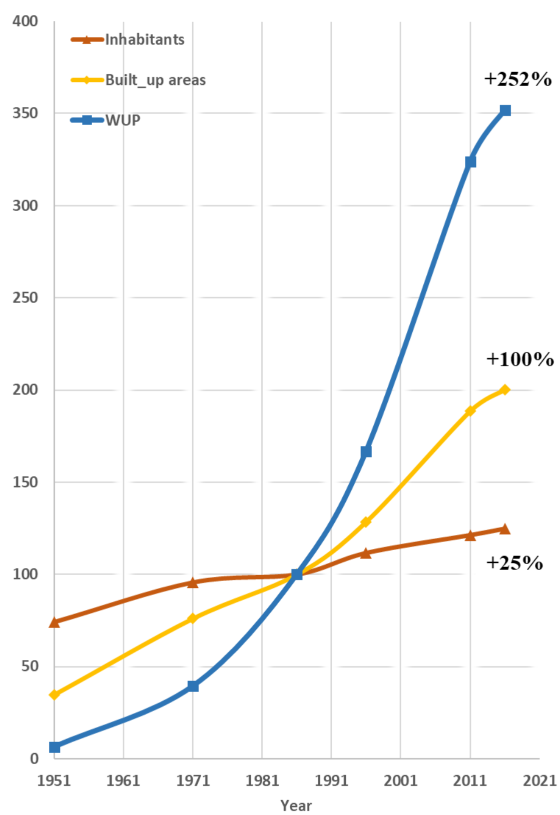


Figure 23 Relative increase in inhabitants, amount of built up areas and urban sprawl in Montreal between1951 to 2016 relative to the value of 1986 (corresponding to 100%)

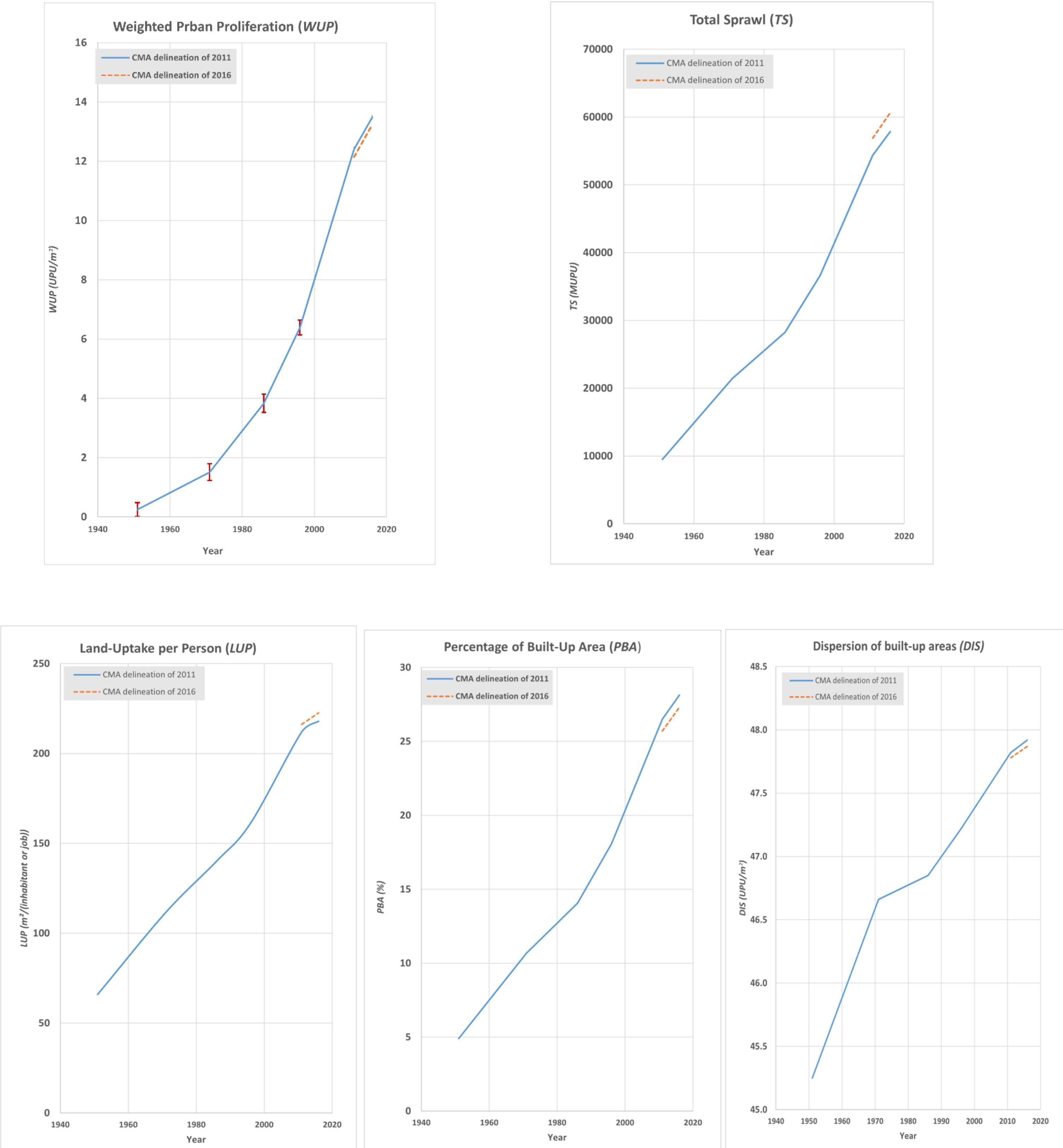


Figure 24 Valus of urban sprawl metrics in Montreal between 1951 and 2016 (for both CMA delineations of 2011 and 2016)

3.5.3 Reference scenarios for defining targets and limit for 2070

Hersperger et al. (2017) emphasized the importance of evaluating the outcomes of landscape planning initiatives and the need for a framework for evaluating planning outcomes. They proposed a reference framework for defining quantitative target values to help evaluate whether various planning objectives have been achieved. They applied their framework to a Swiss landscape as a case study. In this sense, Schwick et al. (2018) discussed the future of urban sprawl and the need for quantitative targets and limits to guide the transformation of spatial planning towards sustainability. Inspired by these two studies, various reference scenarios for Montreal have been developed and evaluated in this thesis.

The reference scenarios 1-6 demonstrate that urban sprawl is likely to increase significantly in the Montreal CMA_{2011}, most dramatically in scenario 1A, following the current trend, with a value of 34.93 UPU/m², corresponding to a 159.51% increase in urban sprawl in 2070 compared to 2016. The half-trend scenario (scenario 1B) also shows a substantial increase in urban sprawl (95.84%). Even in scenario 5 (constant urban sprawl value), which corresponds to no-deterioration for *WUP*, the total urban area still continues to increase (by 9.7%). The only scenario that leads to a decrease in urban sprawl is scenario 6 (-19%). However, other scenarios lying between scenarios 5 and 6 would also lead to a decrease in the extent of urban sprawl.

The assessments of the directions of urban development in this study were inspired by the work by Schwick et al. (2018). If urban sprawl continues to increase at the same rate or faster than the growth in the number of inhabitants and jobs (in scenarios 1 to 3, Figure 25), the built- up areas and the urban sprawl value will move further away from the goal of sustainability than today. Thus, significant improvements are necessary, which cannot be accomplished by a continuation of the previous trends. While scenario 4 shows some improvement and could be considered as a transition zone, it still falls short of the objective of sustainability. While scenario 5 represents a significant improvement over the scenarios 1 to 4 in terms of reducing urban sprawl, it is still not a fully sustainable situation. The fact that the total urban area continues to increase despite limiting the expansion of built-up areas and promoting densification indicates that there are other factors at play that contribute to further sprawl, such as economic and social drivers. Therefore, while scenario 5 can be considered a step in the right direction, it can only be viewed as conditionally sustainable, and further efforts will be needed to achieve a truly sustainable urban development. In brief, scenarios 1 to 3, where urban sprawl increases at the same or a faster rate than population growth, are definitely considered unsustainable. Scenario 4, where urban sprawl increases at half the rate of population growth, shows some improvement but still falls short of sustainability. Scenario 5, which reduces urban sprawl by limiting urban area expansion and promoting densification, represents a significant improvement but is not as sustainable as scenario 6. Scenario 6, which accommodates population and jobs through densification in existing urban areas without creating new urban areas, is considered the most sustainable scenario presented. Although a stricter scenario 7 could be envisioned, where urban areas are reduced and remaining built-up areas are more densely populated, currently seems unrealistic for Montreal, but may gain interest in the future where energy consumption and CO_2 emissions need to be reduced significantly.

The potential future of urban sprawl in Montreal is subject to considerable variation. In the worst-case scenario, the land uptake per person would persistently increase, thereby contributing to a dramatic increase in urban sprawl (Figure 25 for Sc. 1A and 1B). Even if the need for land uptake per person remains unchanged and stable at present levels (scenario 2 in Figure 25), urban sprawl would still augment considerably owing to population growth. However, should all new inhabitants be accommodated within the existing built-up areas, this would promote densification and lead to a substantial reduction in urban sprawl (scenario 6 green dashed line in Figure 25). These scenarios provide a reference framework for defining targets and limits.

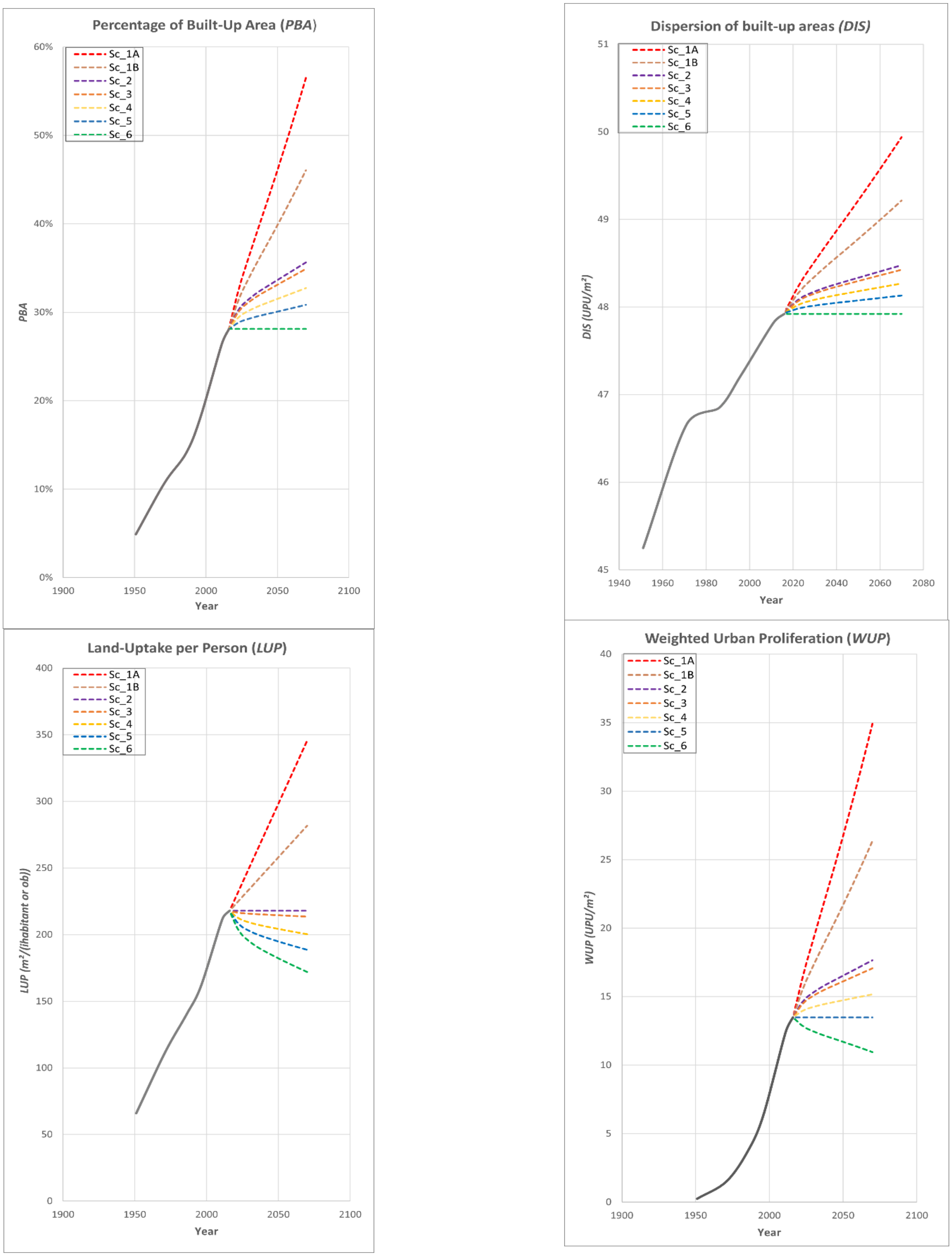


Figure 25 Historical development of urban sprawl in Montreal CMA_{2011}(1951–2016) and possible future development based on the seven scenarios for *WUP*, *PBA*, *LUP* and *DIS*.

3.5.4 Targets and limits for Montreal CMA and CSDs

Table 8 presents target, limit, no-deterioration, and warning values for the *WUP* and its components for Montreal CMA in 2070.

When one of the components of *WUP* shows a higher value than the limit, it signals a potential risk of soon surpassing the warning threshold of *WUP*. The proposed target, limit, and warning values for Montreal are linked to population growth, as the number of inhabitants and jobs has a significant influence on the amount of built-up areas and, consequently, urban sprawl (Figure 26b). These proposed values are specifically rooted in the reference population scenario for Montreal, as data for alternative population scenarios at the CMA and CSD levels are not available. Indeed, with a larger population growth, a more significant densification is required, as the limited land resource must be shared by a growing number of people. This insight reflects the fact that accommodating higher population growth without further urban sprawl requires a substantial increase in densification and consequently, a lower value of *LUP* need to be reached. Accordingly, in a higher population scenario, the values for *LUP* in the warning, no-deterioration, limit, and target categories are all lower than those in a lower population scenario (Figure 26a).

The determination of target, limit, no-deterioration, and warning values for the CSDs results in the values presented in Table 9. Similarly, the target, limit, and warning values for the CSDs, similar to the values for Montreal CMA, depend on population growth.

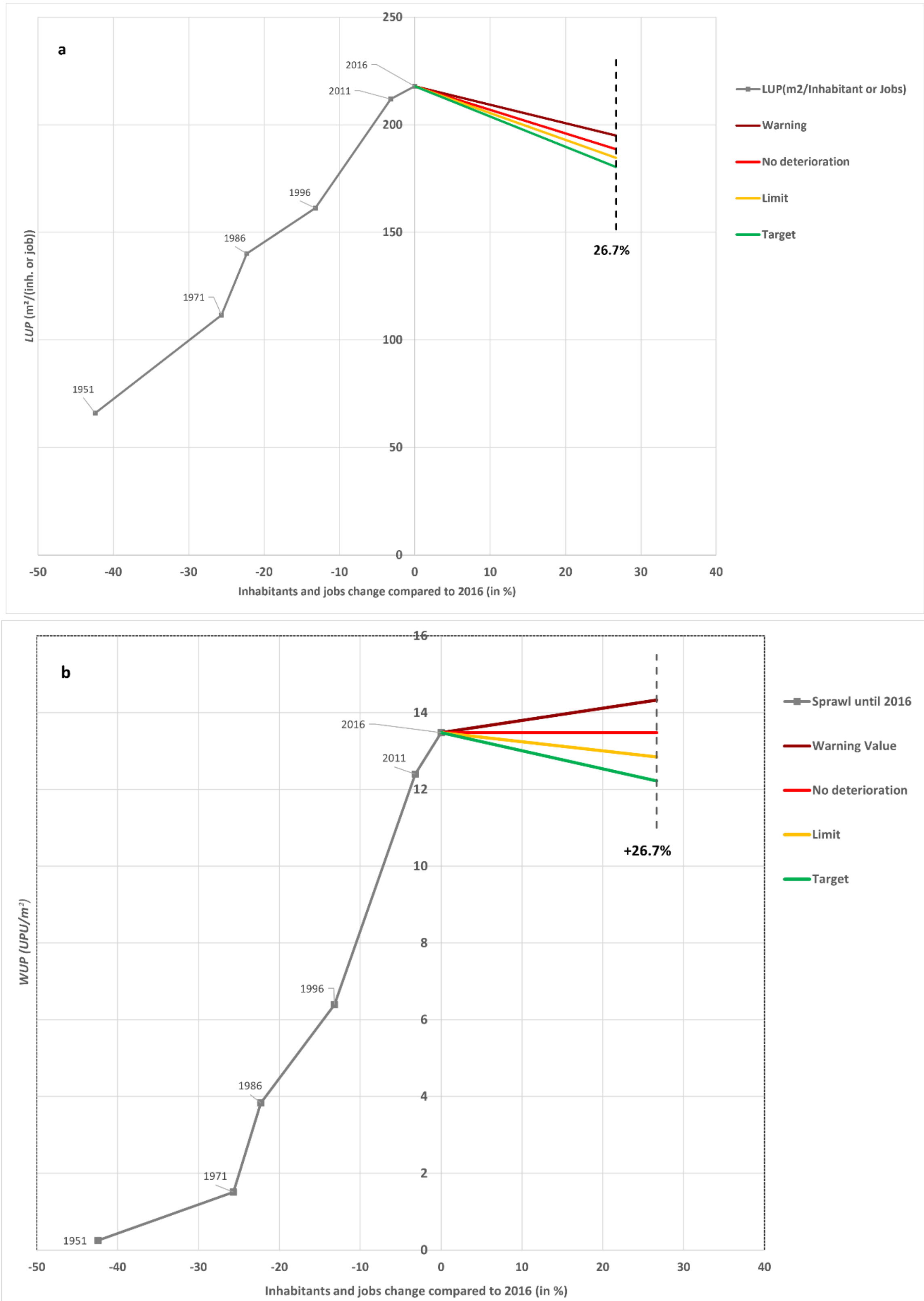


Figure 26 Past development of the **a)** urban Sprawl metric (*WUP*) and **b)** *LUP* as well as proposed values for target, limit, no-deterioration, and warning values for **a)** *WUP* and **b)** *LUP* in CMA_{2011} as a function of the increase in the number of inhabitants and jobs between 2016 and 2070

3.5.5 Greenbelt scenarios

The *WUP* values exhibit some variations between the greenbelt scenarios, as expected. Scenario 1, where a relatively small portion of the land is designated as a greenbelt (total area of the greenbelt including parks water bodies, and protected areas was 2348.5km^2) compared to the other three scenarios, resulted in the highest *WUP* value among all four greenbelt scenarios. Conversely, in scenario 4 is characterized by a larger greenbelt area (240 km^2 larger than in scenario 1) and reduced potential for built-up development, and the *WUP* value was the lowest. This trend was also observed in scenarios 2 (162.19 km^2 larger than in scenario 1) and scenario 3 (78.01 km^2 larger than in scenario 1), where the extent of open land included within the greenbelt had a clear impact on the built-up area, resulting in lower *WUP* values.

When we compare these greenbelt scenarios with the BAU scenario (scenario 1), it becomes evident that in greenbelt scenario 1, the built-up area is projected to increase by up to 61% compared to 2016. However, in reference scenario 1 (BAU), this increase is significantly more pronounced, by 100%. Meanwhile, greenbelt scenarios 2 to 4 demonstrate increases by 48%, 54.5%, and 41.1%, respectively, whereas reference scenario 6 (densification and sustainable scenario) maintains a 0% change in the built-up areas.

Looking at the *WUP* values in 2070, scenario 1 anticipates a substantial increase, reaching 34.93 UPU/m^2. In greenbelt scenarios 1 to 4, the projected *WUP* values are 24.58, 21.79, 23.26, and 20.41 UPU/m^2, respectively. In 2016, the *WUP* value was 13.48 UPU/m^2, while in reference Scenario 6, it is expected to be 10.95 UPU/m^2.

While the greenbelt scenario would indeed exert a substantial influence compared to the current trend, it remains an inefficient strategy for curbing urban sprawl in Montreal. As illustrated in Figure 27, all four greenbelt scenarios are considerably distant from the target and limit values. Even the most promising greenbelt scenario 4, while showing better results compared to the others, still falls short of reaching the no-deterioration or warning values and stays significantly distant from the target and limit values that represent a sustainable development path for the Montreal CMA. In terms of *WUP* values, all four greenbelt scenarios fall between reference scenarios 1B and 2. As mentioned earlier, scenarios 1 to 3 are all deemed unsustainable, while scenario 4 falls into a transition zone. This leads to the conclusion that the greenbelt scenarios considered here, while offering some improvement, by themselves, are unlikely to exert a significant influence on urban sprawl in a manner that would guide Montreal toward a sustainable development trajectory.

It is essential to acknowledge that despite the implementation of various greenbelt scenarios, urban sprawl would remain significant in 2070, well above sustainable levels. This underscores the considerable challenges associated with achieving a more sustainable urban development pattern. The results suggest that additional policies and strategies are imperative to address the complex issue of urban sprawl in Montreal CMA.

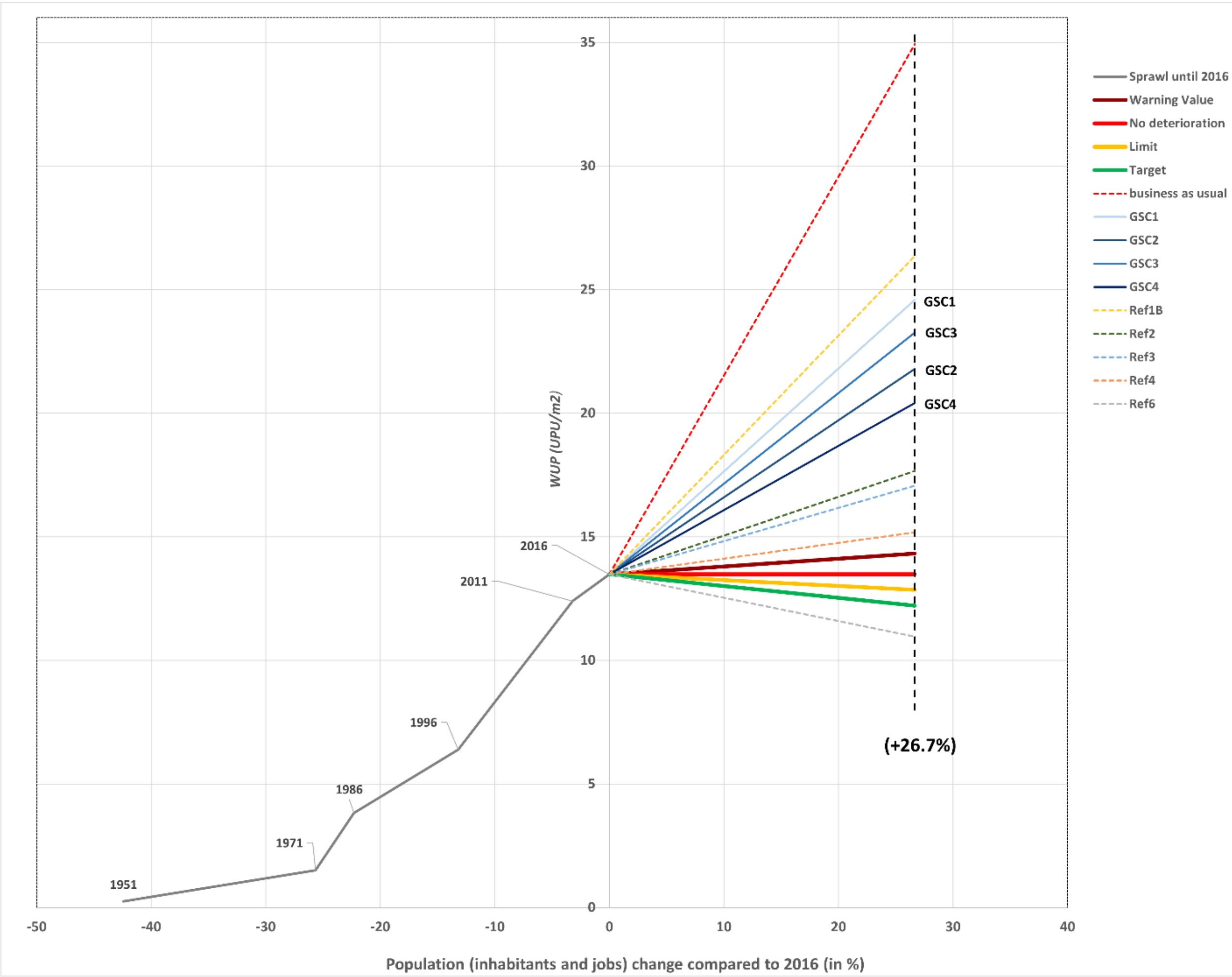


Figure 27 Weighted Urban Proliferation (*WUP*) as a function of population growth (jobs and inhabitants) in the Montreal CMA for all reference scenarios, greenbelt scenarios, and targets and limits

At the CSDs level, for, Brossard, Chambly, Saint-Mathieu, Saint-Amable, Mercier, and Richelieu the value of *WUP* for 2070 is between the warning value and no-deterioration. While they would not meet the targets and limits, these results show the effectiveness of greenbelt for these CSDs in some extent.

In greenbelt scenario 2, along with the CSDs mentioned for greenbelt scenario 1, Gore is expected to meet the target value. Furthermore, Saint-Colomban will achieve a value falling in the warning to no-deterioration range. Moving to scenario 3, Varennes is projected to have a value falling between the no-deterioration and limit values, while Saint-Amable will fall within the range between the warning and no-deterioration values. All the CSDs mentioned for greenbelt scenarios 1 to 3 are expected to be affected similarly in greenbelt scenario 4.

These results highlight the potential of a greenbelt to positively influence urban development patterns in specific areas, even if they may not all achieve the defined targets and limits. The results suggest that further refinement and adaptation of a greenbelt strategies could lead to more sustainable urban development outcomes in the long term.

In the greenbelt scenarios, considered here, the focus was on the currently protected agricultural areas designated by CPTAQ. In these scenarios, we made the assumption that these designated greenbelt areas receive the highest level of protection, with a strict prohibition of any form of urban expansion within them. However, CPTAQ has the authority to grant exemptions and permits for construction or development in agricultural zones under certain conditions, provided the projects aligns with the objectives of preserving agricultural land (CPTAQ, 2022). As a result, there are cases in which construction was permitted. This stands in contrast to the assumption of high protection in the greenbelt scenarios. The presence of such exceptions underscores the complex interplay between land-use regulations, agricultural protection, and urban development goals, which must also be considered when assessing the effectiveness of greenbelt strategies in curbing urban sprawl.

Considering the need for more sustainable land-use management as stated in PMAD, the question arises: If the current trend of increase in built-up areas continues, in how many years will the remaining areas be completely filled up before the proposed greenbelt areas be reached? two current trend options to answer this question are considered here. Trend 1: *PBA* will increase according to "Business as Usual" reference scenario 1 (21.37 km^2/year on average); Trend 2: *PBA* will continue to increase at the same rate as it increased between 1971 and 2016 (16.62 km^2/year)

In trend 1 greenbelt under scenario 4, the relative best option for controlling urban sprawl but still insufficient to reach the target, there are only 14 years left from 2023 for all areas other than the greenbelt to be filled up. After that, any additional urban expansion would extend into the greenbelt. This timeframe extends to 23 years for trend 2. The corresponding time periods for the other greenbelt scenarios are given in Table 15. These findings demonstrate the urgency need to move toward densification, which is also discussed as an objective in the current PMAD (CMM, 2012), as further delays may affect agricultural areas due to urban expansion.

Table 15. Number of years remaining before urban expansion reaches to greenbelt under trend 1 and trend 2

	Greenbelt scenario 1	Greenbelt scenario 2	Greenbelt scenario 3	Greenbelt scenario 4
PBA (%) of greenbelt scenarios in 2070	45.28	41.50	43.46	39.68
Year- (Trend 1)	2049	2041	2045	2037
Year- (Trend 2)	2061	2051	2056	2046
Years left from 2023 (Trend 1)	26	18	22	14
Years left from 2023 (Trend 2)	38	28	33	23

To determine where densification should occur, we suggest that the prioritization of areas to densify depend on factors such as the current level of urban sprawl in the CSDs, mostly *LUP*, but also the average percentage of existing built-up areas. Schwick et al. (2018) proposed two main strategies for the allocation of additional inhabitants and jobs within municipalities. According to approach one, the additional inhabitants and jobs could be distributed evenly among all municipalities, with a certain percentage being accommodated in new settlement areas (at some minimum density) and the remainder through densification of the existing built-up areas. Approach two considers the current levels of sprawl in the municipalities, directing densification efforts more intensively proportionately to the more heavily sprawled areas, with no additional built-up areas permitted in 20% of the municipalities. Approach two appears fairer. Prioritizing densification is also advised in accordance with TOD principles, which emphasize locations with more easily accessible public transportation and the thoughtful integration of commercial and economic centers. Better public transportation (expansion of the metro system) would allow densification around the existing and future transportation hubs and encourages lively, mixed-use neighborhoods, reduces car dependency, and would advance sustainable urban development. Additionally, infrastructure capacity, environmental considerations, and the potential for modified zoning regulations are additional influential factors that should be considered in prioritizing densification.

3.5.6 Greenbelt discussions and initiatives in Montreal

There have been discussions highlighting the significance of establishing a greenbelt in Montreal to preserve natural habitats and promote biodiversity conservation for more than 10 years (Globalnews, 2010; La Maison, 2015). Additionally, the "Trame verte et bleue" initiative, also known as "The Green and Blue Network," has proposed the creation of a greenbelt and a network of corridors for greater Montreal, aiming to protect natural areas in the urban landscape and to control urban sprawl. This vision seeks to connect various sections of the metropolitan area with nature, emphasizing the need for environmental preservation (CMM, nd.; NCC, nd.). Furthermore, the greenbelt Movement (MCV) is a coalition formed in 2012, advocating for the establishment of a green-and-blue belt in Greater Montreal. This initiative aims to create a network of protected natural and agricultural areas to preserve biodiversity and counter the loss of connection between people and nature. Greater Montreal, despite being rich in biodiversity, faces intense urban and industrial development pressure, resulting in substantial decreases in natural and wetland areas. The MCV's goal is to develop a greenbelt project that promotes ecological functionality, sustainability, and accessibility. They are particularly interested in the urban planning scheme of Laval and hope to reverse the decline of natural areas (Perron, 2017).

Despite the attention and discussions surrounding the greenbelt concept and the presence of initiatives and programs reflecting a growing interest in the development of green infrastructure in the Montreal region, there is a notable absence of concrete actions or readily available information regarding its establishment, effectiveness, and any specific proposals. The actual implementation of these ideas appears to be quite challenging.

Moreover, the research on greenbelts in Montreal is still very limited, with the existing studies primarily centered around exploring opportunities, potential obstacles, and challenges. For example, Constantin (2012) proposed a conceptual greenbelt and green network for the Montreal CMM, which used Photoshop (but no GIS) and incorporated various suggestions. Constantin's proposal aimed to identify opportunities and obstacles related to greenbelt implementation. However, it does not include any quantitative analysis of the effectiveness of the implementation of the greenbelt in the Montreal. Dupras et al. (2015) and (Bissonnette et al., 2018) demonstrate the importance and urgency of establishing green structures while addressing opportunities and challenges. Their qualitative research work contributes to categorizing and distinguishing expert viewpoints and insights concerning the establishment of a green infrastructure in the Montreal region.

In contrast, the current study provides a quantitative analysis of four potential greenbelt scenarios for Montreal and assesses their effectiveness, which has not been done previously in the Montreal context. This quantitative approach offers practical insights into the feasibility and potential efforts of greenbelt implementation in the region, paving the way for informed decision-making and policy development for the future.

3.5.7 Strengths and limitations of the study

This research introduces the first quantitative reference framework for evaluating the effectiveness of planning measures in Montreal's CMA and CSDs in the context of urban sprawl. It offers a quantitative perspective on potential future urban sprawl and allows for a comparison of planning alternatives. Such reference values, encompassing targets, limits, and warning thresholds, are indispensable for evaluating whether planning goals are being met and targets are being reached. This study also assesses the effectiveness of potential greenbelts in Montreal, a crucial topic in the region's land-use planning. It marks the initial quantitative evaluation using a reference framework to project the future impact of greenbelts on controlling urban sprawl, using an established quantitative metric of urban sprawl (EEA & FOEN, 2016; Hersperger et al., 2017; Behnisch et al., 2022; Pourtaherian & Jaeger, 2022).

While this study provides valuable insights, it has several limitations. First, a significant constraint stems from the scarcity of up-to-date data regarding Montreal's built-up areas. The most recent available data pertain to the year 2016 (the base year for this study). Additionally, this study used the boundary of the Montreal CMA of 2011 to be able to compare urban sprawl trends over time and facilitate a meaningful and consistent analysis of urban expansion dynamics. Changes in the definition of built-up areas in future data layers, as well as alterations in the delineation of the

CMA and CSDs over time can make future updates difficult. This is exemplified by the difference in the results reported by Pourali et al. (2022) for the values of *WUP* and its components for the Montreal CMA_{2011} in 2011 (*PBA* = 34% and *WUP* = 18.25 UPU/m^2) compared to Nazarnia et al. (2016) and the current study (*PBA* = 26.4% and *WUP* = 12.40 UPU/m^2). The discrepancy can be attributed to the use of different built-up area shapefiles that are based on different definitions of built-up areas. Furthermore, Statistics Canada (2023) newly released data about settled area expansion, which serve to assess the expansion of settled areas in Canada's Contiguously Settled Areas (CSAs), between 2010 and 2020. The existing disparities between definitions used in different data layers pose difficulties in using the data to update the results in future research.

Furthermore, the analysis of potential future scenarios introduces an uncertainty, compounded by assumptions that may not always align with reality. These assumptions can impact the accuracy of the findings and recommendations. The reference scenario analysis and the establishment of targets and limits for urban sprawl are linked to population dynamics. The sole population projection scenario available for the Montreal CMA and its CSDs is the medium population scenario, as provided by Institut de la statistique du Québec. Unfortunately, there is a notable absence of projections for low and high population scenarios at these levels and for future years past 2041.

3.6 Conclusion and recommendations

The issue of urban sprawl in Montreal has become an increasing concern, with a relentless increase since 1951. The substantial growth in built-up areas between 1986 and 2016, surpassing population growth by four times, demonstrate the impact of inefficient planning strategies on urban sprawl. To address this challenge, a range of potential future scenarios, varying from the worst case (BAU) to the most sustainable one were evaluated. In the worst-case scenario, the demand for land uptake per person would continuously rise, leading to an unbroken increase in urban sprawl. Even if land uptake per person remains at the current level, urban sprawl would still increase significantly due to population growth. However, if all new residents are accommodated within the existing built-up areas, through densification, this would result in a substantial reduction in urban sprawl. These various development-path scenarios serve as a quantitative reference framework for evaluating planning measures, including targets, limits, and warning values to urban sprawl for the Montreal CMA and its CSDs. These values offer a vital benchmark for a performance evaluation for planning objectives and for signaling potential risks of exceeding predefined warning values.

The greenbelt policy has been proven to be effective as a growth management strategy in curbing urban sprawl in European cities and it has been recommended to be included in de-sprawling strategies aimed at moving toward more compact, green cities (Pourtaherian and Jaeger, 2022). However, it remains uncertain what kind and size of greenbelt would be an effective strategy for Montreal. Despite ongoing debates and qualitative proposals, there are challenges associated with implementing a greenbelt in Montreal. In this study, four proposed greenbelt scenarios, based on the protection of agricultural land, were evaluated. The results demonstrate a potential influence of proposed greenbelt scenarios on urban sprawl, compared to the current trend. However, these greenbelts remain insufficient to curb urban sprawl in Montreal. Achieving sustainable urban development in the face of population growth will require a more substantial greenbelt that includes significant natural areas in combination with additional policies and strategies. At the CSD level, however, the greenbelt scenarios show varying impacts, with some CSDs effectively achieving their targets and limits values for sprawl, while others do not meet these goals. Further improvement and adaptation of a greenbelt strategy could lead to more sustainable urban development outcomes. It is recommended to assess required extent of the greenbelt to meet defined target and limit for Montreal, as well as its influence on individual CSDs, while also assessing the feasibility of such measures. Moreover, additional research is essential to measure and analyze urban sprawl in more recent times to better assess potential future developments.

Future studies can build on the proposed quantitative reference framework for evaluating potential growth management strategies to assess their effectiveness and sufficiency. Additionally, this study can serve as a valuable component in future urban and regional development planning, environmental monitoring, and the development and assessment of potential scenarios to address urban sprawl.

The findings contribute to discussions about the effectiveness of a future greenbelt implementation and emphasize the need for additional measures to address the complex issue of urban sprawl in Montreal. This research represents a significant step toward more sustainable urban planning in Montreal.

The findings strongly suggest that acting is imperative to prevent further loss of agricultural land and natural areas caused by the expansion of built-up areas. This imperative aligns with the objectives of the COP15 International Biodiversity Summit of 2022, which focuses on biodiversity conservation and on minimizing the loss of areas with high ecological significance and the need for restoration. The results indicate that if the current trend of increase in *PBA* continues, it will take only 23 years to fill up the remaining areas before reaching the proposed greenbelt areas completely. This timeline emphasizes the urgent need to transition toward densification, as any delay poses a risk to agricultural and natural areas due to ongoing urban expansion.

4. Overall conclusion

The increasing concern of urban sprawl in Montreal has gained notable attention. The doubling expansion of built-up areas between 1986 and 2016, outpacing population growth by four times, demonstrates of the consequences of ineffective planning strategies in managing urban sprawl. Given that sprawl poses a significant threat to sustainability in Montreal, there is a crucial need to identify effective measures that can mitigate its negative impacts. Hersperger et al. (2017) highlighted the importance of assessing the results and impacts of landscape planning outcomes and discussed the absence of a structured framework for such evaluations. This study presents a quantitative reference framework designed for the assessment of planning measures, including targets, limits, and warning values for urban sprawl within the Montreal CMA and its CSDs. These values serve as benchmarks to assess whether planning objectives have been met and act as a warning system, signaling increased risks if predefined threshold values are exceeded. It helps the identification of CSDs that are more severely affected by urban sprawl than other and facilitates the development of specific local strategies for assessment and implementation.

These reference values are based on seven potential development scenarios, including "Business as Usual", Half-trend", "Constant *LUP*", "Same increase as population", "Half increase as population", "Constant urban sprawl", and "Constant built-up area". These scenarios range from the continuation of current unsustainable trends to the most sustainable. In the worst-case scenario, the need for land uptake per person would keep rising, causing a dramatic surge in urban sprawl. Even if the land per person stays the same as it is currently, projected population growth would lead to a considerable expansion of built-up areas and increase in urban sprawl. However, adopting a densification approach results in a substantial reduction of urban sprawl.

Despite the widespread discussions about greenbelts as a potential growth management strategy, as well as the existence of initiatives and programs indicating an increasing interest in developing green infrastructure in Montreal, tangible actions are still missing such as readily accessible information about its establishment, effectiveness, and specific proposals for the Montreal CMA.

In this study, several proposed greenbelt scenarios were assessed, with a focus on evaluating the presently protected agricultural zones designated by CPTAQ around Montreal. The findings reveal the potential influence of suggested greenbelt scenarios on urban sprawl compared to the current trends. However, these proposed greenbelts are insufficient to address urban sprawl challenges in Montreal CMA. A more substantial greenbelt and additional policies will be needed to address urban sprawl. At the level of CSD, the impact of the greenbelt scenarios varies, with some CSDs meeting their targets, while others are to some extent affected by these greenbelts. This variation suggests the necessity for further enhancement and adjustment of a greenbelt strategy to foster sustainable urban development. The recommendation is to evaluate the necessary configurations of a greenbelt that can achieve specified targets and limits for Montreal and to examine the feasibility of implementing such measures.

Owing to limited data availability, the study used 2016 as the base year. It is strongly recommended to conduct additional research to assess and analyze urban sprawl in more recent periods to more effectively evaluate potential future developments.

This study marks a pioneering effort in introducing a quantitative reference framework for assessing potential measures to address urban sprawl challenges. It offers valuable insights into Montreal's future urban landscape and provides valuable information about the effectiveness, sufficiency, and the need for adjustments in such measures. The findings can be integrated into future urban and regional development planning efforts and environmental assessment in Montreal.

Additionally, the results highlight the urgent need for action to slow down the loss of natural areas caused by the expansion of built-up areas. This goal aligns with the objectives of the COP15 International Biodiversity Summit of 2022, and the K-M GBF which prioritizes biodiversity conservation and the protection of ecologically significant areas (Findlay, 2023). The results emphasize the immediate need for comprehensive measures to address these critical issues.

The findings contribute substantially to discussions of the efficacy of greenbelt implementation, emphasizing the necessity for supplementary measures to tackle the intricate challenge of urban sprawl in Montreal. The greenbelt approach emerges as a promising strategy, not only effectively curbing urban sprawl but also protecting agricultural areas and supporting ecological preservation. This study contributes to advancing sustainable urban planning in Montreal. It offers valuable insights for evaluating potential de-sprawling strategies in future urban and regional planning.

Various models are available to provide satisfying predictions for land-use change and to evaluate the future of pathways urban expansion (Landis, 2001; Verburg et al., 2002; Verburg & Overmars, 2009; Lavalle et al., 2011; Grigorescu et al., 2021). Such Models are valuable tools to explore a range of potential future scenarios (Fuglsang et al., 2013; Goetzke, 2014). It is recommended to use these models to investigate the effect of anti-sprawl policies on possible land-use changes and the spatial distribution of land-use types, mainly built-up areas, in future studies.

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6. Appendices

Appendix A: Weighted Urban Proliferation (*WUP*) and Weighted Sprawl per Capita (*WSPC*) for the measurement of urban sprawl

To determine the extent of urban sprawl as an independent metric, Schwick et al. (2012) created the weighted urban proliferation (WUP) metric. The WUP method is used in the current study for measuring the degree of urban sprawl since it meets all 13 suitability criteria required for quantifying urban sprawl (Jaeger et al., 2010a; Nazarnia et al., 2019).

Percentage of built-up area *(PBA),* the dispersion of built-up areas *(DIS),* and land uptake per person *(LUP)* are the three components of WUP metric. It is predicated on the notion that the extent of urban sprawl increases as built-up areas grow, become more dispersed, and land uptake for built-up area per resident or worker is higher (Schwick et al., 2012). WUP is calculated as follows:

$$WUP = (PBA \times DIS) \times w_1(DIS) \times w_2(LUP),$$

where $w_1(DIS)$ and $w_2(LUP)$ are weighting functions for dispersion and land uptake per person, respectively. WUP is expressed in urban permeation units per m^2 of land (UPU/m^2).

The values of $w_1(DIS)$ range from 0.5 to 1.5; lower values are assigned to more compact built-up regions, emphasising the distinctions between compact and dispersed built-up areas more clearly. Similarly, values of $w_2(LUP)$ vary from 0 to 1, with larger values denoting greater individual land uptake (Schwick et al., 2012).

In the following, the three WUP components and the other mentioned metrics are described.

Percentage of built-up area (PBA)

The percentage of built-up area (*PBA*) is the portion of a landscape that is made up of built-up areas. It is derived by dividing the size of the built-up area by the entire area of the landscape where the analysis is being done and known as reporting unit. As a result, *PBA* is an intensive metric, meaning that its value is independent on the size of the landscape:

$$PBA = {}^{A_{\text{built-up}}}\!/_{A_{\text{reporting unit}}}.$$

Dispersion of built-up areas (DIS)

A metric that represents the spatial configuration of built-up areas is dispersion (*DIS*), which is measured in urban permeation units per square meter of built-up area (UPU/m^2). It is the "average weighted distance" of each pair of randomly chosen points in populated built-up areas, where the second point is situated inside the horizon of perception (*HP*) surrounding the first. By considering the greatest distance between two points, the horizon of perception defines the scale of analysis (Jaeger et al., 2010b). Section 3.4 provides a more detailed explanation of the horizon of perception. According to this interpretation, greater values of dispersion are caused by points being farther apart from one another; whilst smaller values of this metric are caused by points being closer to one another. Lower degrees of dispersion in the calculation of urban sprawl result in a lower value of the weighting function for this measure ($w_1(DIS)$).

Land Uptake per Person (LUP)

The land uptake per person (*LUP*) refers to the average area that each person occupies, measured in square meters per person or job (m^2/(inhabitant or job)). Therefore, high values of *LUP* show that more space is being used per resident or job (EEA & FOEN, 2016). Lower *LUP* values, or higher utilization density levels, result in lower weighting factor w_2(*LUP*) values.

$$LUP = {A_{\text{built-up}}}/{N_{\text{inh+job}}}$$

Figure A.1 presents the relationship between *WUP* and its three components *PBA, DIS*, and *LUP*.

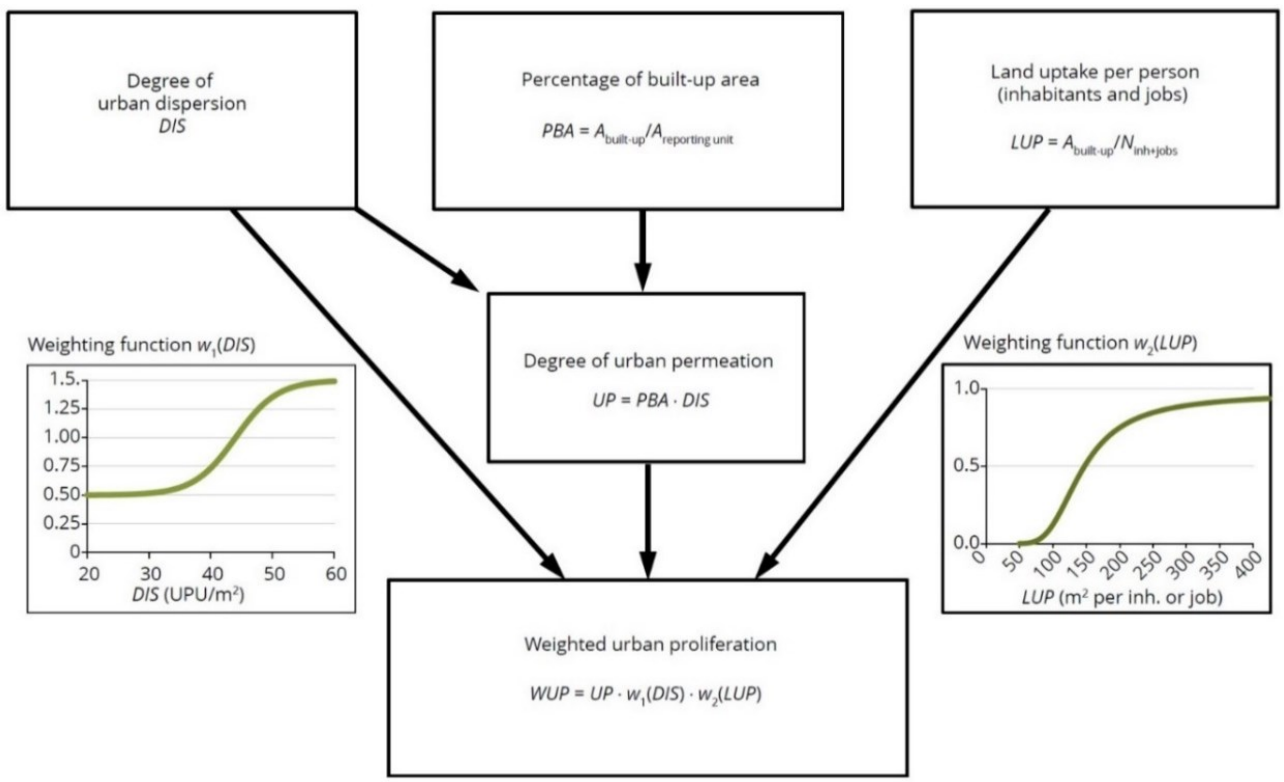

Figure A.1 The relationship between *WUP* and its three components of *DIS*, *PBA*, and *LUP*, as well as figures of the two weighting functions w_1(*DIS*) and w_2(*LUP*) (EEA & FOEN, 2016).

Total Sprawl (TS)

If we consider dispersion (*DIS*) to be the mean necessary "effort" for linking two random points while maintaining within the perceptual horizon, total sprawl (*TS*) would be the overall mean "effort" required to connect every point to a different random point inside the initial point's horizon of perception. According to this definition, the value of this indicator always increases when more built-up areas in the reporting unit are developed (Jaeger et al., 2010b).

The following equation measures total sprawl, represented in mega urban permeation units (MUPU):

$$TS = DIS \cdot A_{\text{built-up}}$$

Sprawl per Capita (SPC) and Weighted Sprawl per Capita (WSPC)

Sprawl per capita (*SPC*) is calculated by dividing total sprawl (*TS*) by the number of people who live or work in the reporting unit (Jaeger et al., 2010b).

$$SPC = {}^{TS}\!/_{N_{\text{inh+job}}}$$

Similar to *SPC*, weighted sprawl per capita (*WSPC)* estimates the average contribution of each individual to urban sprawl. The value of *WSPC* depicts how much urban sprawl is formed on average by each job or person residing in the reporting unit, whereas *WUP* indicates how much sprawl there is in one square meter of the landscape (Behnisch et al., subm.).

$$WSPC = w_1(DIS) \cdot w_2(LUP) \cdot SPC$$

Horizon of Perception (HP)

Establishing a maximum distance up to which the built-up area pattern will be examined is necessary for quantifying the degree of dispersion (*DIS*) and weighted urban proliferation (*WUP)*. The cut-off radius or horizon of perception (*HP*) refers to this distance (Nazarnia et al., 2016). This concept holds that two points only contribute to urban sprawl when they are located within each other's horizons of perception, and that their contribution is greater when they are further away (Jaeger at al., 2010b). According to the Pythagorean theorem and the curvature of the earth, a person with hypothetical eye height of 1.80 m would see up to a distance of 4.9 km as long as there are no obstructions in the way. Therefore, an acceptable range for the perceptual horizon would be between 1 and 10 kilometres (Jaeger et al., 2010b) (Figure A.2).

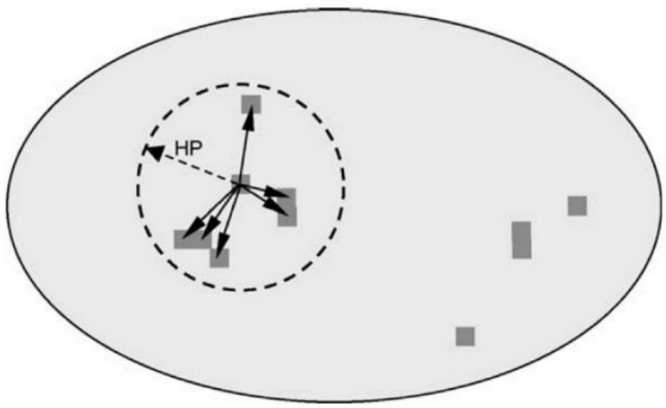

Figure A.2 An illustration of the horizon of perception (source: Jaeger et al. (2010b), Fig. 2)

Appendix B: Entities from the CanMap Route logistics dataset that were used for the built-up area delineation in the Montreal CMA

Table B.1 Entities from the CanMap Route logistics dataset that were used for the built-up area delineation in the Montreal CMA (BFR: building footprint regions, LUR: land use region) (Nazarnia et al., 2016; DMTI Spatial, 2011).

Entity description	**Theme**	**Code**	**Shape file type**
Arena	BFR	106	Region
Armoury	BFR	107	Region
Automobile plant	BFR	108	Region
Barn/machinery shed	BFR	109	Region
Cement plant	BFR	111	Region
Chemical plant	BFR	112	Region
Church	BFR	113	Region
City hall	BFR	114	Region
Coast guard station	BFR	115	Region
College	BFR	116	Region
Community centre	BFR	117	Region
Convent	BFR	118	Region
Correctional institute	BFR	119	Region
Courthouse	BFR	120	Region
Court house	BFR	120	Region
Customs post	BFR	121	Region
Dome	BFR	122	Region
Electric power station	BFR	123	Region
Factory	BFR	124	Region
Filtration plant	BFR	125	Region
Fire station	BFR	126	Region
Fire/police station	BFR	127	Region
Fish hatchery	BFR	128	Region
Fish processing plant	BFR	129	Region
Grain elevator	BFR	130	Region
Hall	BFR	131	Region
Highway service centre	BFR	132	Region
Hospital	BFR	133	Region
Hostel	BFR	134	Region
Hotel	BFR	135	Region
Kiln (tobacco)	BFR	136	Region
Lumber mill	BFR	137	Region
Medical centre	BFR	139	Region
Monastery	BFR	140	Region
Motel	BFR	141	Region
Municipal hall	BFR	142	Region
Museum	BFR	143	Region
Non-Christian place of worship	BFR	144	Region
Observatory	BFR	145	Region
Oil/gas facilities building	BFR	146	Region
Gas and oil facilities	BFR	146	Region
Other	BFR	147	Region
Parliament building	BFR	149	Region
Penitentiary	BFR	150	Region
Petroleum refinery	BFR	151	Region
Plant	BFR	152	Region

Police station	BFR	153	Region
Pulp/paper mill	BFR	154	Region
Railway station	BFR	155	Region
Reformatory	BFR	156	Region
Sanatorium	BFR	157	Region
Satellite-tracking station	BFR	158	Region
Sawmill	BFR	159	Region
School	BFR	160	Region
Seminary	BFR	161	Region
Senior citizens home	BFR	162	Region
Sewage treatment plant	BFR	163	Region
Shipyard	BFR	164	Region
Shopping centre	BFR	165	Region
Sportsplex	BFR	166	Region
Steel mill	BFR	167	Region
Trading post	BFR	168	Region
University	BFR	169	Region
Warden/ranger station	BFR	170	Region
Water treatment plant	BFR	171	Region
Weigh scale (highway)	BFR	172	Region
Weight scale	BFR	172	Region
Greenhouse	BFR	174	Region
Penal building	BFR	175	Region
Lodging facilities	BFR	176	Region
Industrial building	BFR	177	Region
Religious building	BFR	178	Region
Educational building	BFR	179	Region
Fort: generic/unknown	BFR	585	Region
Fort	BFR	585	Region
Greenhouse	BFR	618	Region
Stadium	BFR	1220	Region
Commercial	LUR	–	Region
Residential	LUR	–	Region

Appendix C: Entities from the CanMap Content Suite dataset that were used for the built-up area delineation in the Montreal CMA

Table C.1 Entities from the CanMap Content Suite dataset that were used for the built-up area delineation in the Montreal CMA (BFR: building footprint regions, LUR: land use region) (DMTI Spatial, 2016).

Feature	**Layer name**	**Description**	**Theme Category**	**Shape file type**
Building footprint	BuildingFootprintsRegion	"A building footprint is a polygon that represents the rooftop of a detached building. Examples of this includes features such as city hall, fire stations, schools, churches or police stations."	Structure	Region
Residential	LandCoverRegion	"Land primarily occupied by private residences regardless of physical building type and ownership structure."	Planning and Development	Region
Commercial	LandCoverRegion	"Land occupied by establishments involved in the sale of goods and services: category includes, but is not limited to, retail stores, restaurants, doctor's offices, laboratories, home furniture stores, equipment stores, gas stations, and auto dealerships."	Planning and Development	Region
Chimney (Flare Stack, Industrial, Burner, and Unknown)	ChimneyPoint	"An upright flue through which combustion gases and smoke are discharged into the air."	Industry and Resource	Point
Tank	TankPoint /TankRegion	"A cylindrical structure used to store liquids."	Structures	Region/ Point
Silo	SiloPoint	"An upright, cylindrical structure 20 meters or more in height used for storing silage."	Structures	Point
Tower	TowerPoint	"A structure of 10 meters or more built to provide clearance above the surrounding objects or features."	Structures	Point
SolidDepotDumpsRegion	Solids Depot/Dump (domestic/ industrial)	"Accumulation of solid material or waste from domestic or industrial activity"	Industry and Resource	Region
GasAndOilFacilitiesPoint	Gas and Oil Facilities	"An area involved in the production or distribution of oil or natural gas products."	Industry and Resource	Point
RunwayRegion/ Runwaypoint	Airfield Airport Heliport	"A prepared surface used by airplanes and helicopters for take-off and landing."	Transportation	Region/ Point

Appendix D: Entities from the CanVec dataset that were used for the built-up area delineation in the Montreal CMA

Table D.1 Entities from the CanVec dataset that were used for the built-up area delineation in the Montreal CMA (BS: building and structures, LX: places of interest, IC: industrial and commercial areas, EN: energy, TR: transportation).

Entity	Entity description	Theme	Name (point)	Name (surface)
Building	Arena	BS	2010009 0	2010009 2
Building	Other	BS	2010009 0	2010009 2
Building	Community centre	BS	2010009 0	2010009 2
Building	Highway service centre	BS	2010009 0	2010009 2
Building	Medical centre	BS	2010009 0	2010009 2
Building	Sportsplex	BS	2010009 0	2010009 2
Building	Gas and oil facilities building	BS		2010009 2
Building	Parliament building	BS	2010009 0	2010009 2
Building	Educational building	BS	2010009 0	2010009 2
Building	Penal building	BS	2010009 0	2010009 2
Building	Industrial building	BS		2010009 2
Building	Religious building	BS	2010009 0	2010009 2
Building	Railway station	BS	2010009 0	2010009 2
Building	Hospital	BS	2010009 0	2010009 2
Building	City hall	BS	2010009 0	2010009 2
Building	Unknown	BS	2010009 0	2010009 2
Building	Armoury	BS	2010009 0	2010009 2
Building	Courthouse	BS	2010009 0	2010009 2
Building	Customs post	BS	2010009 0	2010009 2
Building	Police station	BS	2010009 0	2010009 2
Building	Fire station	BS	2010009 0	2010009 2
Building	Electric power station	BS	2010009 0	2010009 2
Building	Municipal hall	BS	2010009 0	2010009 2
Building	Satellite-tracking station	BS	2010009 0	2010009 2
Building	Coast guard station	BS	2010009 0	2010009 2
Chimney	Burner	BS	2060009 0	
Chimney	Unknown	BS	2060009 0	
Chimney	Industrial	BS	2060009 0	
Chimney	Flare stack	BS	2060009 0	
Tank	Horizontal, unknown	BS	2080009 0	2080009 2
Tank	Unknown, unknown	BS	2080009 0	
Tank	Vertical, other	BS	2080009 0	2080009 2
Tank	Vertical, water	BS	2080009 0	2080009 2
Tank	Vertical, unknown	BS	2080009 0	2080009 2
Cross	Cross	BS	2120009 0	
Navigational aid	Navigation beacon	BS	1250009 0	
Navigational aid	Navigation light	BS	1250009 0	
Navigational aid	Unknown	BS	1250009 0	
Silo	Silo	BS	2440009 0	

Tower	Communication	BS	2530009 0	
Tower	Control	BS	2530009 0	
Tower	Clearance	BS	2530009 0	
Tower	Firebreak	BS	2530009 0	
Tower	Lookout	BS	2530009 0	
Residential area	Residential area	BS		1370009 2
Domestic waste	Domestic waste	IC		1360019 2
Industrial solid depot	Industrial solid depot	IC	1360029 0	1360029 2
Gas and oil facilities	Gas and oil facilities	EN	1360049 0	1360049 2
Runway	Airport, indefinite	TR	1190009 0	1190009 2
Runway	Airport, nonofficial	TR	1190009 0	1190009 2
Runway	Airport, official	TR	1190009 0	1190009 2
Runway	Heliport, indefinite	TR	1190009 0	
Runway	Heliport, nonofficial	TR	1190009 0	
Runway	Heliport, official	TR	1190009 0	
Runway	Hospital heliport, nonofficial	TR	1190009 0	
Runway	Hospital heliport, official	TR	1190009 0	
Runway	Water aerodrome, indefinite	TR	1190009 0	
Runway	Water aerodrome, official	TR	1190009 0	

Appendix E: Modification of built-up areas for 2011 and 2016 delineation

According to Nazarnia et al. (2016) and due to limitations in the data, certain modifications were applied to the CanMap dataset. The first modification involved identification of settlement areas in groups of buildings provided in point format. First, buffers were created with a radius of 15 meters around all the points representing buildings and assumed an area of each building to be 706.5 m^2. Additionally, according to the definition of built-up areas in the study, small vacant lands located between individual buildings should be included in the built-up areas. As a result, wherever four or more buildings were located within a 100-meter radius, a settlement area was delineated. However, if four or more buildings were arranged in a row, the original pattern was preserved, and no modification was needed.

Another modification, as done by Nazarnia et al. (2016), was made in regard to the representation of building footprints in the datasets. While some urban features were identified as building footprint regions, other areas including industrial and residential areas, were classified as settlement areas, which include alleys and small open spaces between the buildings. Nazarnia et al. (2016) converted building footprints into settlement areas, recognizing that small vacant spaces between building footprints are essential elements of urban areas and should therefore be factored into the calculation of urban sprawl. So, they incorporated these alleys and vacant lands into the settlement areas surrounding the building footprints.

For an accurate comparison, these modifications have also been applied in the delineation of built-up areas for 2016, see example in Figure E.1.

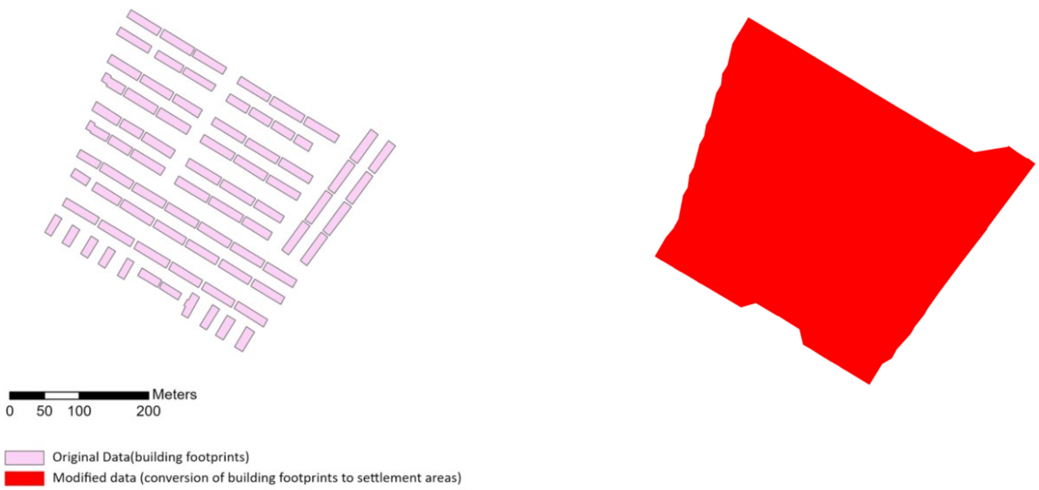

Figure E.1 Example of converting the building footprints to settlement areas. Vacant spaces between building footprints are essential elements of urban areas and should be factored into the calculation of urban sprawl.

Appendix F: Built-up areas in 2011 and 2016 within Montreal CMA_{2016}

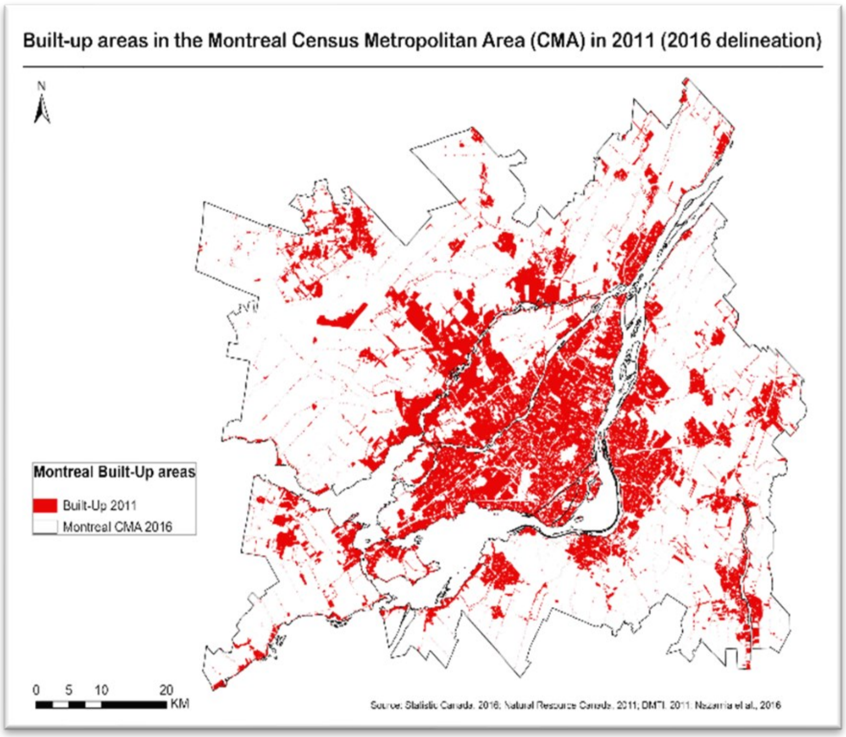

Figure F.1 Built-up areas in 2011 within Montreal CMA_{2016}.

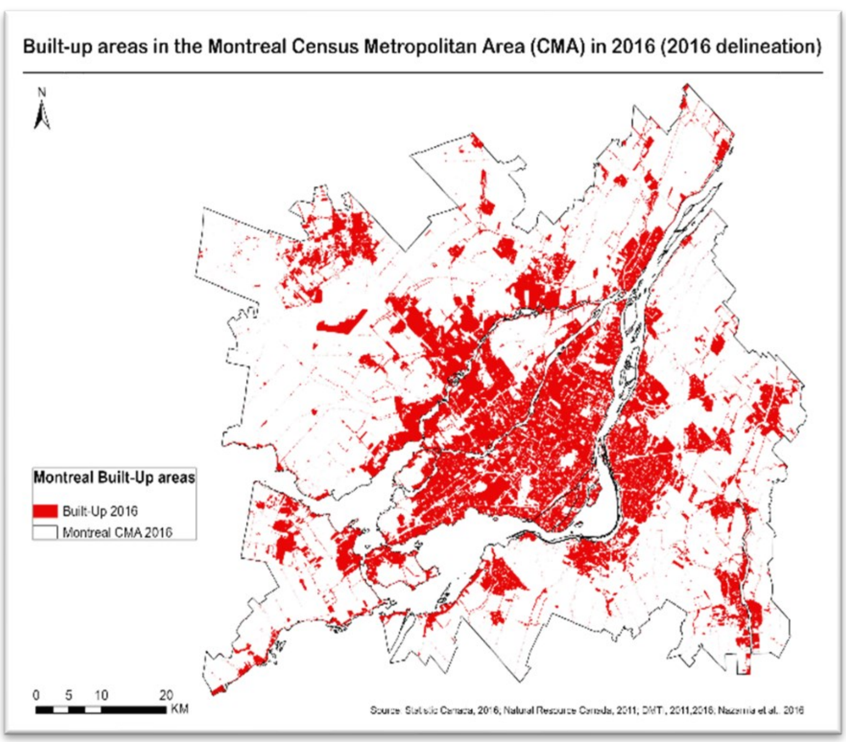

Figure F.2 Built-up areas in 2016 within Montreal CMA_{2016}

Appendix G: Population in the 93 census subdivisions in the Montreal CMA_{2016} for 2011 and 2016

Table G.1 Population in the 93 census subdivisions in the Montreal CMA in 2011 and 2016

CSD Code	CSD Name	Type*	Inhabitants 2011	Inhabitants 2016	Change (%)
2452007	Lavaltrie	V	13267	13657	2.9
2455065	Saint-Mathias-sur-Richelieu	MÉ	4618	4531	-1.9
2456083	Saint-Jean-sur-Richelieu	V	92394	95114	2.9
2457005	Chambly	V	25571	29120	13.9
2457010	Carignan	V	7966	9462	18.8
2459010	Sainte-Julie	V	30104	29881	-0.7
2460005	Charlemagne	V	5853	5913	1.0
2463048	Saint-Lin--Laurentides	V	17463	20786	19.0
2464008	Terrebonne	V	106322	111575	4.9
2466058	Côte-Saint-Luc	V	32321	32448	0.4
2466092	L'Île-Dorval	V	5	5	0.0
2466097	Pointe-Claire	V	30790	31380	1.9
2466102	Kirkland	V	21253	20151	-5.2
2466112	Baie-D'Urfé	V	3850	3823	-0.7
2467005	Saint-Mathieu	MÉ	1879	2156	14.7
2467010	Saint-Philippe	MÉ	5495	6320	15.0
2467802	Kahnawake	IRI	NA	NA	NA
2470022	Beauharnois	V	12011	12884	7.3
2471025	Saint-Zotique	MÉ	6773	7934	17.1
2471095	L'Île-Cadieux	V	105	126	20.0
2472005	Saint-Eustache	V	44154	44008	-0.3
2472802	Kanesatake	S-É	NA	NA	NA
2473010	Sainte-Thérèse	V	26025	25989	-0.1
2474005	Mirabel	V	41957	50513	20.4
2475005	Saint-Colomban	V	13080	16019	22.5
2475017	Saint-Jérôme	V	68456	74346	8.6
2476025	Gore	CT	1775	1904	7.3
2455057	Richelieu	V	5467	5236	-4.2
2457020	Saint-Basile-le-Grand	V	16736	17059	1.9
2457025	McMasterville	MÉ	5615	5698	1.5
2457030	Otterburn Park	V	8450	8421	-0.3
2457035	Mont-Saint-Hilaire	V	18200	18585	2.1
2457040	Beloeil	V	20783	22458	8.1
2457045	Saint-Mathieu-de-Beloeil MÉ	MÉ	2624	2619	-0.2
2458007	Brossard	V	79273	85721	8.1
2458012	Saint-Lambert	V	21555	21861	1.4

2458033	Boucherville	V	40753	41671	2.3
2458037	Saint-Bruno-de-Montarville	V	26107	26394	1.1
2458227	Longueuil	V	231409	239700	3.6
2459015	Saint-Amable	MÉ	10870	12167	11.9
2459020	Varennes	V	20994	21257	1.3
2459025	Verchères	MÉ	5692	5835	2.5
2460013	Repentigny	V	82000	84285	2.8
2460020	Saint-Sulpice	PE	3273	3439	5.1
2460028	L'Assomption	V	20065	22429	11.8
2460035	L'Épiphanie	V	5353	5493	2.6
2460040	L'Épiphanie	PE	3296	3200	-2.9
2464015	Mascouche	V	42491	46692	9.9
2465005	Laval V	V	401553	422993	5.3
2466007	Montréal-Est	V	3728	3850	3.3
2466023	Montréal	V	1649519	1704694	3.3
2466032	Westmount	V	19931	20312	1.9
2466047	Montréal-Ouest	V	5085	5050	-0.7
2466062	Hampstead	V	7153	6973	-2.5
2466072	Mont-Royal	V	19503	20276	4.0
2466087	Dorval	V	18208	18980	4.2
2466107	Beaconsfield	V	19505	19324	-0.9
2466117	Sainte-Anne-de-Bellevue	V	5073	4958	-2.3
2466127	Senneville	VL	920	921	0.1
2466142	Dollard-Des Ormeaux	V	49637	48899	-1.5
2467015	La Prairie	V	23357	24110	3.2
2467020	Candiac	V	19876	21047	5.9
2467025	Delson	V	7462	7457	-0.1
2467030	Sainte-Catherine	V	16762	17047	1.7
2467035	Saint-Constant	V	24980	27359	9.5
2467040	Saint-Isidore	PE	2581	2608	1.0
2467045	Mercier	V	11584	13115	13.2
2467050	Châteauguay	V	45904	47906	4.4
2467055	Léry	V	2307	2318	0.5
2471033	Les Coteaux	MÉ	4568	5368	17.5
2471040	Coteau-du-Lac	V	6842	7044	3.0
2471050	Les Cèdres	MÉ	6079	6777	11.5
2471055	Pointe-des-Cascades	VL	1340	1481	10.5
2471060	L'Île-Perrot	V	10503	10756	2.4
2471065	Notre-Dame-de-l'Île-Perrot	V	10620	10654	0.3
2471070	Pincourt	V	14305	14558	1.8
2471075	Terrasse-Vaudreuil	MÉ	1971	1986	0.8

2471083	Vaudreuil-Dorion	V	33305	38117	14.4
2471090	Vaudreuil-sur-le-Lac	VL	1359	1341	-1.3
2471100	Hudson	V	5135	5185	1.0
2471105	Saint-Lazare	V	19295	19889	3.1
2472010	Deux-Montagnes	V	17552	17496	-0.3
2472015	Sainte-Marthe-sur-le-Lac	V	15689	18074	15.2
2472020	Pointe-Calumet	MÉ	6396	6428	0.5
2472025	Saint-Joseph-du-Lac	MÉ	6195	6687	7.9
2472032	Oka	MÉ	3969	3824	-3.7
2472043	Saint-Placide	MÉ	1715	1686	-1.7
2473005	Boisbriand	V	26816	26884	0.3
2473015	Blainville	V	53510	56863	6.3
2473020	Rosemère	V	14294	13958	-2.4
2473025	Lorraine	V	9479	9352	-1.3
2473030	Bois-des-Filion	V	9485	9636	1.6
2473035	Sainte-Anne-des-Plaines	V	14535	14421	-0.8

*Type :
V: Ville
VL: Village
MÉ: Municipalité
PE: Paroisse (municipalité de)
CT: Canton (municipalité de)
S-É: Indian settlement / Établissement indien
IRI: Indian reserve / Réserve indienne

Appendix H: Job data for Montreal

The reference week, as defined by the Labour Force Survey, refers to the full calendar week, running from Sunday to Saturday, which is covered by the Labour Force Survey each month, with the 15th day of the month usually included within this timeframe. Interviews were conducted during the following week, referred to as the Survey Week. The labor force status determined for the survey is based on the respondent's situation during the reference week (Statistics Canada, Guide to the Labour Force Survey, 2016).

Unfortunately, the data did not include the numbers of part-time and full-time employees who were not working during the reference week. In order to calculate these numbers, we assumed that the proportion of part-time employees among those who were not working during the reference week was the same as that among those who were working during the reference week. Using this assumption, to estimate the number of part-time employees who were not working during the reference week, we used the following formula:

Number of part-time employees who did not work during the reference week = (Number of part-time employees who worked during the reference week / (Number of full-time employees who worked during the reference week + Number of part-time employees who worked during the reference week)) * Total number of employees who did not work during the reference week.

In addition, we estimated the number of full-time employees who did not work during the reference week by subtracting the estimated number of part-time employees who did not work during the reference week from the total number of employees who did not work during the reference week.

In the end, to obtain the best possible estimates for both part-time and full-time jobs, we added the estimated number of part-time employees who did not work during the reference week to the actual number of employees who worked part-time. Similarly, we added the estimated number of full-time employees who did not work during the reference week to the actual number of employees who worked full-time.

To account for the difference in the amount of time spent by part-time and full-time workers in built-up areas, the concept of full-time equivalents (FTEs) was used, as part-time workers spend less time in the built-up areas. A conversion factor for FTEs can be obtained from available national data sets. Our study used FTEs to more accurately represent land uptake per person (*LUP*). FTEs were calculated using information about full-time and part-time jobs (all jobs, both sexes, 15 years and over), and the hours for full-time and part-time workers for Quebec were obtained from Statistics Canada. The conversion factors were determined by dividing the weekly hours of part-time employment by the weekly hours of full-time employment (Hennig et al. 2015). The same steps were applied separately for 2011 and 2016 to obtain the most accurate results for of *LUP*, *WUP*, and *WSPC.* To estimate the FTEs, the number of part-time jobs was multiplied by the conversion factor and added to the number of full-time jobs.

The approach for estimating the numbers of jobs between 2016 and 2070, based on the available population data for the CMA and all CSDs, as well as job data for 2016, was as follows:

First, we calculated the ratio of people who were working compared to the total population in 2016 (the base year). In the Montreal CMA for the year 2016, the number of inhabitants was 3,824,221, and the number of jobs was 1,539,664.09, resulting in a ratio of 39.1%.

To estimate the number of jobs for each year between 2016 and 2070, we multiplied this ratio by the number of inhabitants for each respective year. For example, to estimate the number of jobs for 2025:

Number of Inhabitants in 2025 * 39.1% = Estimated Number of Jobs in 2025

This approach provided an approximation of the number of jobs for each year within the given time frame, using 2016 as a base year, assuming the ratio will be the same for the Montreal CMA between 2016 and 2070.

The conversion factors for FTEs (full-time equivalents) in Quebec for the years 2011 and 2016 are 0.474 and 0.473, respectively. Table H.1 provides an overview of the total numbers of jobs, which includes both full-time and FTEs, for the CSDs in 2011 and 2016, and subsequently for the Montreal CMA.

In four CSDs, the number of FTEs exceeds the number of inhabitants. This occurs due to people commuting from neighboring CSDs to work in these areas. For instance, there are industrial parks in Baie-D'Urfé and Dorval that include various types of commercial and industrial establishment, such as the Pierre-Elliott-Trudeau International airport.

Table H.1 Total numbers of jobs including both full-time and FTEs, for the CSDs in 2011 and 2016

		2016			2011		
CSDUID	**Name**	**Inhabitants**	**Total FTEs**	**Inhabitants and jobs**	**inhabitants 2011**	**Total FTEs**	**Inhabitants and jobs**
2466112	Baie-D'Urfé	3823	4052.9	7875.9	3850	3650.0	7500.0
2466107	Beaconsfield	19324	1942.7	21266.7	19505	1964.6	21469.6
2470022	Beauharnois	12884	2706.3	15590.3	12011	2816.7	14827.7
2457040	Beloeil	22458	6564.0	29022.0	20783	6201.9	26984.9
2473015	Blainville	56863	12482.2	69345.2	53510	10591.5	64101.5
2473005	Boisbriand	26884	12062.3	38946.3	26816	11085.5	37901.5
2473030	Bois-des-Filion	9636	2040.8	11676.8	9485	2195.9	11680.9
2458033	Boucherville	41671	29063.9	70734.9	40753	28047.7	68800.7
2458007	Brossard	85721	24440.9	110161.9	79273	21807.0	101080.0
2467020	Candiac	21047	5840.8	26887.8	19876	5192.3	25068.3
2457010	Carignan	9462	934.1	10396.1	7966	1109.9	9075.9
2457005	Chambly	29120	6698.3	35818.3	25571	6311.6	31882.6
2460005	Charlemagne	5913	920.5	6833.5	5853	972.2	6825.2
2467050	Châteauguay	47906	11606.0	59512.0	45904	10744.9	56648.9
2471040	Coteau-du-Lac	7044	2338.9	9382.9	6842	1613.9	8455.9
2466058	Côte-Saint-Luc	32448	5151.1	37599.1	32321	4821.0	37142.0
2467025	Delson	7457	3869.6	11326.6	7462	3525.9	10987.9
2472010	Deux-Montagnes	17496	1527.5	19023.5	17552	1758.3	19310.3
2466142	Dollard-Des Ormeaux	48899	7890.5	56789.5	49637	8184.3	57821.3
2466087	Dorval	18980	39324.4	58304.4	18208	41242.9	59450.9
2476025	Gore	1904	88.7	1992.7	1775	0.0	1775.0
2466062	Hampstead	6973	557.6	7530.6	7153	549.0	7702.0
2471100	Hudson	5185	1025.8	6210.8	5135	1093.6	6228.6
2466102	Kirkland	20151	7528.7	27679.7	21253	7523.7	28776.7
2467015	La Prairie	24110	5583.2	29693.2	23357	5287.2	28644.2
2460028	L'Assomption	22429	4217.5	26646.5	20065	5582.3	25647.3
2465005	Laval	422993	125649.3	548642.3	401553	122252.1	523805.1
2452007	Lavaltrie	13657	1834.5	15491.5	13267	1699.5	14966.5
2460040	L'Épiphanie	3200	310.9	3510.9	3296	213.1	3509.1
2460035	L'Épiphanie	5493	677.5	6170.5	5353	514.5	5867.5
2467055	Léry	2318	138.7	2456.7	2307	166.9	2473.9
2471050	Les Cèdres	6777	827.8	7604.8	6079	962.2	7041.2
2471033	Les Coteaux	5368	657.1	6025.1	4568	552.3	5120.3
2471095	L'Île-Cadieux	126	0.0	126.0	105	0.0	105.0
2471060	L'Île-Perrot	10756	1824.4	12580.4	10503	2121.4	12624.4
2458227	Longueuil	239700	73976.4	313676.4	231409	76803.9	308212.9
2473025	Lorraine	9352	550.9	9902.9	9479	712.4	10191.4
2464015	Mascouche	46692	7876.2	54568.2	42491	7661.7	50152.7
2457025	McMasterville	5698	866.6	6564.6	5615	869.5	6484.5
2467045	Mercier	13115	1683.3	14798.3	11584	1631.0	13215.0
2474005	Mirabel	50513	17699.4	68212.4	41957	13920.9	55877.9
2466023	Montréal	1704694	874611.7	2579305.7	1649519	875296.5	2524815.5
2466007	Montréal-Est	3850	4901.1	8751.1	3728	4785.7	8513.7
2466047	Montréal-Ouest	5050	978.2	6028.2	5085	853.4	5938.4
2466072	Mont-Royal	20276	16647.1	36923.1	19503	16936.0	36439.0

2457035	Mont-Saint-Hilaire	18585	3902.4	22487.4	18200	4067.1	22267.1
2471065	Notre-Dame-de-l'Île-Perrot	10654	812.6	11466.6	10620	717.5	11337.5
2472032	Oka	3824	802.5	4626.5	3969	838.7	4807.7
2457030	Otterburn Park	8421	489.6	8910.6	8450	393.8	8843.8
2471070	Pincourt	14558	1437.2	15995.2	14305	1287.4	15592.4
2472020	Pointe-Calumet	6428	299.1	6727.1	6396	268.4	6664.4
2466097	Pointe-Claire	31380	25134.3	56514.3	30790	24940.2	55730.2
2471055	Pointe-des-Cascades	1481	0.0	1481.0	1340	47.1	1387.1
2460013	Repentigny	84285	17096.7	101381.7	82000	17772.0	99772.0
2455057	Richelieu	5236	1656.3	6892.3	5467	1517.1	6984.1
2473020	Rosemère	13958	4895.4	18853.4	14294	4932.3	19226.3
2459015	Saint-Amable	12167	1086.7	13253.7	10870	949.1	11819.1
2457020	Saint-Basile-le-Grand	17059	2058.1	19117.1	16736	2086.4	18822.4
2458037	Saint-Bruno-de-Montarville	26394	11579.4	37973.4	26107	10646.4	36753.4
2475005	Saint-Colomban	16019	646.4	16665.4	13080	487.8	13567.8
2467035	Saint-Constant	27359	4004.8	31363.8	24980	3502.8	28482.8
2466117	Sainte-Anne-de-Bellevue	4958	3845.2	8803.2	5073	4276.3	9349.3
2473035	Sainte-Anne-des-Plaines	14421	2838.5	17259.5	14535	2990.1	17525.1
2467030	Sainte-Catherine	17047	3139.5	20186.5	16762	2908.1	19670.1
2459010	Sainte-Julie	29881	6457.8	36338.8	30104	6339.5	36443.5
2472015	Sainte-Marthe-sur-le-Lac	18074	1411.5	19485.5	15689	1287.9	16976.9
2473010	Sainte-Thérèse	25989	9024.3	35013.3	26025	9278.6	35303.6
2472005	Saint-Eustache	44008	17029.4	61037.4	44154	16795.9	60949.9
2467040	Saint-Isidore	2608	656.8	3264.8	2581	435.0	3016.0
2475017	Saint-Jérôme	74346	28094.4	102440.4	68456	27955.4	96411.4
2472025	Saint-Joseph-du-Lac	6687	993.4	7680.4	6195	1049.5	7244.5
2458012	Saint-Lambert	21861	5586.7	27447.7	21555	5141.0	26696.0
2471105	Saint-Lazare	19889	1752.2	21641.2	19295	1830.3	21125.3
2455065	Saint-Mathias-sur-Richelieu	4531	554.2	5085.2	4618	510.3	5128.3
2467005	Saint-Mathieu	2156	221.2	2377.2	1879	0.0	1879.0
2457045	Saint-Mathieu-de-Beloeil	2619	1686.8	4305.8	2624	1234.3	3858.3
2467010	Saint-Philippe	6320	426.5	6746.5	5495	399.8	5894.8
2472043	Saint-Placide	1686	277.8	1963.8	1715	187.1	1902.1
2460020	Saint-Sulpice	3439	320.2	3759.2	3273	240.6	3513.6
2471025	Saint-Zotique	7934	776.5	8710.5	6773	801.6	7574.6
2466127	Senneville	921	1529.8	2450.8	920	1351.5	2271.5
2471075	Terrasse-Vaudreuil	1986	208.0	2194.0	1971	200.0	2171.0
2464008	Terrebonne	111575	27719.3	139294.3	106322	25643.0	131965.0
2459020	Varennes	21257	7661.1	28918.1	20994	6526.2	27520.2
2471083	Vaudreuil-Dorion	38117	13573.7	51690.7	33305	12115.5	45420.5
2471090	Vaudreuil-sur-le-Lac	1341	125.0	1466.0	1359	15.0	1374.0
2459025	Verchères	5835	922.2	6757.2	5692	1049.7	6741.7
2466032	Westmount	20312	12720.1	33032.1	19931	12821.3	32752.3
2456083	Saint-Jean-sur-Richelieu*	95114	30998.4	126112.4	92394	30783.8	123177.8
2463048	Saint-Lin—Laurentides*	20786	2795.4	23581.4	17463	2478.7	19941.7
	CMA 2011	3983027	1557623.6	5540650.6	3824221	1539664.1	5363885.1
	CMA 2016	4098927	1591417.4	5690344.4	3934078	1572926.5	5507004.5

*these two CSDs are within the Montreal CMA of 2016 but they are not included in Montreal CMA 2011

Appendix I: Population projections for CSDs for 2070

Table I.1 Population projections for 86 CSDs of Montreal CMA_{2011} for 2070

Municipality	Name	Population 2016	% of total increase	Population 2070
52007	Lavaltrie	13657	0.748	21437.9
55057	Richelieu	5236	0.154	6842.0
55065	Saint-Mathias-sur-Richelieu	4531	0.016	4698.2
57005	Chambly	29120	1.650	46274.7
57010	Carignan	9462	1.368	23688.2
57020	Saint-Basile-le-Grand	17059	0.136	18476.5
57025	McMasterville	5698	0.056	6284.7
57030	Otterburn Park	8421	0.023	8663.5
57035	Mont-Saint-Hilaire	18585	0.116	19794.4
57040	Beloeil	22458	1.054	33421.4
57045	Saint-Mathieu-de-Beloeil	2619	0.033	2966.4
58007	Brossard	85721	3.302	120058.2
58012	Saint-Lambert	21861	0.479	26842.9
58033	Boucherville	41671	0.504	46908.5
58037	Saint-Bruno-de-Montarville	26394	0.346	29987.8
58227	Longueuil	239700	8.936	332631.6
59010	Sainte-Julie	29881	0.209	32054.0
59015	Saint-Amable	12167	0.838	20882.0
59020	Varennes	21257	0.130	22604.1
59025	Verchères	5835	-0.006	5772.7
60005	Charlemagne	5913	0.083	6771.7
60013	Repentigny	84285	1.315	97963.8
60020	Saint-Sulpice	3439	0.002	3458.7
60028	L'Assomption	22429	1.021	33049.9
60037	L'Épiphanie	8693	0.208	10857.8
64008	Terrebonne	111575	4.042	153609.5
64015	Mascouche	46692	2.550	73212.3
65005	Laval	422993	11.832	546035.4
66007	Montréal-Est	3850	0.098	4867.7
66023	Montréal	1704694	20.829	1921305.5
66032	Westmount	20312	-0.302	17168.8
66047	Montréal-Ouest	5050	0.063	5708.8
66058	Côte-Saint-Luc	32448	0.748	40227.3
66062	Hampstead	6973	0.128	8300.4
66072	Mont-Royal	20276	0.297	23363.4
66087	Dorval	18980	0.085	19868.2
66097	Pointe-Claire	31380	1.084	42651.5
66102	Kirkland	20151	-0.119	18908.8
66107	Beaconsfield	19324	0.182	21221.7
66112	Baie-D'Urfé	3823	0.001	3832.8
66117	Sainte-Anne-de-Bellevue	4958	0.022	5190.7
66127	Senneville	921	0.017	1099.6
66142	Dollard-Des Ormeaux	48899	-0.064	48236.9

67005	Saint-Mathieu	2156	0.117	3373.6
67010	Saint-Philippe	6320	0.811	14756.4
67015	La Prairie	24110	1.049	35021.0
67020	Candiac	21047	0.830	29681.7
67025	Delson	7457	0.315	10731.3
67030	Sainte-Catherine	17047	0.196	19087.3
67035	Saint-Constant	27359	1.786	45932.9
67040	Saint-Isidore	2608	0.120	3860.0
67045	Mercier	13115	1.163	25205.9
67050	Châteauguay	47906	1.723	65822.7
67055	Léry	2318	0.030	2627.7
70022	Beauharnois	12884	0.783	21022.2
71025	Saint-Zotique	7934	0.922	17517.5
71033	Les Coteaux	5368	0.298	8470.2
71040	Coteau-du-Lac	7044	0.187	8984.3
71050	Les Cèdres	6777	0.264	9520.3
71055	Pointe-des-Cascades	1481	0.175	3303.3
71060	L'Île-Perrot	10756	0.247	13327.2
71065	Notre-Dame-de-l'Île-Perrot	10654	0.298	13752.9
71070	Pincourt	14558	0.209	16729.4
71075	Terrasse-Vaudreuil	1986	-0.004	1941.8
71083	Vaudreuil-Dorion	38117	2.662	65795.9
71090	Vaudreuil-sur-le-Lac	1341	0.009	1436.0
71100	Hudson	5185	-0.005	5137.5
71105	Saint-Lazare	19889	1.094	31262.1
72005	Saint-Eustache	44008	0.934	53719.4
72010	Deux-Montagnes	17496	0.353	21163.6
72015	Sainte-Marthe-sur-le-Lac	18074	1.562	34317.5
72020	Pointe-Calumet	6428	0.077	7229.4
72025	Saint-Joseph-du-Lac	6687	0.351	10338.2
72032	Oka	3824	0.221	6121.6
72043	Saint-Placide	1686	0.042	2126.8
73005	Boisbriand	26884	0.745	34627.2
73010	Sainte-Thérèse	25989	0.284	28945.3
73015	Blainville	56863	3.556	93843.6
73020	Rosemère	13958	0.209	16132.7
73025	Lorraine	9352	0.239	11834.7
73030	Bois-des-Filion	9636	0.376	13547.8
73035	Sainte-Anne-des-Plaines	14421	0.672	21408.7
74005	Mirabel	50513	5.305	105680.7
75005	Saint-Colomban	16019	1.656	33242.5
75017	Saint-Jérôme	74346	3.796	113827.3
76025	Gore	1904	0.129	3242.9

Appendix J: Relationship between *PBA* and *DIS* (at the CMA level)

Various models were evaluated to determine the most suitable model that fits the observed relationship between dispersion and *PBA*. A scatter plot depicting *DIS* as a function of *PBA* was visually examined which showed a non-linear pattern. In order to determine the most suitable relationship between *DIS* and *PBA*, both logarithmic and non-linear regression models using a quadratic equation were evaluated. The nls() function was employed in R to fit this model. The resulting equation was.

$$DIS = -0.8069\left({}^{UPU}/_{m^2}\right) * PBA^2 + 7.7469\left({}^{UPU}/_{m^2}\right) * PBA + 45.8192\left({}^{UPU}/_{m^2}\right).$$

To explore the logarithmic relationship between the two variables, the data were transformed by taking the logarithm of one or both variables, and then fitting a linear model to the transformed data using the lm() function. The transformed data was plotted along with the linear model using the plot () and abline() functions. The resulting linear model fitted the transformed data well, which suggests that the relationship between the *PBA* and *DIS* variables could be logarithmic. Adjusted R-squared = 0.98, The logarithmic equation was

$$DIS = 1.3615\left({}^{UPU}/_{m^2}\right) * \log(PBA) + 49.6098\left({}^{UPU}/_{m^2}\right).$$

The coefficient of determination (R^2) and root mean squared error (RMSE) were used to evaluate the goodness of fit of the models. The R^2 value for the quadratic model was 99.73 %, whereas the R^2 value for the logarithmic model was 98.18 %, suggesting that the quadratic model provided a better fit. The RMSE value for the quadratic model was 0.0262, whereas the RMSE value for the logarithmic model was 0.0681. The lower RMSE value of the quadratic model indicates that it has smaller residuals on average and provides better predictions than the logarithmic model. Therefore, quadratic equation was used. The differences between values of *DIS* resulting from the logarithmic and quadratic equations were negligible.

With all the necessary values at hand, the value of *WUP and WSPC* can be calculated using the following equations:

$$WUP = PBA * DIS * \frac{e^{4.159-613.125(INH+J)/m^2/LUP}}{1+e^{4.159-613.125(INH+J)/m^2/LUP}} * (0.5 + \frac{e^{0.294432m^2/UPU*DIS-12.955}}{1+e^{0.294432m^2/UPU*DIS-12.955}})$$

$$WSPC = WUP * (area\ of\ reporting\ unit) / (Number\ of\ jobs\ and\ inhabintant)$$

Appendix K: Relationship between *PBA* and *DIS* (across all CSDs)

To identify the most suitable model to capture the relationship between *DIS* and *PBA* for all CSDs, we plotted *DIS* as a function of *PBA* for all CSDs based on the 2016 data (Figure K.1), including dots for the entire CMA for comparison.

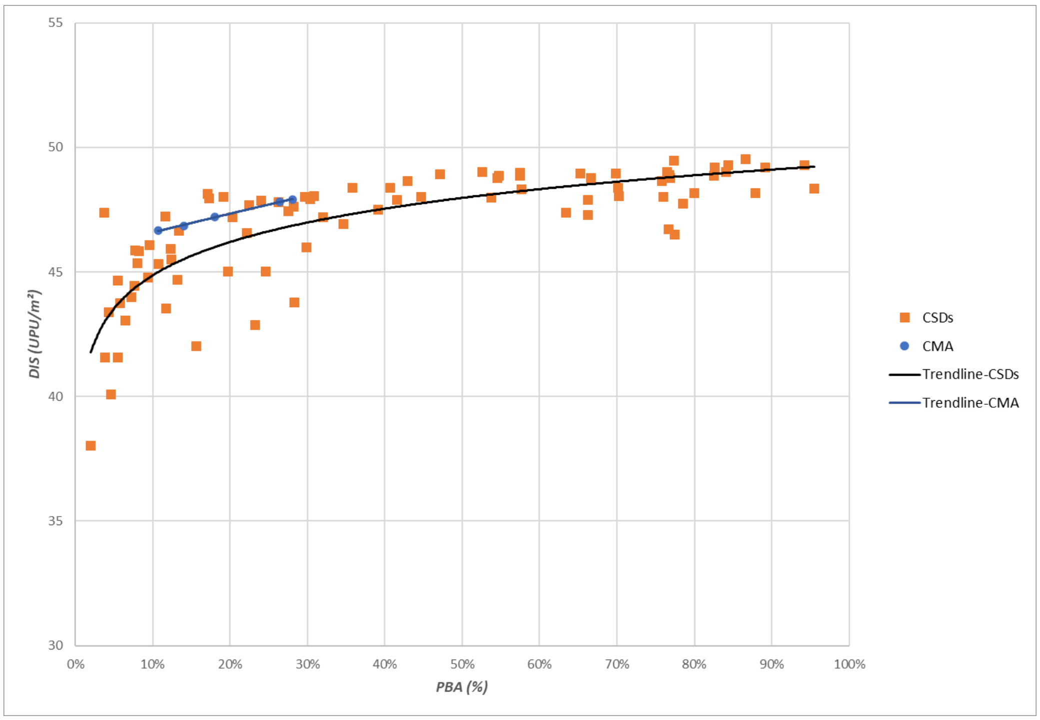

Figure K.1 Value of *DIS* as a function of *PBA* for all CSDs within the Montreal CMA 2011 in 2016

Using R, we assessed the goodness of fit for various models by calculating the coefficient of determination (R^2) (Table K.1). Based on their R^2 values, the logarithmic model provides the best fit for the data (R^2 = 66%).

Table K.1 Mathematical models used to evaluate relationship between *DIS* and *PBA* for with corresponding R^2

Model	**R squared**
Polynomial (degree 2)	0.61
Logarithmic	0.66
exponential model	0.49
power model	0.64

The following equation was employed to represent the relationship between *DIS* and *PBA*:

$$DIS_{\ General} = 49.3125\left({}^{UPU}/_{m^2}\right) + 1.9315\left({}^{UPU}/_{m^2}\right) * log(PBA).$$

We decided to apply the formula to the CSDs by allowing the intercept to vary based on *DIS* value for each CSD in the year 2016. This modification was made with the intention of improving the accuracy of the estimates for 2070, considering that *DIS* can vary significantly among different CSDs.

The formula was modified for each CSD based on its *PBA* and *DIS* values in 2016 by adjusting the intercept. For CSD_i, with corresponding $PBA_{CSD_{i-2016}}$ and $DIS_{CSD_{i-2016}}$ values, the adjustment was carried out as follows: first, the general formula was applied to estimate *DIS* corresponding to the $PBA_{CSD_{i-2016}}$ value for CSD_i:

$$DIS_{\ General_i} = 49.3125\left({}^{UPU}/_{m^2}\right) + 1.9315\left({}^{UPU}/_{m^2}\right) * log\left(PBA_{CSD_{i-2016}}\right).$$

Then we calculate the residual as follow:

$$DIS_{resid_i} = DIS_{CSD_{i-2016}} - DIS_{\ General_i}.$$

Then we adjust the $DIS_{\ General}$ formula by incorporating DIS_{resid_i} to formulate:

$$\text{Adjusted\_DIS}_{CSD_i} = DIS_{\ General_i} + DIS_{resid_i}, or$$

$$\text{Adjusted\_DIS}_{CSD_i} = 49.3125\left({}^{\text{UPU}}/_{\text{m}^2}\right) + DIS_{resid_i} + 1.9315\left({}^{\text{UPU}}/_{\text{m}^2}\right) * log(PBA).$$

Accordingly, the adjusted intercept is $49.3125\left({}^{\text{UPU}}/_{\text{m}^2}\right) + DIS_{resid_i}$.

As an example, for the CSD of Candiac, the values of *PBA* and *DIS* for 2016 are 41% and 48.36 (UPU/m^2), respectively. the adjusted formula for this CSD will be:

$$\text{Adjusted\_DIS}_{CSD_{Candic}} = 50.1\left(\text{UPU}/_{\text{m}^2}\right) + 1.9315\left(\text{UPU}/_{\text{m}^2}\right) * log(PBA).$$

So, for a value of *PBA* = 50% for 2070 the value of *DIS* will be 48.76 (UPU/m^2) (Figure K.2).

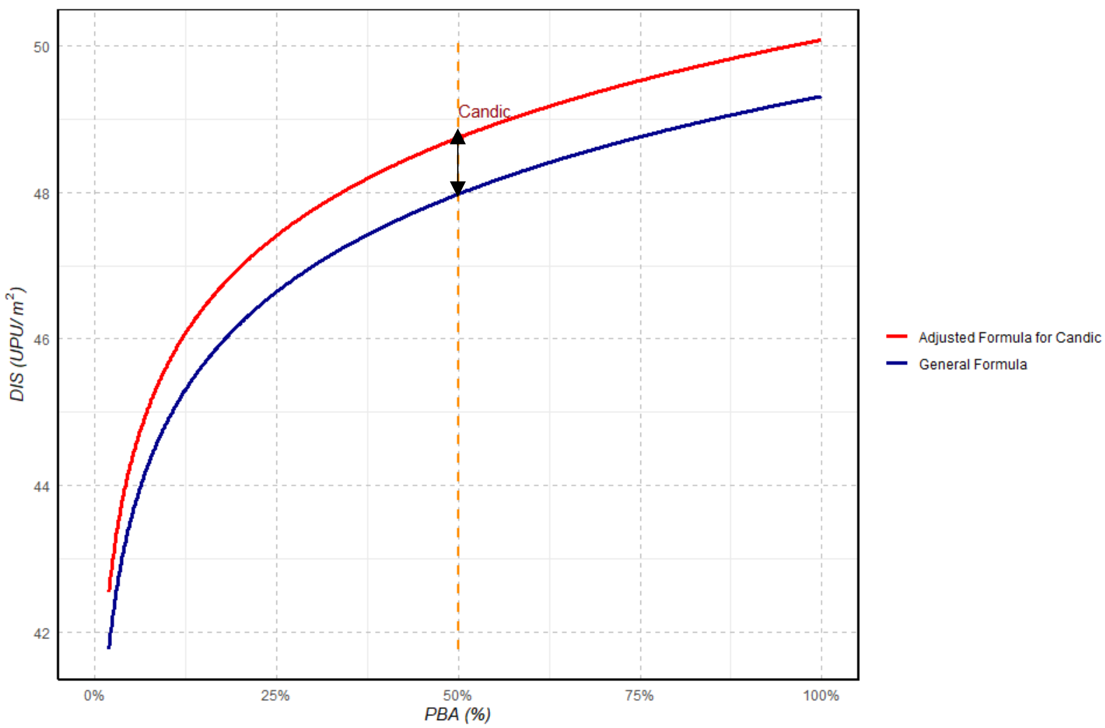

Figure K.2 Example of adjustment of formula for *DIS* as a function of *PBA* for the CSD of Candiac

Appendix L: Detailed calculations of reference Scenarios

A function was defined in R to apply a numerical optimization algorithm for calculating the value of *PBA* that corresponds to a given value of *WUP*, along with the number of jobs and inhabitants. This is achieved through an iterative approach, wherein the value of *PBA* is obtained by adjusting the value of *LUP* until the calculated *WUP* is within a specified tolerance level of the given value of *WUP*. Once the value of *PBA* is found, it is easy to calculate the corresponding values of *DIS* and *LUP*. The following equations are used to calculate the *PBA*, *DIS*, and *LUP*.

$$WUP = PBA * DIS * \frac{e^{4.159-613.125(INH+J)/m^2/LUP}}{1+e^{4.159-613.125(INH+J)/m^2/LUP}} * \left(0.5+\frac{e^{0.294432m^2/UPU*DIS-12.955}}{1+e^{0.294432m^2/UPU*DIS-12.955}}\right)$$ where:

$DIS = -0.8069 * PBA^2 + 7.7469PBA + 45.8192$ *(Quadratic relationship between DIS and PBA in Montreal CMA)*

$$PBA = (Number\ of\ jobs\ and\ inhabintant) * LUP\ /\ Area$$

The area is equal to 4291.69 km^2 which is the area of the reporting unit (Montreal CMA 2011).

Appendix M: Results of the analysis of reference scenarios

Scenario 1A: "Business as usual"

Table M.1 Urban sprawl metrics values in scenario 1A- "Business as Usual" (1951-2070) in the Montreal 2011 CMA boundary

Year	*LUP* (m²/ (inh or Job))	Inhabitants	Jobs	Inhabitants and jobs	Area (km²)	*PBA*	*DIS* (UPU/m²)	*WUP* (UPU/m²)	*WSPC* (UPU/ (inb. or job))
1951	65.90	2334237	856362.9	3192412.7	210.38	0.049	45.250	0.25	336.09
1971	111.50	3013203	1105478.7	4118296.0	459.19	0.107	46.660	1.51	1573.58
1986	140.08	3149616	1155483.6	4305099.6	603.07	0.141	46.850	3.83	3818.07
1996	161.27	3518815	1290951.7	4809766.7	775.68	0.181	47.220	6.39	5701.71
2011	211.90	3824221	1539664.1	5363885.1	1137.08	0.264	47.821	12.40	9921.35
2016	217.90	3983027	1557623.6	5540650.6	1207.11	0.281	47.922	13.48	10441.37
2017	220.26	4030022	1575738.6	5605760.6	1234.75	0.288	47.981	13.92	10659.72
2018	222.63	4077017	1594113.6	5671130.6	1262.55	0.294	48.028	14.36	10869.90
2019	224.99	4124012	1612488.7	5736500.7	1290.67	0.301	48.076	14.81	11080.22
2020	227.36	4171007	1630863.7	5801870.7	1319.09	0.307	48.124	15.26	11290.70
2021	229.72	4218003	1649239.2	5867242.2	1347.82	0.314	48.173	15.72	11501.39
2022	232.08	4257624	1664731.0	5922355.0	1374.48	0.320	48.218	16.16	11709.44
2023	234.45	4290360	1677530.8	5967890.8	1399.16	0.326	48.259	16.57	11914.91
2024	236.81	4323434	1690462.7	6013896.7	1424.16	0.332	48.301	16.98	12120.58
2025	239.18	4352634	1701879.9	6054513.9	1448.09	0.337	48.341	17.39	12324.75
2026	241.54	4375801	1710938.2	6086739.2	1470.19	0.343	48.378	17.77	12526.45
2027	243.90	4396322	1718961.9	6115283.9	1491.54	0.348	48.414	18.13	12727.01
2028	246.27	4416406	1726814.7	6143220.7	1512.88	0.353	48.450	18.50	12927.34
2029	248.63	4436089	1734510.8	6170599.8	1534.21	0.357	48.485	18.87	13127.48
2030	251.00	4455387	1742056.3	6197443.3	1555.53	0.362	48.521	19.25	13327.45
2031	253.36	4474299	1749450.9	6223749.9	1576.85	0.367	48.557	19.62	13527.27
2032	255.72	4492839	1756700.0	6249539.0	1598.16	0.372	48.592	19.99	13726.94
2033	258.09	4510710	1763687.6	6274397.6	1619.35	0.377	48.627	20.36	13926.35
2034	260.45	4527964	1770433.9	6298397.9	1640.43	0.382	48.662	20.73	14125.51
2035	262.82	4544655	1776960.1	6321615.1	1661.42	0.387	48.697	21.10	14324.46
2036	265.18	4560808	1783275.9	6344083.9	1682.32	0.392	48.732	21.47	14523.22
2037	267.54	4576474	1789401.3	6365875.3	1703.15	0.397	48.766	21.84	14721.81
2038	269.91	4591687	1795349.6	6387036.6	1723.91	0.402	48.801	22.20	14920.26
2039	272.27	4606512	1801146.2	6407658.2	1744.63	0.407	48.835	22.57	15118.61
2040	274.64	4620981	1806803.6	6427784.6	1765.30	0.411	48.869	22.94	15316.87
2041	277.00	4635119	1812331.5	6447450.5	1785.94	0.416	48.903	23.31	15515.08
2042	279.36	4649257	1817859.5	6467116.5	1806.68	0.421	48.937	23.68	15713.42
2043	281.73	4663395	1823387.4	6486782.4	1827.51	0.426	48.972	24.05	15911.89
2044	284.09	4677533	1828915.4	6506448.4	1848.43	0.431	49.006	24.42	16110.52
2045	286.46	4691671	1834443.4	6526114.4	1869.44	0.436	49.041	24.80	16309.32
2046	288.82	4705809	1839971.3	6545780.3	1890.55	0.441	49.075	25.18	16508.30

2047	291.18	4719947	1845499.3	6565446.3	1911.75	0.445	49.110	25.56	16707.46
2048	293.55	4734085	1851027.2	6585112.2	1933.05	0.450	49.145	25.94	16906.83
2049	295.91	4748223	1856555.2	6604778.2	1954.43	0.455	49.180	26.33	17106.41
2050	298.28	4762361	1862083.2	6624444.2	1975.91	0.460	49.215	26.71	17306.20
2051	300.64	4776499	1867611.1	6644110.1	1997.49	0.465	49.250	27.10	17506.23
2052	303.00	4790637	1873139.1	6663776.1	2019.15	0.470	49.285	27.49	17706.49
2053	305.37	4804775	1878667.0	6683442.0	2040.91	0.476	49.321	27.89	17907.00
2054	307.73	4818913	1884195.0	6703108.0	2062.76	0.481	49.356	28.28	18107.77
2055	310.10	4833051	1889722.9	6722773.9	2084.71	0.486	49.392	28.68	18308.79
2056	312.46	4847189	1895250.9	6742439.9	2106.74	0.491	49.428	29.08	18510.09
2057	314.82	4861327	1900778.9	6762105.9	2128.87	0.496	49.463	29.48	18711.66
2058	317.19	4875465	1906306.8	6781771.8	2151.10	0.501	49.499	29.89	18913.51
2059	319.55	4889603	1911834.8	6801437.8	2173.41	0.506	49.535	30.29	19115.65
2060	321.92	4903741	1917362.7	6821103.7	2195.82	0.512	49.572	30.70	19318.09
2061	324.28	4917879	1922890.7	6840769.7	2218.32	0.517	49.608	31.12	19520.82
2062	326.64	4932017	1928418.6	6860435.6	2240.92	0.522	49.644	31.53	19723.86
2063	329.01	4946155	1933946.6	6880101.6	2263.61	0.527	49.681	31.95	19927.21
2064	331.37	4960293	1939474.6	6899767.6	2286.39	0.533	49.717	32.36	20130.87
2065	333.74	4974431	1945002.5	6919433.5	2309.26	0.538	49.754	32.79	20334.85
2066	336.10	4988569	1950530.5	6939099.5	2332.23	0.543	49.791	33.21	20539.16
2067	338.46	5002707	1956058.4	6958765.4	2355.29	0.549	49.828	33.64	20743.79
2068	340.83	5016845	1961586.4	6978431.4	2378.44	0.554	49.865	34.06	20948.75
2069	343.19	5030983	1967114.4	6998097.4	2401.69	0.560	49.902	34.49	21154.04
2070	345.56	5045121	1972642.3	7017763.3	2425.03	0.565	49.939	34.93	21359.67

Scenario 1B: "Half-trend"

Table M.2 Urban sprawl metrics values in scenario 1B (1951-2070)- "Half trend"

Year	*LUP* (m²/ (inh or Job))	Inhabitants	Jobs	Inhabitants and jobs	Area (km²)	*PBA*	*DIS* (UPU/m²)	*WUP* (UPU/m²)	*WSPC (*UPU/ (inb. or job))
1951	65.90	2334237	856362.9	3192412.7	210.38	0.049	45.250	0.25	336.09
1971	111.50	3013203	1105478.7	4118296.0	459.19	0.107	46.660	1.51	1573.58
1986	140.08	3149616	1155483.6	4305099.6	603.07	0.141	46.850	3.83	3818.07
1996	161.27	3518815	1290951.7	4809766.7	775.68	0.181	47.220	6.39	5701.71
2011	211.90	3824221	1539664.1	5363885.1	1137.08	0.264	47.821	12.40	9921.35
2016	217.90	3983027	1557623.6	5540650.6	1207.11	0.281	47.922	13.48	10441.37
2017	219.08	4030022	1575738.6	5605760.6	1228.12	0.286	47.970	13.80	10562.77
2018	220.26	4077017	1594113.6	5671130.6	1249.15	0.291	48.006	14.11	10676.09
2019	221.45	4124012	1612488.7	5736500.7	1270.33	0.296	48.042	14.42	10789.60
2020	222.63	4171007	1630863.7	5801870.7	1291.66	0.301	48.078	14.74	10903.32
2021	223.81	4218003	1649239.2	5867242.2	1313.15	0.306	48.114	15.06	11017.24
2022	224.99	4257624	1664731.0	5922355.0	1332.48	0.310	48.147	15.36	11128.71
2023	226.17	4290360	1677530.8	5967890.8	1349.78	0.315	48.176	15.63	11237.82
2024	227.36	4323434	1690462.7	6013896.7	1367.30	0.319	48.205	15.90	11347.16
2025	228.54	4352634	1701879.9	6054513.9	1383.69	0.322	48.233	16.16	11455.19
2026	229.72	4375801	1710938.2	6086739.2	1398.25	0.326	48.258	16.40	11561.03
2027	230.90	4396322	1718961.9	6115283.9	1412.03	0.329	48.281	16.62	11665.93
2028	232.08	4416406	1726814.7	6143220.7	1425.74	0.332	48.304	16.85	11770.69
2029	233.27	4436089	1734510.8	6170599.8	1439.39	0.335	48.327	17.07	11875.34
2030	234.45	4455387	1742056.3	6197443.3	1452.98	0.339	48.349	17.30	11979.87
2031	235.63	4474299	1749450.9	6223749.9	1466.50	0.342	48.372	17.52	12084.29
2032	236.81	4492839	1756700.0	6249539.0	1479.97	0.345	48.395	17.75	12188.59
2033	237.99	4510710	1763687.6	6274397.6	1493.27	0.348	48.417	17.97	12292.66
2034	239.18	4527964	1770433.9	6298397.9	1506.43	0.351	48.439	18.19	12396.52
2035	240.36	4544655	1776960.1	6321615.1	1519.45	0.354	48.461	18.41	12500.18
2036	241.54	4560808	1783275.9	6344083.9	1532.35	0.357	48.482	18.63	12603.66
2037	242.72	4576474	1789401.3	6365875.3	1545.14	0.360	48.504	18.85	12706.96
2038	243.90	4591687	1795349.6	6387036.6	1557.82	0.363	48.525	19.06	12810.10
2039	245.09	4606512	1801146.2	6407658.2	1570.43	0.366	48.546	19.28	12913.11
2040	246.27	4620981	1806803.6	6427784.6	1582.96	0.369	48.567	19.49	13015.99
2041	247.45	4635119	1812331.5	6447450.5	1595.42	0.372	48.588	19.71	13118.76
2042	248.63	4649257	1817859.5	6467116.5	1607.93	0.375	48.608	19.92	13221.57
2043	249.81	4663395	1823387.4	6486782.4	1620.49	0.378	48.629	20.14	13324.41
2044	251.00	4677533	1828915.4	6506448.4	1633.09	0.381	48.650	20.36	13427.28
2045	252.18	4691671	1834443.4	6526114.4	1645.74	0.383	48.671	20.57	13530.20
2046	253.36	4705809	1839971.3	6545780.3	1658.44	0.386	48.692	20.79	13633.16
2047	254.54	4719947	1845499.3	6565446.3	1671.18	0.389	48.713	21.01	13736.16

2048	255.72	4734085	1851027.2	6585112.2	1683.97	0.392	48.735	21.23	13839.21
2049	256.91	4748223	1856555.2	6604778.2	1696.81	0.395	48.756	21.46	13942.31
2050	258.09	4762361	1862083.2	6624444.2	1709.69	0.398	48.777	21.68	14045.46
2051	259.27	4776499	1867611.1	6644110.1	1722.62	0.401	48.799	21.90	14148.67
2052	260.45	4790637	1873139.1	6663776.1	1735.59	0.404	48.820	22.13	14251.94
2053	261.63	4804775	1878667.0	6683442.0	1748.62	0.407	48.842	22.36	14355.26
2054	262.82	4818913	1884195.0	6703108.0	1761.68	0.410	48.863	22.58	14458.64
2055	264.00	4833051	1889722.9	6722773.9	1774.80	0.414	48.885	22.81	14562.09
2056	265.18	4847189	1895250.9	6742439.9	1787.96	0.417	48.907	23.04	14665.61
2057	266.36	4861327	1900778.9	6762105.9	1801.17	0.420	48.928	23.27	14769.19
2058	267.54	4875465	1906306.8	6781771.8	1814.42	0.423	48.950	23.50	14872.84
2059	268.73	4889603	1911834.8	6801437.8	1827.72	0.426	48.972	23.73	14976.56
2060	269.91	4903741	1917362.7	6821103.7	1841.07	0.429	48.994	23.97	15080.36
2061	271.09	4917879	1922890.7	6840769.7	1854.46	0.432	49.016	24.20	15184.23
2062	272.27	4932017	1928418.6	6860435.6	1867.90	0.435	49.038	24.44	15288.17
2063	273.45	4946155	1933946.6	6880101.6	1881.39	0.438	49.060	24.68	15392.20
2064	274.64	4960293	1939474.6	6899767.6	1894.92	0.442	49.082	24.91	15496.31
2065	275.82	4974431	1945002.5	6919433.5	1908.50	0.445	49.105	25.15	15600.49
2066	277.00	4988569	1950530.5	6939099.5	1922.13	0.448	49.127	25.39	15704.76
2067	278.18	5002707	1956058.4	6958765.4	1935.80	0.451	49.149	25.63	15809.12
2068	279.36	5016845	1961586.4	6978431.4	1949.52	0.454	49.172	25.88	15913.56
2069	280.55	5030983	1967114.4	6998097.4	1963.29	0.457	49.194	26.12	16018.09
2070	281.73	5045121	1972642.3	7017763.3	1977.10	0.461	49.217	26.36	16122.71

Scenario 2. "Constant LUP"

Table M.3 Urban sprawl metrics values in scenario 2 (1951-2070)- "Constant *LUP*"

Year	***LUP*** **(m^2/ (inh. or Job))**	**Inhabitants**	**Jobs**	**Inhabitants and jobs**	**Area (km^2)**	***PBA***	***DIS*** **(UPU/m^2)**	***WUP*** **(UPU/m^2)**	***WSPC*** **(UPU/ (inb. or job))**
1951	65.90	2334237	856362.9	3192412.7	210.38	0.049	45.250	0.25	336.09
1971	111.50	3013203	1105478.7	4118296.0	459.19	0.107	46.660	1.51	1573.58
1986	140.08	3149616	1155483.6	4305099.6	603.07	0.141	46.850	3.83	3818.07
1996	161.27	3518815	1290951.7	4809766.7	775.68	0.181	47.220	6.39	5701.71
2011	211.90	3824221	1539664.1	5363885.1	1137.08	0.264	47.821	12.40	9921.35
2016	217.90	3983027	1557623.6	5540650.6	1207.11	0.281	47.922	13.48	10441.37
2017	217.90	4030022	1575738.6	5605760.6	1221.50	0.285	47.959	13.67	10465.65
2018	217.90	4077017	1594113.6	5671130.6	1235.74	0.288	47.983	13.85	10481.60
2019	217.90	4124012	1612488.7	5736500.7	1249.98	0.291	48.007	14.03	10497.51
2020	217.90	4171007	1630863.7	5801870.7	1264.23	0.295	48.031	14.21	10513.39
2021	217.90	4218003	1649239.2	5867242.2	1278.47	0.298	48.055	14.39	10529.22
2022	217.90	4257624	1664731.0	5922355.0	1290.48	0.301	48.076	14.55	10542.54
2023	217.90	4290360	1677530.8	5967890.8	1300.40	0.303	48.092	14.68	10553.51
2024	217.90	4323434	1690462.7	6013896.7	1310.43	0.305	48.109	14.80	10564.59
2025	217.90	4352634	1701879.9	6054513.9	1319.28	0.307	48.124	14.92	10574.35
2026	217.90	4375801	1710938.2	6086739.2	1326.30	0.309	48.136	15.01	10582.08
2027	217.90	4396322	1718961.9	6115283.9	1332.52	0.310	48.147	15.09	10588.92
2028	217.90	4416406	1726814.7	6143220.7	1338.61	0.312	48.157	15.17	10595.60
2029	217.90	4436089	1734510.8	6170599.8	1344.57	0.313	48.167	15.24	10602.15
2030	217.90	4455387	1742056.3	6197443.3	1350.42	0.315	48.177	15.32	10608.56
2031	217.90	4474299	1749450.9	6223749.9	1356.16	0.316	48.187	15.39	10614.84
2032	217.90	4492839	1756700.0	6249539.0	1361.77	0.317	48.196	15.47	10620.98
2033	217.90	4510710	1763687.6	6274397.6	1367.19	0.319	48.205	15.54	10626.90
2034	217.90	4527964	1770433.9	6298397.9	1372.42	0.320	48.214	15.60	10632.61
2035	217.90	4544655	1776960.1	6321615.1	1377.48	0.321	48.223	15.67	10638.13
2036	217.90	4560808	1783275.9	6344083.9	1382.38	0.322	48.231	15.73	10643.46
2037	217.90	4576474	1789401.3	6365875.3	1387.12	0.323	48.239	15.80	10648.63
2038	217.90	4591687	1795349.6	6387036.6	1391.74	0.324	48.247	15.86	10653.64
2039	217.90	4606512	1801146.2	6407658.2	1396.23	0.325	48.254	15.91	10658.52
2040	217.90	4620981	1806803.6	6427784.6	1400.61	0.326	48.261	15.97	10663.29
2041	217.90	4635119	1812331.5	6447450.5	1404.90	0.327	48.269	16.03	10667.93
2042	217.90	4649257	1817859.5	6467116.5	1409.18	0.328	48.276	16.08	10672.58
2043	217.90	4663395	1823387.4	6486782.4	1413.47	0.329	48.283	16.14	10677.22
2044	217.90	4677533	1828915.4	6506448.4	1417.76	0.330	48.290	16.19	10681.86
2045	217.90	4691671	1834443.4	6526114.4	1422.04	0.331	48.298	16.25	10686.49
2046	217.90	4705809	1839971.3	6545780.3	1426.33	0.332	48.305	16.31	10691.12
2047	217.90	4719947	1845499.3	6565446.3	1430.61	0.333	48.312	16.36	10695.75

2048	217.90	4734085	1851027.2	6585112.2	1434.90	0.334	48.319	16.42	10700.37
2049	217.90	4748223	1856555.2	6604778.2	1439.18	0.335	48.326	16.47	10704.99
2050	217.90	4762361	1862083.2	6624444.2	1443.47	0.336	48.334	16.53	10709.60
2051	217.90	4776499	1867611.1	6644110.1	1447.75	0.337	48.341	16.59	10714.21
2052	217.90	4790637	1873139.1	6663776.1	1452.04	0.338	48.348	16.64	10718.82
2053	217.90	4804775	1878667.0	6683442.0	1456.32	0.339	48.355	16.70	10723.43
2054	217.90	4818913	1884195.0	6703108.0	1460.61	0.340	48.362	16.76	10728.03
2055	217.90	4833051	1889722.9	6722773.9	1464.89	0.341	48.369	16.81	10732.62
2056	217.90	4847189	1895250.9	6742439.9	1469.18	0.342	48.377	16.87	10737.21
2057	217.90	4861327	1900778.9	6762105.9	1473.46	0.343	48.384	16.93	10741.80
2058	217.90	4875465	1906306.8	6781771.8	1477.75	0.344	48.391	16.98	10746.39
2059	217.90	4889603	1911834.8	6801437.8	1482.03	0.345	48.398	17.04	10750.97
2060	217.90	4903741	1917362.7	6821103.7	1486.32	0.346	48.405	17.09	10755.55
2061	217.90	4917879	1922890.7	6840769.7	1490.60	0.347	48.413	17.15	10760.12
2062	217.90	4932017	1928418.6	6860435.6	1494.89	0.348	48.420	17.21	10764.69
2063	217.90	4946155	1933946.6	6880101.6	1499.17	0.349	48.427	17.26	10769.26
2064	217.90	4960293	1939474.6	6899767.6	1503.46	0.350	48.434	17.32	10773.82
2065	217.90	4974431	1945002.5	6919433.5	1507.74	0.351	48.441	17.38	10778.38
2066	217.90	4988569	1950530.5	6939099.5	1512.03	0.352	48.448	17.43	10782.93
2067	217.90	5002707	1956058.4	6958765.4	1516.31	0.353	48.456	17.49	10787.49
2068	217.90	5016845	1961586.4	6978431.4	1520.60	0.354	48.463	17.55	10792.03
2069	217.90	5030983	1967114.4	6998097.4	1524.89	0.355	48.470	17.61	10796.58
2070	217.90	5045121	1972642.3	7017763.3	1529.17	0.356	48.477	17.66	10801.12

Scenario 3: "Same increase as population"

Table M.4 Urban sprawl metrics values in scenario 3 (1951-2070) - "Same increase as population".

Year	***LUP*** **(m^2/ (inh. or Job))**	**Inhabitants**	**Jobs**	**Inhabitants and jobs**	**Area (km^2)**	***PBA***	***DIS*** **(UPU/m^2)**	***WUP*** **(UPU/m^2)**	***WSPC*** **(UPU/ (inb. or job))**
1951	65.90	2334237	856362.9	3192412.7	210.38	0.049	45.250	0.25	336.09
1971	111.50	3013203	1105478.7	4118296.0	459.19	0.107	46.660	1.51	1573.58
1986	140.08	3149616	1155483.6	4305099.6	603.07	0.141	46.850	3.83	3818.07
1996	161.27	3518815	1290951.7	4809766.7	775.68	0.181	47.220	6.39	5701.71
2011	211.90	3824221	1539664.1	5363885.1	1137.08	0.264	47.821	12.40	9921.35
2016	217.90	3983027	1557623.6	5540650.6	1207.11	0.281	47.922	13.48	10441.37
2017	217.42	4030022	1575738.6	5605760.6	1218.79	0.284	47.954	13.62	10441.37
2018	217.22	4077017	1594113.6	5671130.6	1231.91	0.287	47.976	13.78	10441.37
2019	217.03	4124012	1612488.7	5736500.7	1245.01	0.290	47.999	13.94	10441.37
2020	216.84	4171007	1630863.7	5801870.7	1258.10	0.293	48.021	14.09	10441.37
2021	216.66	4218003	1649239.2	5867242.2	1271.17	0.296	48.043	14.25	10441.37
2022	216.50	4257624	1664731.0	5922355.0	1282.17	0.299	48.062	14.39	10441.37
2023	216.37	4290360	1677530.8	5967890.8	1291.26	0.301	48.077	14.50	10441.37
2024	216.24	4323434	1690462.7	6013896.7	1300.43	0.303	48.093	14.61	10441.37
2025	216.12	4352634	1701879.9	6054513.9	1308.52	0.305	48.106	14.71	10441.37
2026	216.03	4375801	1710938.2	6086739.2	1314.93	0.306	48.117	14.79	10441.37
2027	215.95	4396322	1718961.9	6115283.9	1320.61	0.308	48.127	14.86	10441.37
2028	215.87	4416406	1726814.7	6143220.7	1326.16	0.309	48.136	14.92	10441.37
2029	215.80	4436089	1734510.8	6170599.8	1331.60	0.310	48.145	14.99	10441.37
2030	215.72	4455387	1742056.3	6197443.3	1336.93	0.312	48.154	15.06	10441.37
2031	215.65	4474299	1749450.9	6223749.9	1342.15	0.313	48.163	15.12	10441.37
2032	215.58	4492839	1756700.0	6249539.0	1347.27	0.314	48.172	15.18	10441.37
2033	215.51	4510710	1763687.6	6274397.6	1352.20	0.315	48.180	15.24	10441.37
2034	215.44	4527964	1770433.9	6298397.9	1356.96	0.316	48.188	15.30	10441.37
2035	215.38	4544655	1776960.1	6321615.1	1361.56	0.317	48.196	15.36	10441.37
2036	215.32	4560808	1783275.9	6344083.9	1366.01	0.318	48.203	15.41	10441.37
2037	215.26	4576474	1789401.3	6365875.3	1370.32	0.319	48.210	15.46	10441.37
2038	215.20	4591687	1795349.6	6387036.6	1374.51	0.320	48.218	15.52	10441.37
2039	215.15	4606512	1801146.2	6407658.2	1378.58	0.321	48.224	15.57	10441.37
2040	215.09	4620981	1806803.6	6427784.6	1382.56	0.322	48.231	15.62	10441.37
2041	215.04	4635119	1812331.5	6447450.5	1386.45	0.323	48.238	15.66	10441.37
2042	214.99	4649257	1817859.5	6467116.5	1390.34	0.324	48.244	15.71	10441.37
2043	214.93	4663395	1823387.4	6486782.4	1394.22	0.325	48.251	15.76	10441.37
2044	214.88	4677533	1828915.4	6506448.4	1398.10	0.326	48.257	15.81	10441.37
2045	214.83	4691671	1834443.4	6526114.4	1401.99	0.327	48.264	15.85	10441.37
2046	214.77	4705809	1839971.3	6545780.3	1405.87	0.328	48.270	15.90	10441.37
2047	214.72	4719947	1845499.3	6565446.3	1409.74	0.328	48.277	15.95	10441.37

2048	214.67	4734085	1851027.2	6585112.2	1413.62	0.329	48.283	16.00	10441.37
2049	214.62	4748223	1856555.2	6604778.2	1417.50	0.330	48.290	16.05	10441.37
2050	214.56	4762361	1862083.2	6624444.2	1421.37	0.331	48.296	16.09	10441.37
2051	214.51	4776499	1867611.1	6644110.1	1425.25	0.332	48.303	16.14	10441.37
2052	214.46	4790637	1873139.1	6663776.1	1429.12	0.333	48.309	16.19	10441.37
2053	214.41	4804775	1878667.0	6683442.0	1432.99	0.334	48.316	16.24	10441.37
2054	214.36	4818913	1884195.0	6703108.0	1436.86	0.335	48.322	16.28	10441.37
2055	214.31	4833051	1889722.9	6722773.9	1440.72	0.336	48.329	16.33	10441.37
2056	214.25	4847189	1895250.9	6742439.9	1444.59	0.337	48.335	16.38	10441.37
2057	214.20	4861327	1900778.9	6762105.9	1448.46	0.338	48.342	16.43	10441.37
2058	214.15	4875465	1906306.8	6781771.8	1452.32	0.338	48.348	16.48	10441.37
2059	214.10	4889603	1911834.8	6801437.8	1456.18	0.339	48.355	16.52	10441.37
2060	214.05	4903741	1917362.7	6821103.7	1460.04	0.340	48.361	16.57	10441.37
2061	214.00	4917879	1922890.7	6840769.7	1463.90	0.341	48.368	16.62	10441.37
2062	213.95	4932017	1928418.6	6860435.6	1467.76	0.342	48.374	16.67	10441.37
2063	213.90	4946155	1933946.6	6880101.6	1471.62	0.343	48.381	16.71	10441.37
2064	213.84	4960293	1939474.6	6899767.6	1475.48	0.344	48.387	16.76	10441.37
2065	213.79	4974431	1945002.5	6919433.5	1479.33	0.345	48.394	16.81	10441.37
2066	213.74	4988569	1950530.5	6939099.5	1483.18	0.346	48.400	16.86	10441.37
2067	213.69	5002707	1956058.4	6958765.4	1487.04	0.346	48.407	16.91	10441.37
2068	213.64	5016845	1961586.4	6978431.4	1490.89	0.347	48.413	16.95	10441.37
2069	213.59	5030983	1967114.4	6998097.4	1494.74	0.348	48.419	17.00	10441.37
2070	213.54	5045121	1972642.3	7017763.3	1498.58	0.349	48.426	17.05	10441.37

Scenario 4. "Half increase as population"

Table M.5 Urban sprawl metrics values in scenario 4 (1951-2070)- "Half increase as population"

Year	*LUP* (m^2/ (inh. or Job))	Inhabitants	Jobs	Inhabitants and jobs	Area (km^2)	*PBA*	*DIS* (UPU/m^2)	*WUP* (UPU/m^2)	*WSPC* (UPU/ (inb. or job))
1951	65.90	2334237	856362.9	3192412.7	210.38	0.049	45.250	0.25	336.09
1971	111.50	3013203	1105478.7	4118296.0	459.19	0.107	46.660	1.51	1573.58
1986	140.08	3149616	1155483.6	4305099.6	603.07	0.141	46.850	3.83	3818.07
1996	161.27	3518815	1290951.7	4809766.7	775.68	0.181	47.220	6.39	5701.71
2011	211.90	3824221	1539664.1	5363885.1	1137.08	0.264	47.821	12.40	9921.35
2016	217.90	3983027	1557623.6	5540650.6	1207.11	0.281	47.922	13.48	10441.37
2017	216.68	4030022	1575738.6	5605760.6	1214.66	0.283	47.947	13.54	10380.73
2018	215.77	4077017	1594113.6	5671130.6	1223.65	0.285	47.962	13.62	10320.90
2019	214.87	4124012	1612488.7	5736500.7	1232.62	0.287	47.978	13.70	10262.10
2020	213.99	4171007	1630863.7	5801870.7	1241.57	0.289	47.993	13.77	10204.29
2021	213.13	4218003	1649239.2	5867242.2	1250.50	0.291	48.008	13.85	10147.44
2022	212.42	4257624	1664731.0	5922355.0	1258.02	0.293	48.021	13.92	10100.22
2023	211.84	4290360	1677530.8	5967890.8	1264.22	0.295	48.031	13.97	10061.69
2024	211.26	4323434	1690462.7	6013896.7	1270.48	0.296	48.042	14.02	10023.21
2025	210.75	4352634	1701879.9	6054513.9	1276.00	0.297	48.051	14.07	9989.58
2026	210.36	4375801	1710938.2	6086739.2	1280.38	0.298	48.059	14.11	9963.14
2027	210.01	4396322	1718961.9	6115283.9	1284.25	0.299	48.065	14.14	9939.89
2028	209.67	4416406	1726814.7	6143220.7	1288.03	0.300	48.072	14.17	9917.29
2029	209.34	4436089	1734510.8	6170599.8	1291.74	0.301	48.078	14.21	9895.28
2030	209.02	4455387	1742056.3	6197443.3	1295.38	0.302	48.084	14.24	9873.85
2031	208.71	4474299	1749450.9	6223749.9	1298.93	0.303	48.090	14.27	9852.99
2032	208.40	4492839	1756700.0	6249539.0	1302.42	0.303	48.096	14.30	9832.66
2033	208.11	4510710	1763687.6	6274397.6	1305.78	0.304	48.102	14.33	9813.18
2034	207.83	4527964	1770433.9	6298397.9	1309.02	0.305	48.107	14.35	9794.48
2035	207.57	4544655	1776960.1	6321615.1	1312.15	0.306	48.112	14.38	9776.50
2036	207.31	4560808	1783275.9	6344083.9	1315.18	0.306	48.117	14.40	9759.18
2037	207.06	4576474	1789401.3	6365875.3	1318.12	0.307	48.122	14.43	9742.48
2038	206.82	4591687	1795349.6	6387036.6	1320.97	0.308	48.127	14.45	9726.34
2039	206.59	4606512	1801146.2	6407658.2	1323.75	0.308	48.132	14.48	9710.69
2040	206.36	4620981	1806803.6	6427784.6	1326.45	0.309	48.136	14.50	9695.49
2041	206.14	4635119	1812331.5	6447450.5	1329.10	0.310	48.141	14.52	9680.70
2042	205.93	4649257	1817859.5	6467116.5	1331.74	0.310	48.145	14.54	9665.98
2043	205.71	4663395	1823387.4	6486782.4	1334.39	0.311	48.150	14.57	9651.33
2044	205.49	4677533	1828915.4	6506448.4	1337.03	0.312	48.154	14.59	9636.74
2045	205.28	4691671	1834443.4	6526114.4	1339.67	0.312	48.159	14.61	9622.22
2046	205.06	4705809	1839971.3	6545780.3	1342.31	0.313	48.163	14.63	9607.77

2047	204.85	4719947	1845499.3	6565446.3	1344.95	0.313	48.168	14.65	9593.38
2048	204.64	4734085	1851027.2	6585112.2	1347.59	0.314	48.172	14.68	9579.06
2049	204.43	4748223	1856555.2	6604778.2	1350.22	0.315	48.177	14.70	9564.79
2050	204.22	4762361	1862083.2	6624444.2	1352.86	0.315	48.181	14.72	9550.60
2051	204.01	4776499	1867611.1	6644110.1	1355.49	0.316	48.185	14.74	9536.46
2052	203.81	4790637	1873139.1	6663776.1	1358.12	0.316	48.190	14.76	9522.39
2053	203.60	4804775	1878667.0	6683442.0	1360.75	0.317	48.194	14.79	9508.38
2054	203.40	4818913	1884195.0	6703108.0	1363.39	0.318	48.199	14.81	9494.43
2055	203.19	4833051	1889722.9	6722773.9	1366.01	0.318	48.203	14.83	9480.55
2056	202.99	4847189	1895250.9	6742439.9	1368.64	0.319	48.208	14.85	9466.72
2057	202.79	4861327	1900778.9	6762105.9	1371.27	0.320	48.212	14.87	9452.95
2058	202.59	4875465	1906306.8	6781771.8	1373.90	0.320	48.217	14.89	9439.25
2059	202.39	4889603	1911834.8	6801437.8	1376.52	0.321	48.221	14.92	9425.60
2060	202.19	4903741	1917362.7	6821103.7	1379.14	0.321	48.225	14.94	9412.01
2061	201.99	4917879	1922890.7	6840769.7	1381.77	0.322	48.230	14.96	9398.49
2062	201.79	4932017	1928418.6	6860435.6	1384.39	0.323	48.234	14.98	9385.01
2063	201.60	4946155	1933946.6	6880101.6	1387.01	0.323	48.239	15.00	9371.60
2064	201.40	4960293	1939474.6	6899767.6	1389.63	0.324	48.243	15.02	9358.25
2065	201.21	4974431	1945002.5	6919433.5	1392.25	0.324	48.247	15.04	9344.95
2066	201.02	4988569	1950530.5	6939099.5	1394.87	0.325	48.252	15.07	9331.70
2067	200.82	5002707	1956058.4	6958765.4	1397.48	0.326	48.256	15.09	9318.52
2068	200.63	5016845	1961586.4	6978431.4	1400.10	0.326	48.261	15.11	9305.39
2069	200.44	5030983	1967114.4	6998097.4	1402.71	0.327	48.265	15.13	9292.31
2070	200.25	5045121	1972642.3	7017763.3	1405.33	0.327	48.269	15.15	9279.29

Scenario 5: "Constant urban sprawl"

Table M.6 Urban sprawl metrics values in scenario 5 (1951-2070)- "Constant urban sprawl"

Year	***LUP*** **(m^2/ (inh. or Job))**	**Inhabitants**	**Jobs**	**Inhabitants and jobs**	**Area (km^2)**	***PBA***	***DIS*** **(UPU/m^2)**	***WUP*** **(UPU/m^2)**	***WSPC*** **(UPU/ (inb. or job))**
1951	65.90	2334237	856362.9	3192412.7	210.38	0.049	45.250	0.25	336.09
1971	111.50	3013203	1105478.7	4118296.0	459.19	0.107	46.660	1.51	1573.58
1986	140.08	3149616	1155483.6	4305099.6	603.07	0.141	46.850	3.83	3818.07
1996	161.27	3518815	1290951.7	4809766.7	775.68	0.181	47.220	6.39	5701.71
2011	211.90	3824221	1539664.1	5363885.1	1137.08	0.264	47.821	12.40	9921.35
2016	217.90	3983027	1557623.6	5540650.6	1207.11	0.281	47.922	13.48	10441.37
2017	215.95	4030022	1575738.6	5605760.6	1210.55	0.282	47.940	13.48	10320.09
2018	214.32	4077017	1594113.6	5671130.6	1215.46	0.283	47.948	13.48	10201.14
2019	212.74	4124012	1612488.7	5736500.7	1220.40	0.284	47.957	13.48	10084.89
2020	211.21	4171007	1630863.7	5801870.7	1225.39	0.286	47.965	13.48	9971.26
2021	209.71	4218003	1649239.2	5867242.2	1230.42	0.287	47.974	13.48	9860.17
2022	208.48	4257624	1664731.0	5922355.0	1234.68	0.288	47.981	13.48	9768.41
2023	207.48	4290360	1677530.8	5967890.8	1238.22	0.289	47.987	13.48	9693.87
2024	206.49	4323434	1690462.7	6013896.7	1241.82	0.289	47.993	13.48	9619.72
2025	205.63	4352634	1701879.9	6054513.9	1245.01	0.290	47.999	13.48	9555.18
2026	204.96	4375801	1710938.2	6086739.2	1247.55	0.291	48.003	13.48	9504.59
2027	204.37	4396322	1718961.9	6115283.9	1249.81	0.291	48.007	13.48	9460.23
2028	203.81	4416406	1726814.7	6143220.7	1252.03	0.292	48.011	13.48	9417.21
2029	203.25	4436089	1734510.8	6170599.8	1254.20	0.292	48.014	13.48	9375.42
2030	202.72	4455387	1742056.3	6197443.3	1256.34	0.293	48.018	13.48	9334.81
2031	202.20	4474299	1749450.9	6223749.9	1258.44	0.293	48.021	13.48	9295.36
2032	201.70	4492839	1756700.0	6249539.0	1260.51	0.294	48.025	13.48	9257.00
2033	201.22	4510710	1763687.6	6274397.6	1262.51	0.294	48.028	13.48	9220.32
2034	200.76	4527964	1770433.9	6298397.9	1264.44	0.295	48.032	13.48	9185.19
2035	200.31	4544655	1776960.1	6321615.1	1266.31	0.295	48.035	13.48	9151.46
2036	199.89	4560808	1783275.9	6344083.9	1268.12	0.295	48.038	13.48	9119.04
2037	199.48	4576474	1789401.3	6365875.3	1269.89	0.296	48.041	13.48	9087.83
2038	199.09	4591687	1795349.6	6387036.6	1271.61	0.296	48.044	13.48	9057.72
2039	198.71	4606512	1801146.2	6407658.2	1273.28	0.297	48.047	13.48	9028.57
2040	198.35	4620981	1806803.6	6427784.6	1274.92	0.297	48.049	13.48	9000.30
2041	197.99	4635119	1812331.5	6447450.5	1276.52	0.297	48.052	13.48	8972.85
2042	197.64	4649257	1817859.5	6467116.5	1278.13	0.298	48.055	13.48	8945.56
2043	197.28	4663395	1823387.4	6486782.4	1279.74	0.298	48.057	13.48	8918.44
2044	196.94	4677533	1828915.4	6506448.4	1281.35	0.299	48.060	13.48	8891.48
2045	196.59	4691671	1834443.4	6526114.4	1282.96	0.299	48.063	13.48	8864.69
2046	196.25	4705809	1839971.3	6545780.3	1284.58	0.299	48.066	13.48	8838.06

2047	195.90	4719947	1845499.3	6565446.3	1286.20	0.300	48.068	13.48	8811.58
2048	195.57	4734085	1851027.2	6585112.2	1287.82	0.300	48.071	13.48	8785.27
2049	195.23	4748223	1856555.2	6604778.2	1289.44	0.300	48.074	13.48	8759.11
2050	194.89	4762361	1862083.2	6624444.2	1291.07	0.301	48.077	13.48	8733.11
2051	194.56	4776499	1867611.1	6644110.1	1292.70	0.301	48.079	13.48	8707.26
2052	194.23	4790637	1873139.1	6663776.1	1294.33	0.302	48.082	13.48	8681.56
2053	193.91	4804775	1878667.0	6683442.0	1295.96	0.302	48.085	13.48	8656.02
2054	193.58	4818913	1884195.0	6703108.0	1297.60	0.302	48.088	13.48	8630.62
2055	193.26	4833051	1889722.9	6722773.9	1299.24	0.303	48.090	13.48	8605.37
2056	192.94	4847189	1895250.9	6742439.9	1300.88	0.303	48.093	13.48	8580.27
2057	192.62	4861327	1900778.9	6762105.9	1302.52	0.303	48.096	13.48	8555.32
2058	192.30	4875465	1906306.8	6781771.8	1304.16	0.304	48.099	13.48	8530.51
2059	191.99	4889603	1911834.8	6801437.8	1305.81	0.304	48.102	13.48	8505.85
2060	191.68	4903741	1917362.7	6821103.7	1307.46	0.305	48.104	13.48	8481.32
2061	191.37	4917879	1922890.7	6840769.7	1309.11	0.305	48.107	13.48	8456.94
2062	191.06	4932017	1928418.6	6860435.6	1310.77	0.305	48.110	13.48	8432.70
2063	190.76	4946155	1933946.6	6880101.6	1312.42	0.306	48.113	13.48	8408.59
2064	190.45	4960293	1939474.6	6899767.6	1314.08	0.306	48.116	13.48	8384.63
2065	190.15	4974431	1945002.5	6919433.5	1315.74	0.307	48.118	13.48	8360.80
2066	189.85	4988569	1950530.5	6939099.5	1317.40	0.307	48.121	13.48	8337.10
2067	189.55	5002707	1956058.4	6958765.4	1319.07	0.307	48.124	13.48	8313.54
2068	189.26	5016845	1961586.4	6978431.4	1320.74	0.308	48.127	13.48	8290.11
2069	188.97	5030983	1967114.4	6998097.4	1322.40	0.308	48.130	13.48	8266.82
2070	188.67	5045121	1972642.3	7017763.3	1324.07	0.309	48.132	13.48	8243.65

Scenario 6: "Constant built-up area"

Table M.7 Urban sprawl metrics values in scenario 6 (1951-2070)- "Constant built-up area"

Year	***LUP*** **(m^2/ (inh. or Job))**	**Inhabitants**	**Jobs**	**Inhabitants and jobs**	**Area (km^2)**	***PBA***	***DIS*** **(UPU/m^2)**	***WUP*** **(UPU/m^2)**	***WSPC (*UPU/ (inb. or job))**
1951	65.90	2334237	856362.9	3192412.7	210.38	0.049	45.250	0.25	336.0851
1971	111.50	3013203	1105478.7	4118296.0	459.19	0.107	46.660	1.51	1573.576
1986	140.08	3149616	1155483.6	4305099.6	603.07	0.141	46.850	3.83	3818.07
1996	161.27	3518815	1290951.7	4809766.7	775.68	0.181	47.220	6.39	5701.711
2011	211.90	3824221	1539664.1	5363885.1	1137.08	0.264	47.821	12.40	9921.345
2016	217.90	3983027	1557623.6	5540650.6	1207.11	0.281	47.922	13.48	10441.37
2017	215.33	4030022	1575738.6	5605760.6	1207.11	0.281	47.934	13.39	10246.17
2018	212.85	4077017	1594113.6	5671130.6	1207.11	0.281	47.934	13.30	10056.02
2019	210.43	4124012	1612488.7	5736500.7	1207.11	0.281	47.934	13.20	9868.859
2020	208.06	4171007	1630863.7	5801870.7	1207.11	0.281	47.934	13.10	9684.585
2021	205.74	4218003	1649239.2	5867242.2	1207.11	0.281	47.934	13.00	9503.102
2022	203.82	4257624	1664731.0	5922355.0	1207.11	0.281	47.934	12.92	9352.207
2023	202.27	4290360	1677530.8	5967890.8	1207.11	0.281	47.934	12.84	9228.95
2024	200.72	4323434	1690462.7	6013896.7	1207.11	0.281	47.934	12.77	9105.696
2025	199.37	4352634	1701879.9	6054513.9	1207.11	0.281	47.934	12.70	8997.921
2026	198.32	4375801	1710938.2	6086739.2	1207.11	0.281	47.934	12.65	8913.099
2027	197.39	4396322	1718961.9	6115283.9	1207.11	0.281	47.934	12.60	8838.463
2028	196.49	4416406	1726814.7	6143220.7	1207.11	0.281	47.934	12.56	8765.864
2029	195.62	4436089	1734510.8	6170599.8	1207.11	0.281	47.934	12.51	8695.14
2030	194.78	4455387	1742056.3	6197443.3	1207.11	0.281	47.934	12.47	8626.204
2031	193.95	4474299	1749450.9	6223749.9	1207.11	0.281	47.934	12.42	8559.03
2032	193.15	4492839	1756700.0	6249539.0	1207.11	0.281	47.934	12.38	8493.544
2033	192.39	4510710	1763687.6	6274397.6	1207.11	0.281	47.934	12.34	8430.759
2034	191.65	4527964	1770433.9	6298397.9	1207.11	0.281	47.934	12.29	8370.455
2035	190.95	4544655	1776960.1	6321615.1	1207.11	0.281	47.934	12.25	8312.409
2036	190.27	4560808	1783275.9	6344083.9	1207.11	0.281	47.934	12.21	8256.503
2037	189.62	4576474	1789401.3	6365875.3	1207.11	0.281	47.934	12.18	8202.534
2038	188.99	4591687	1795349.6	6387036.6	1207.11	0.281	47.934	12.14	8150.36
2039	188.39	4606512	1801146.2	6407658.2	1207.11	0.281	47.934	12.10	8099.737
2040	187.80	4620981	1806803.6	6427784.6	1207.11	0.281	47.934	12.07	8050.539
2041	187.22	4635119	1812331.5	6447450.5	1207.11	0.281	47.934	12.03	8002.665
2042	186.65	4649257	1817859.5	6467116.5	1207.11	0.281	47.934	12.00	7954.985
2043	186.09	4663395	1823387.4	6486782.4	1207.11	0.281	47.934	11.96	7907.499
2044	185.53	4677533	1828915.4	6506448.4	1207.11	0.281	47.934	11.93	7860.205
2045	184.97	4691671	1834443.4	6526114.4	1207.11	0.281	47.934	11.89	7813.101
2046	184.41	4705809	1839971.3	6545780.3	1207.11	0.281	47.934	11.85	7766.188
2047	183.86	4719947	1845499.3	6565446.3	1207.11	0.281	47.934	11.82	7719.463

2048	183.31	4734085	1851027.2	6585112.2	1207.11	0.281	47.934	11.78	7672.926
2049	182.76	4748223	1856555.2	6604778.2	1207.11	0.281	47.934	11.75	7626.576
2050	182.22	4762361	1862083.2	6624444.2	1207.11	0.281	47.934	11.71	7580.411
2051	181.68	4776499	1867611.1	6644110.1	1207.11	0.281	47.934	11.67	7534.431
2052	181.15	4790637	1873139.1	6663776.1	1207.11	0.281	47.934	11.64	7488.635
2053	180.61	4804775	1878667.0	6683442.0	1207.11	0.281	47.934	11.60	7443.022
2054	180.08	4818913	1884195.0	6703108.0	1207.11	0.281	47.934	11.56	7397.59
2055	179.56	4833051	1889722.9	6722773.9	1207.11	0.281	47.934	11.53	7352.34
2056	179.03	4847189	1895250.9	6742439.9	1207.11	0.281	47.934	11.49	7307.269
2057	178.51	4861327	1900778.9	6762105.9	1207.11	0.281	47.934	11.45	7262.378
2058	177.99	4875465	1906306.8	6781771.8	1207.11	0.281	47.934	11.41	7217.665
2059	177.48	4889603	1911834.8	6801437.8	1207.11	0.281	47.934	11.38	7173.131
2060	176.97	4903741	1917362.7	6821103.7	1207.11	0.281	47.934	11.34	7128.772
2061	176.46	4917879	1922890.7	6840769.7	1207.11	0.281	47.934	11.30	7084.591
2062	175.95	4932017	1928418.6	6860435.6	1207.11	0.281	47.934	11.26	7040.584
2063	175.45	4946155	1933946.6	6880101.6	1207.11	0.281	47.934	11.23	6996.753
2064	174.95	4960293	1939474.6	6899767.6	1207.11	0.281	47.934	11.19	6953.095
2065	174.45	4974431	1945002.5	6919433.5	1207.11	0.281	47.934	11.15	6909.611
2066	173.96	4988569	1950530.5	6939099.5	1207.11	0.281	47.934	11.11	6866.299
2067	173.47	5002707	1956058.4	6958765.4	1207.11	0.281	47.934	11.07	6823.16
2068	172.98	5016845	1961586.4	6978431.4	1207.11	0.281	47.934	11.03	6780.192
2069	172.49	5030983	1967114.4	6998097.4	1207.11	0.281	47.934	10.99	6737.395
2070	172.01	5045121	1972642.3	7017763.3	1207.11	0.281	47.934	10.96	6694.769