# Mapping regional accessibility of public transport and services in support of spatial planning: a case study in Flanders


## Abstract

The Flemish region in Belgium is characterised by a high and ever-growing proportion of settlement area. Moreover, the historical growth pattern has resulted in fragmented urban development causing societal and environmental problems such as strong competition for space by multiple sectors and traffic congestion. The Flemish government has incorporated in its Spatial Policy Plan the goal to reduce land take to zero by 2040 and to guide future urban development according to the Transit-Oriented Development (TOD) planning model. One of the principles of the plan is to concentrate urban development (to house the growing population and employment) at locations with good access to public transport and public and private services. Moreover, accessibility should be reached by means of active modes of transportation (e.g. walking, cycling). This paper offers a method to assist spatial planners that operate at a regional scale level by operationalizing these TOD-principles through mapping the urban development potential area-wide at high resolution. The proposed method builds upon the 'node-place model' put forward by Bertolini (1999). The method is applied to assess the urban development potential of locations in Flanders at a full-scale (i.e. for every location in Flanders, not only in areas around train stations). The method can be used to

support policy makers operating at various levels (regional – local) to identify and prioritise locations that qualify for expansion, densification or reduction of the built-up area.

Keywords: decision support; spatial planning; TOD; accessibility; public transport; services

# 1 Introduction

Over the past ten years, the settlement area in Flanders, a region in Belgium, has grown at an average rate of 6 ha/day (Poelmans & Engelen, 2014, Statbel, 2020). Rapid urban growth causes a significant decrease in spatial opportunities for other purposes such as open area, biodiversity, ecosystem services, renewable energy production etc. In addition, it is causing societal and environmental problems for example related to traffic and mobility. Although the European strategic development goals (European Commission, 2011) advice to reduce land take to zero by 2050, the Flemish Government has incorporated a deadline of 2040 in its Spatial Policy Plan. One of the guiding principles of the plan is to concentrate development at locations with high public transport accessibility, and, with good accessibility of services (Government of Flanders, 2018). Both principles are related to the Transit-Oriented Development (TOD) planning model (Calthorpe, 1993; Cervero, 2002).

In order to assist policy makers in implementing such TOD principles in their spatial planning practices, Bertolini (1999) introduced the 'node-place model'. This is a conceptual framework to identify the potential for public transport-oriented urban-regional development. In Bertolini's original model, the 'node' and 'place' indices respectively represent the accessibility of a public transport node and the intensity and activities there. Since then, the conceptual model has been operationalized in different forms in spatial planning practices worldwide (e.g. Caset et al., 2019; Chorus & Bertolini, 2011; Olaru et al., 2019; Vale et al., 2018). The original node-place model has, however, some drawbacks that limit its applicability for spatial planners that operate at the regional scale level. Firstly, the model is generally applied to generate typologies for public transport stops ('stations') in order to analyse and compare the development potential of station areas (Chorus & Bertolini, 2011, Vale et al., 2018, Peek et al., 2006). The station area is defined as a 'walkable radius' that ranges between 700 m (Bertolini, 1999) and 1.6 kilometres (Olaru et al., 2019) around the station locations. When solely focusing on these station areas, only locations with a high accessibility of public transport are considered. Especially in regions where urban sprawl is persistent and public transport is not so widespread a large part of the territory is thus left outside of the analyses. In the highly fragmented Flanders, for example, the station areas around public transport stops only account for roughly 1/3rd of the total area of the region. The original node-place model, which is limited to station areas, is therefore not able to generate a complete overview on the development potential in the entire region. Insights in the accessibility to public transport and the level of activities throughout the whole region are however important to create and improve awareness of the car dependency of locations, especially in regions that are subject of urban sprawl.

Second shortcoming of the commonly used node-place model is the visualization of the results by means of radar graphs (Vale et al., 2018, Caset et al., 2019). This type of graph allows to structure the different indicators that are used to operationalize the node and place dimensions. Although this is a very intuitive way to visualize and compare the performance of a limited number of locations simultaneously, it is not useful to generate a comprehensive and full-scale overview of the development potential throughout the whole region of interest. Such an area-wide or full-scale overview can only be achieved by means of a map.

As a consequence, applications are therefore often limited to the local scale level (city or agglomeration). Not many applications can be found that apply the model to a wider geographical scale.

Given these drawbacks, the objective of this paper is to develop a method to apply Bertolini's node-place model at a regional scale level. The method is implemented for a case study in Flanders and is developed in close collaboration with the spatial planners of the Flemish government, who are the intended end-users of the results. Such a participatory approach is important to increase the adoption of scientific tool, such as the node-place model, as planning support tools (PSS) that can be used to assist policy development (Geertman & Stillwell, 2009; Geertman et al., 2013; Hewitt et al., 2014; Van Delden et al., 2011).

The paper is structured as follows. In the next section, the adoption of TOD-principles in the Flemish spatial policy is described. Subsequently, section 3 describes the methodology to translate the original node-place concepts in a full-scale 'urban development potential' map for the Flemish region (with at a 1-hectare spatial resolution). This map differentiates zones belonging to different types, each with a specific urban development potential. This typology is based on the accessibility of public transport stops and their quality in terms of number of connections and frequency (as an operationalization of the *node* dimension), on the one hand, and the accessibility to a variety of services (as an operationalization of the *place* dimension) on the other hand. Accessibility is defined as the degree in which the public transport stops and the services can be reached by bicycle or on foot. The method is applied to Flanders, making use of the public transport stops and schedules and data on the locations of a large set of public (e.g. schools, hospitals, …) and private (e.g. shops, leisure activities, …) services. These data are described in section 4. Section 5 shows the results for both dimensions (node and place) separately and for the urban development potential in Flanders. Finally, section 6, concludes with some reflections on the usability of the resulting urban development potential map as a planning support system that can be applied at a regional level.

# 2 Transit-oriented development in the Spatial Policy Plan for Flanders

With over 6 million inhabitants, the Flemish region, the northern part of Belgium, features the importance of a metropolis, but not the classical core structure of cities like Paris or London. The region is characterized by a mix of large and regional cities and a number of smaller settlements, all connected to each other by a dense road network which is often accompanied by ribbon-development (Poelmans & Van Rompaey, 2009; Verbeek et al., 2014). Although this polycentric urban pattern has its roots already in medieval times, the sprawled nature of the urban landscape was initiated at the end of the 19$^{th}$ and the first half of the 20$^{th}$ century due to several policy interventions and laws promoting single-family home ownership (De Decker, 2008, 2011). By the end of the 1960s the weak spatial planning policies were crystalized in the regional zoning plans, which legitimized a large amount of existing fragmented urban development and stimulated further urban sprawl (Verbeek et al., 2014). As a result, Flanders has turned into one of the regions in Europe which has the highest degree of urban sprawl (EEA & FOEN, 2016; Vermeiren et al., 2019). A first attempt to revert this trend and promote a more compact urban development was made in the 1990s by means of the first comprehensive Spatial Structure Plan for Flanders (RSV). Although the ambitions of this plan were high and it succeeded in altering the former negative attitude towards planning (Albrechts, 1999; Boussauw & Boelens, 2015), it failed nevertheless to make an end to the urban expansion, which nowadays still continues at a rate of almost 6 ha/day (Pisman et al., 2018; Poelmans & Engelen, 2014). One of the ambitions of the recently approved strategy of the new Spatial Policy Plan of Flanders to end this further urban expansion is to reduce net land take to zero by 2040 (Government of Flanders, 2018). A final version of the Spatial Policy Plan is intended to replace the RSV of the 1990s.

The proposed strategy in the Spatial Policy Plan is strongly inspired by transit-oriented development (TOD), for which the definition of Cervero et al. (2002, p. 6) has been adopted; *"… most TOD definitions share several common elements: Mixed-use development, Development that is close to and well-served by transit, Development that is conducive to transit riding*". It is considered to be a strategy for reducing the environmental impacts of mobility by enhancing the coordination between land use and transport development, thereby avoiding unnecessary transport activity and promoting the shift to more environmentally friendly modes (Aguilar Jaber & Glocker, 2015). The Spatial Policy Plan is therefore putting strong emphasis on encouraging the use public transport and more active modes of transport (walking, cycling) (Government of Flanders, 2018).

The Spatial Policy Plan has implemented the concept of transit-oriented development by means of a number of spatial principles referring to the need of accessibility of public transport and services.

Inspired by the TOD-principles only active modes of transport are taken into account when determining accessibility according to the Spatial Policy Plan's vision to reduce car dependency and consequently reduce traffic congestion. In order to facilitate and stimulate Flanders spatial development into this more sustainable direction, the Flemish government requested to operationalize these spatial principles in a map discerning location with a high accessibility of public transport and good accessibility to services[1]. This paper reports on the spatial modelling of these indicators and its added value in guiding and supporting spatial policy.

This study focusses on the spatial planning for the Flemish region, one of the three regions of the federal state of Belgium. However, the Brussels-Capital Region (BCR) was included in the analyses because of its large influence on the Flemish region due to its geographical location enclosed within the Flemish territory and thus the exchanges of people, services and commodities.

# 3 Methodology

Because of the importance of the usability of the result for the regional policy-makers, a participatory approach was set-up to translate the original node-place concept in a full-scale 'urban development potential' map for Flanders. The methodology has been developed in close collaboration with the intended end-users (Environment Department of the Flemish government) and a number of other stakeholders, all operating at the regional policy level of Flanders and the Brussels-Capital region:

- Policy development and legal Support of the Environment Department, who are responsible for the development and implementation of the Spatial Policy Plan for Flanders
- Flemish Planning bureau for the Environment and Spatial Development, who are responsible for research, monitoring and evaluation in support of environmental and spatial policy preparation

[1] in Dutch 'knooppuntwaarde en voorzieningenniveau' (Verachtert et al., 2016)

- the Flemish Department of Mobility and Public Works, who are responsible for policy preparation regarding mobility and transport
- Flemish transport company 'De Lijn', who are operating all (urban, suburban and intercity) bus lines and tram lines in Flanders
- National Railway Company of Belgium (NMBS), who is the public railway operator that manages passenger services
- Informatie Vlaanderen agency, who are responsible for managing all digital Flemish (geo)data
- Agency for Innovation and Entrepreneurship, a governmental agency that facilitates the development of business areas and simulates entrepreneurship
- Brussels Planning Agency (perspective.brussels), who are responsible for statistics, socio-economic information and strategic and regulatory planning in the Brussels-Capital Region

Four workshops were organized in which the methodology described in the subsequent section was developed. All assumptions made and results were discussed with and supported by the stakeholders.

The conversion of the two dimensions of the original node-place concept to maps are described in subsequent sections. Firstly, the 'node' dimension is defined as the accessibility of public transport stops. Secondly, the 'place' dimension was operationalized as the accessibility to a wide range of public and private services. Because of the importance of active modes of transportation (walking, cycling) in the Spatial policy plan for Flanders, accessibility is herein defined as the degree in which the public transport stops and the services can be reached by bicycle or on foot. Both the accessibility to public transport and services are calculated for each hectare in Flanders. Finally, the two dimensions are combined into one map presenting 16 types of urban development potential.

## 3.1 Accessibility of public transport ('node' dimension)

This section describes how the accessibility of locations in Flanders and the Brussels-Capital Region (BCR) in terms of public transport is measured. The first input is a measure of the accessibility of the different transit nodes, where a node is defined as a public transport stop or station. Next, every 1-hectare cell in Flanders and Brussels was assigned a score by using a distance decay function.

The study considers (i) the transit nodes belonging to the rail network (nodes served by train, tram, (pre)metro or light rail) and (ii) the nodes on the main bus lines. The first set of nodes is selected based on the ambition of spatial policy makers in Flanders to stimulate the future (re)development of areas as much as possible in the neighbourhood of the rail nodes. The underlying motivation is that the existing rail network can be expected to remain relatively stable during the next decades and is therefore suited to guide future urban developments. The urban development in the station area can also be extended, densified or optimized strategically if required. Among the rail stations only those with at least two arrivals and departures between 9 am and 4 pm were included, which means that some very small railway stations are not included. The main bus stops are included because they can also be expected to be sufficiently stable in order to play a similar role as the rail stops in the future. Main bus stops are defined as stops of bus lines having the highest intrinsic potential by an internal research done by the Flemish bus company 'De Lijn' based on neighbourhood population and employment. They are served at least 4 times per hour during off-peak times and have the potential to evolve to a (light) rail line in the future according to the mobility vision of 'De Lijn'. However, as will be shown, the choice to include the main bus stops only, implies that in some parts of the territory no or only a limited number of public transport nodes are included in the analysis.

The accessibility of the transit nodes is represented by means of a composite indicator based on six sub-indicators. Each sub-indicator measures a specific aspect of the accessibility or characteristic of the transit node. The EU-COST-Action 'Accessibility Instruments for Planning Practice' (Technical

University of Munich, 2020) that was finalized in 2014 gives a rich overview of such indicators and how they are implemented in Europe and other parts of the world. The approach used in this paper draws upon the SNAMUTS (‘Spatial Network Analysis for Multi-modal Urban Transport Systems’) approach of which the theoretical background is given in Scheurer et al. (2006), Porta & Scheurer (2006), Scheurer & Curtis (2008) and Curtis & Scheurer (2009, 2010). Its concepts are taken from network analysis (Newman, 2010). The choice for this framework is largely based on the fact that it is well documented with several applications developed across the world, not in the least in the rather similar Zuid Holland area in the Netherlands (Curtis & Scheurer, 2016).

Five of the six SNAMUTS sub-indicators are calculated for Flanders and the BCR. These are complemented by a sixth indicator. The SNAMUTS sub-indicators can be briefly summarized as follows:

- The *Closeness Centrality* sub-indicator describes the ease of making trips starting in each transit node, in terms of the speed and frequency of the transit supply. It measures the minimal cumulative resistance to travel to all other nodes in the network. The cumulative resistance is calculated used the resistance between consecutive nodes. The resistance between two nodes becomes lower as the average travel time falls and/or the frequency of the service increases.
- The *Degree Centrality* sub-indicator describes the directness of the trips originating in each node. It is based on the average minimum number of transfers between the node and all other transport nodes in the network.
- The *Contour Catchment* sub-indicator presents the share of inhabitants and jobs within walking distance of transport nodes that can be reached within maximum 30 minutes from the reference node.

- The *Nodal Betweenness Centrality* sub-indicator measures the degree to which each transit node facilitates trips on the network. For each node it is calculated as the share of the paths between all other nodes that pass through that particular node.
- The *Nodal Connectivity* sub-indicator measures the extent to which the node is integrated in the network and how attractive it is to make transfers or to interrupt one's trips.

To this set of sub-indicators of the SNAMUTS framework, a sixth indicator that symbolizes the importance that is given to active travel modes in the Spatial Policy Plan (see Section 2), was added. This sixth sub-indicator represents the *density of walking and cycling infrastructure* in a radius of 3.75 km (equivalent to 15 minutes of cycling) around the transit nodes.

Based on the six sub-indicators a composite indicator is developed representing the overall accessibility for each transit node. This composite indicator is made by linearly normalizing the scores of the separate sub-indicators between the minimum and maximum value. The composite indicator is calculated as the average of all sub-indicators since each indicator was evaluated as being equally important by the stakeholders involved in the process. The result is a resulting accessibility score for each selected transport node that can range between 0 (i.e. minimum value for each of the six sub-indicators) and 10 (i.e. maximum value for each of the six sub-indicators).

In order to use the results of the study for the whole Flemish region, each 1-hectare cell of the study area is assigned a score by applying a distance decay function to this accessibility score per transit node.

The distance decay function determines how the score of the composite indicator of a specific transit node evolves over a certain distance, expressed as the travel time to the transit nodes. The distance decay function that is used is a negative logistic function, adopted from Martínez & Viegas (2013) and calculated as follows:

$$CV_{i\in k,j} = CI_i * \frac{\exp{(a_k - b_k d_{ij})}}{1+\exp{(a_k - b_k d_{ij})}} \text{ (Eq. 1)}$$

In which $CV_{i \in k,j}$ is the score of the composite indicator for transit node *i* at location *j* in which *k* is the type of transit node (bus/tram, metro, train), $CI_i$ is the score of the composite indicator for transit node *i*, $d_{ij}$ the shortest path between node *i* and location *j* (distance in minutes) and *a* and *b* are parameters that are calibrated.

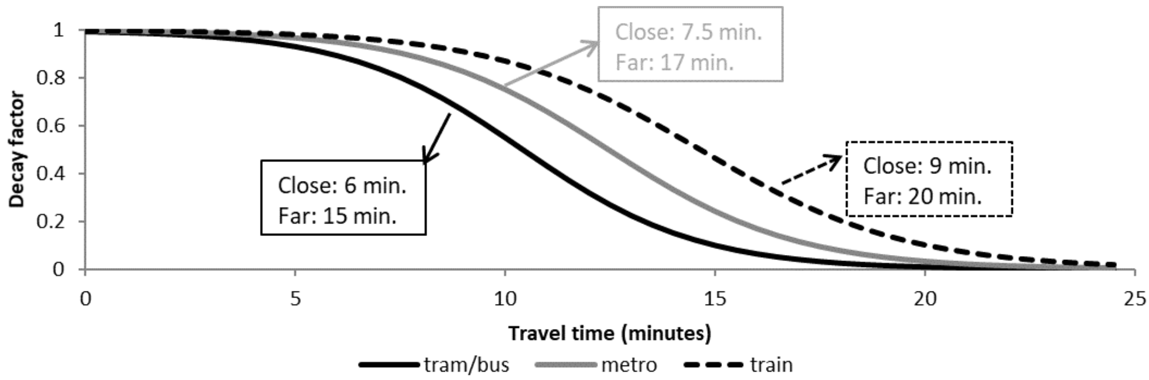
The function is applied on a raster map with a 1-hectare resolution and for each cell on the map, the function is calculated.

The shortest path ($d_{ij}$) is defined as the shortest travel time on foot (for bus, tram and metro stops) or bicycle (for train stops), linking the node (i) to all surrounding 1-hectare cells (j). The shortest path is calculated based on a map of the walking and bicycle paths of Flanders. As an input, a travel time map at a 1-hectare resolution was used. This map shows the travel time in minutes to cross each 1-hectare cell assuming a speed of 15 km/h on a bicycle path (i.e. 0.4 minutes at the 1 ha resolution) and 4 km/h at the walking paths (i.e. 1.5 minutes at the 1 ha resolution).

For the calibration of parameters *a* and *b*, the method proposed by Martínez & Viegas (2013) is adopted. They differentiate the travel times to a number of functions in 'close' and 'far' based on the perception of respondents. It is assumed that at travel times from 'close by' functions the value of the distance decay function is 90 %, while for functions that are considered 'far away', the value is 10 %. Based on the perception of the stakeholders involved in the project, the travel times corresponding to the 'close' and 'far' categories are defined for bus and tram stops, metro stops and train stops separately (Figure 1). Figure 1 shows that, according to the stakeholder's perception, the willingness to travel far to a bus or tram stop ('close' = 6 minutes, 'far' = 15 minutes) is lower than for a train stop ('close' = 9 minutes, 'far' = 20 minutes). Based on these definitions of 'close' and 'far' travel times, the parameter a and b are calibrated. Parameter a has values of 6, 5.6 and 5 respectively for train, metro and tram/bus and parameter *b* has values of 0.41, 0.45 and 0.48.

Figure 1 presents the corresponding distance decay functions used for the train, metro and tram/bus nodes, based on Equation 1. If a certain 1-hectare location falls within the range of several transit nodes, the highest value is assigned to that location.

*Figure 1: Distance decay functions for the accessibility scores. With 'Close' = perception of short travel time, resulting in 90 % of the original value, and 'Far' = perception of long travel time, resulting in 10% of the original value (figure developed on the basis of Martínez & Viegas (2013)).*




The choice in the study to work with the negative logistic rather than the more classic negative exponential is based on the fact that this function drops to zero for a given distance, which is consistent with reality as people will not walk or cycle to transit nodes beyond a reasonable limit. In this study that threshold is set to 25 minutes.

All indicators and map manipulations were programmed and calculated using tailored scripts and algorithms in the open source GeoDynamiX-Toolbox (https://github.com/VITObelgium/geodynamix), a generic toolkit for spatial modelling at high spatial resolutions developed by VITO (VITO, 2020). The distance decay function was developed by using the toolbox and using the following inputs: (1) a raster map with the transit node value (i.e. result of the composite indicator) at each 1-hectare cell, (b) the travel time per 1-hectare cell, and (c) the distance decay function with the parameters calibrated for each type of transit node (bus/tram, metro, train).

The result is a map for Flanders and the BCR showing the accessibility of each location to the public transport network at a resolution of 1 hectare (Figure 5).

## 3.2 Accessibility of services ('place' dimension)

The services considered contain any type of public or private service that provide goods or services to residents and require physical presence of the resident at the service location, such as education and health facilities, childcare services, cultural and sports facilities, commercial areas for food or goods. In total, 50 different types of services were taken into account (Table 1). This list was compiled based on a long list developed by the stakeholders' of services they found necessary to be considered, and data availability to locate these services in Flanders and the Brussels-Capital region. To calculate the accessibility to services, a similar methodology as used for the calculation of accessibility of the public transport was adopted. First, for each of the 50 different types of services, maps were generated containing the various point locations. Subsequently, the accessibility to services was computed for every 1-hectare location by searching the shortest path on foot or bicycle paths radiating out of the point locations for all 50 service types.

The 50 service types were classified together with the stakeholders as either basic, regional or metropolitan, based on the frequency at which they are needed and the area served (Table 1):

- **Basic services** needed for daily living and participation in society, such as primary school, childcare, general practitioner, pharmacy, …
- **Regional** services having a larger area of influence, serving different centres in a region, e.g. high school, general hospital, assisted-living complex, shopping centre, cultural centre, government services. A well-served region has access to a complete set of regional services.
- **Metropolitan** services with a large reach and the potential to present themselves internationally. Examples are universities, large cultural centres or tourist attractions that are accessible for students, entrepreneurs, visitors and inhabitants of Flanders and beyond.

*Table 1: list of 50 services classified into the three main types*

| | Basic | Regional | Metropolitan |
|---|---|---|---|
| Education | Kindergarten*<br>Primary school* | Secondary school<br>Adult education<br>Art education (part-time)<br>Student guidance | Higher education |
| Culture & sports | Library<br>Sport: sport centre, outdoor sport field | Cultural centre<br>Movie theatre<br>Sport: athletics track, tennis hall, riding stable<br>Swimming pool<br>Natural reserve with visitors centre | Theatres and concert hall<br>Museum<br>Monument<br>Zoo, amusement park<br>Sport: ice rink, racecourse, water sports centre, cycling track<br>Hotel |
| Care | General medicine*<br>Dentist<br>Pharmacies*<br>Eye health care by ophthalmologists and opticians<br>Childcare<br>Residential care centres and service flats for elderly people<br>Health insurance fund<br>Public Social Welfare Centre | General hospital<br>Mental health care centre<br>Local service centre | Academic hospital |

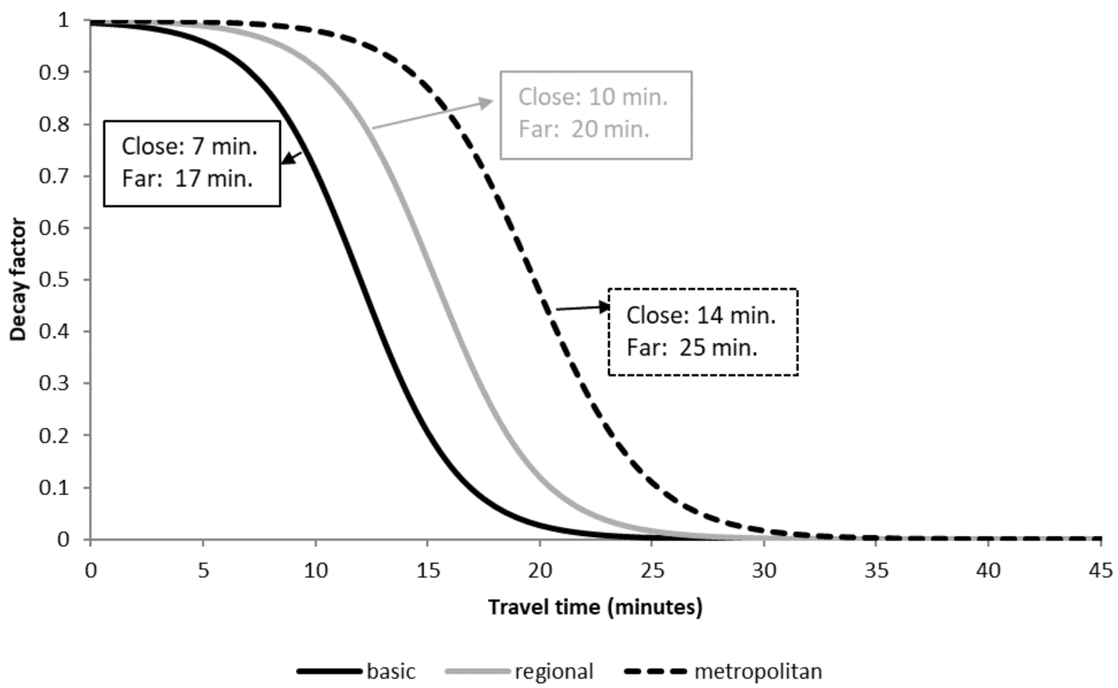
| | | | |
|---|---|---|---|
| Living amenities | Bakeries, butchers*<br>Grocery stores (< 400 $m^2$)*<br>Restaurants and pubs<br>Post office<br>Non-food services (hairdresser, newsagent, beauty, kiosks, funeral services)<br>Green area > 5 ha<br>Bank and insurance | Supermarket (> 400 $m^2$)<br>Specialized food stores (fruit & vegetable, fish, drink, chocolate)<br>Government: fire department, police, town halls, law courts<br>Retail clothing<br>Retail electronics, garden, construction materials<br>Shops for biking, animal(food), travel<br>Car services (sell, repair, gas station)<br>Work-related services (accountants, employment agencies)<br>Other regional services (architect, advocate, notary, veterinarian, taxi)<br>Niche product shops (art, antiquities, music instruments...) | Provincial and federal governments, governments of communities and regions |

* Subcategory “basic direct surroundings”, preferably at walking distance.

Three distance decay functions, one for each group of services (basic, regional, metropolitan), were defined. The same equation that was used for the accessibility of public transport was applied (Equation 1). The stakeholders defined the 'close' and 'far' travel times for each group of services (Figure 2). For basic services, the range between the 'close' and 'far' travel distance is 7 to 17 minutes. When assuming a biking speed of 15 km/h, this corresponds to a distance of 1.75 to 4.25 km. This distance is in line to the 'ideal' (2.5 km) and 'maximum' (5 km) distance that have been used for 'local facilities' in a recent study in which the accessibility to generic services in the whole of Europe was studied (Kompil et al., 2019). For the regional and metropolitan services, however, the travel times used in this study correspond to much smaller distances than applied by Kompil et al. (2019) for subregional and regional facilities. Assuming a biking speed of 15 km/h the travel times for regional services correspond to 2,5 to 5 km (10 to 20 minutes) and for metropolitan services to 3.5 to 6.25 km (14 to 25 minutes), while Kompil et al. (2019) use an ideal distance of 10 and 50 km for their selection of subregional and regional facilities. This choice has however been made according to the expectations of the stakeholders, who's wish is to promote active modes of transportation towards these types of services and thus urban development at a close enough distance to these types of services. Moreover, although public transport can be used as well to reach services, especially the regional and metropolitan services, it was decided to focus on just walking and biking in the 'place' dimension. The implementation of the 'node' dimension already shows the accessibility to public transport. The separate approach makes it possible to differentiate between these locations where public transport is needed for reaching the services (low 'place' dimension, high 'node' dimension), and locations where the services are available at walking or biking distance. The thresholds for 'close' and 'far' travel times were subsequently used to calibrate the parameters $a$ and $b$ in Equation 1. Calibrated values for parameter a are 5.4, 6.6 and 7.9 and values for parameter b are 0.45, 0.43 and 0.4 for respectively basis, regional and metropolitan services. Figure 2 shows the distance decay functions resulting from the calibrated negative logistic function for each group of services.

Via the GeoDynamiX-toolbox, the distance decay functions of Figure 2 were calculated at a raster of 1 ha resolution, starting from the point locations of the services and using the same travel time map that was used for the transit node calculations. Distance is expressed in travel times that are calculated via the foot and bicycle paths at maximum speeds of 4 km/h and 15 km/h respectively. Some basic services are preferred to be found in the direct surroundings, i.e. within walking distance (indicated with a '*' in Table 1). For all other service types travel times were calculated based on biking speeds. This resulted in 50 different maps, each showing the accessibility (in terms of a value between 0 and 1) of each 1-hectare location in Flanders to the respective service type.

*Figure 2: Distance decay of the value of the services level, including the average perception of 'close' and 'far' in terms of travel time to a service. With 'Close' = perception of short travel time, resulting in 90 % of the original value, and 'Far' = perception of long travel time, resulting in 10% of the original value (figure developed on the basis of Martínez & Viegas (2013))*



In addition to the distance decay function, a marginal utility function was applied to aggregate the various accessible services of the same type. Marginal utility functions are often used in economic and behavioural research to measure the added value of an increase in the supply of goods (Howey, 1989). But can also be used to indicate that, for example, having access to more than 1 bakery will increase one's accessibility services, but an umpteenth bakery no longer gives significant advantage. The marginal utility function that was used was defined by the stakeholders involved in the process. In this function, the added value of a second service of the same type was set at 0.5 (thus half as important as the first one), a third one added 0.3, a fourth one 0.2, which corresponds to a correction factor of 1.5, 1.8 and 2 respectively. The function assumes that the accessibility score increase is limited from 4 onwards so that a 5$^{th}$ bakery or school no longer gives any benefit. The marginal utility function was used as a correction factor for the calculated distance decay value and was the same for each of the 50 service types.

Next, the resulting maps for each service type were aggregated per category (basic, regional metropolitan) by applying equal weights to all service types within the same category. This resulted in three maps portraying accessibility to basic services (Figure 6, top - left), regional services (Figure 6, top - middle) and metropolitan services on a 1-hectare resolution (Figure 6, top - right). Finally, a weighted average of these three maps resulted in a map showing the total accessibility to services for each 1-hectare location (Figure 6, bottom). The weights were set by the stakeholders involved in the process. As they regarded all services types as equally important, equal weights were applied in the weighted average.

## 3.3. Urban development potential

As discussed in the introduction, the Flemish Spatial Policy Plan aims to focus further urban development at locations with both a good accessibility to the public transport system and to services. In order to provide the Flemish government with a decision supporting instrument to further implement and corroborate their strategic principles put forward in the Spatial Policy Plan, a visually concise map indicating the ‘urban development potential’ was generated, based on a combination of accessibility of public transport and services.  In a first step, the scores for both accessibility maps are classified into one of 4 by means of Jenks’ natural breaks method (Jenks, 1967, McMaster 1997): poor, limited, good and very good (Figure 3). Subsequently, the categorized accessibility maps are combined by means of a GIS-overlay, to distinguish 4 by 4 types (Figure 3). Four general categories are highlighted in four main colours:

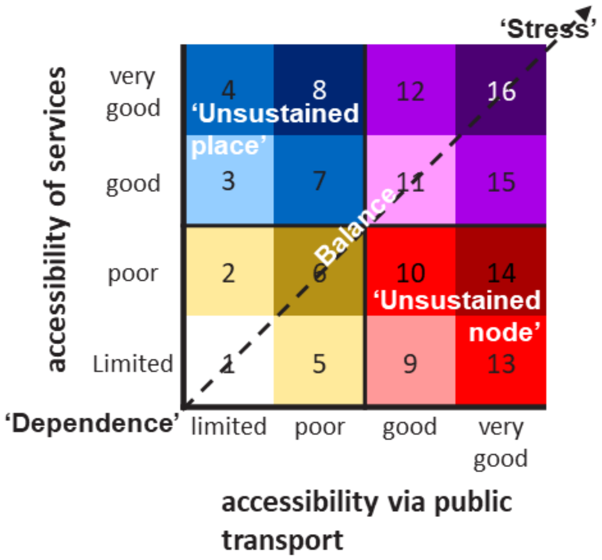
- Category A: good to very good accessibility of public transport and service (purple). According to Bertolini’s node-place model, both dimensions are in balance in this category. In Flanders, these locations are considered to have the highest potential for mixed-use development, both by means of intensification or densification of the already used space (settlement area) and new infill or green field development within category A locations (Poelmans et al., 2022).
- Category B: good to very good accessibility of public transport, but poor to limited accessibility of services (red). This category corresponds with the so-called ‘unsustained nodes’ in Bertolini’s node-place model.
- Category C: poor to limited accessibility of public transport, but good to very good accessibility of service (blue). This category corresponds with the so-called ‘unsustained places’ in Bertolini’s node-place model.

Both category B and C locations are considered to have a lower potential for mixed-use development than category A locations. This means that other (spatial) criteria and local conditions have to be taken into account when considering the urban development potential within these locations (Poelmans et al., 2022). Moreover, new green field development in these locations should come with extra investments for improving either the accessibility of public transport (in category C) or the accessibility of services (in category B).

- Category D: poor to limited accessibility of public transport and accessibility of services (yellow). According to Bertolini's node-place model, both dimensions are in balance in this category, but urban development is depending on other factors than accessibility. According to policy makers at the Flemish level, these locations should be safeguarded from green field development and intensification or densification of the already used space should be limited (Poelmans et al., 2022).

The result is a theoretical urban development potential map classifying every 1-hectare location in Flanders in one of 16 categories based on the colours assigned to each category in Figure 3.

*Figure 3: 16 urban development potential categories (figure developed on the basis of Bertolini (1999))*



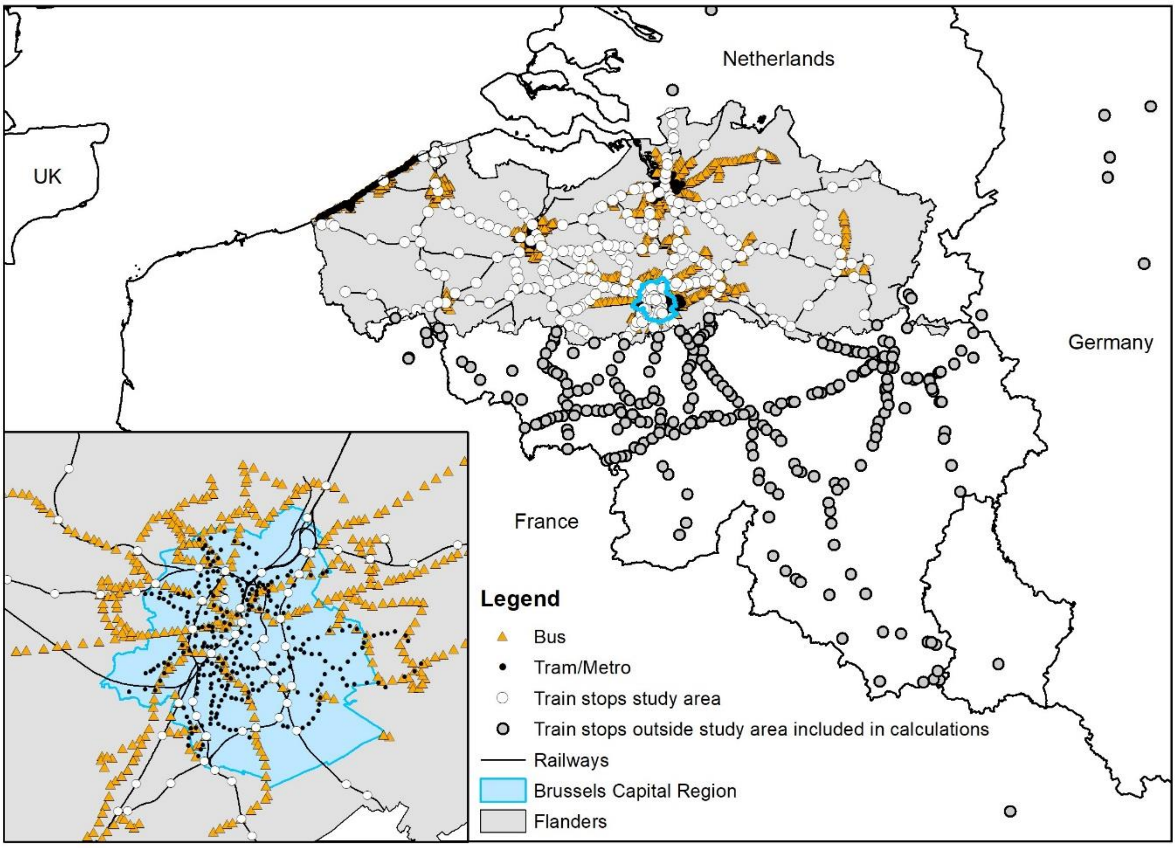

# 4 Data

## 4.1 Public transport ('node' dimension)

The information on the location of the transit stops and schedules was obtained from the Belgian public transport companies De Lijn (operator of tram, light rail and bus in Flanders), MIVB (operator of tram, metro, bus and light rail in the Brussels-Capital Region) and NMBS (rail operator in the whole of Belgium), and pertained to the situation in 2015.

Stops within 200m from each other were grouped and represented as a single node. This is relevant for (i) stops where a change from one mode to the other can be made, and (ii) stops in both directions of a line but slightly separated in space. The calculations were made for 2576 nodes (*Figure 4*), of which 834 nodes belonged to the rail network (train, tram, metro). The analysis also took into account the connections with railway stations in Wallonia, the southern part of Belgium, as well as with major railway stations in neighbouring countries, such as Paris Nord, London St. Pancras or Aachen (*Figure 4*). The population and employment maps required for calculating the Contour Catchment were based on the population grid for Belgium in 2013 (Crols, 2017) and the employment grid available for Flanders and the BCR (Crols et al., 2015), both at a 1-hectare resolution.

*Figure 4: Overview of the transit nodes (2015) in Flanders and the Brussels-Capital region (zoom)*



## 4.2 Services ('place' dimension)

The Flemish Government provided detailed information of the address of several public services such as schools, cultural and sports infrastructures, tourism and health services (hospitals) via its web-portal www.geopunt.be (POI – point of interest, FGIA, download October 2015). Addresses of doctors and dentists were obtained from the National Institute for Health and Disability (RIZIV, 2015). Public services in the Brussels-Capital Region were provided by the Brussels Planning Agency. For all other 50 service types, the service locations were obtained from the governmental register of enterprises and their establishments in Belgium (Verrijkte Kruispuntbank Ondernemingen (VKBO) - Enriched Cross-referenced Enterprises Database). This database reports for each enterprise the address and economic activities at the level of NACE-codes (the statistical classification of economic activities in the European Union). These reported NACE-codes were attributed to one of the 50 different service types used in the study.

# 5 Results and discussion

## 5.1 Accessibility of public transport

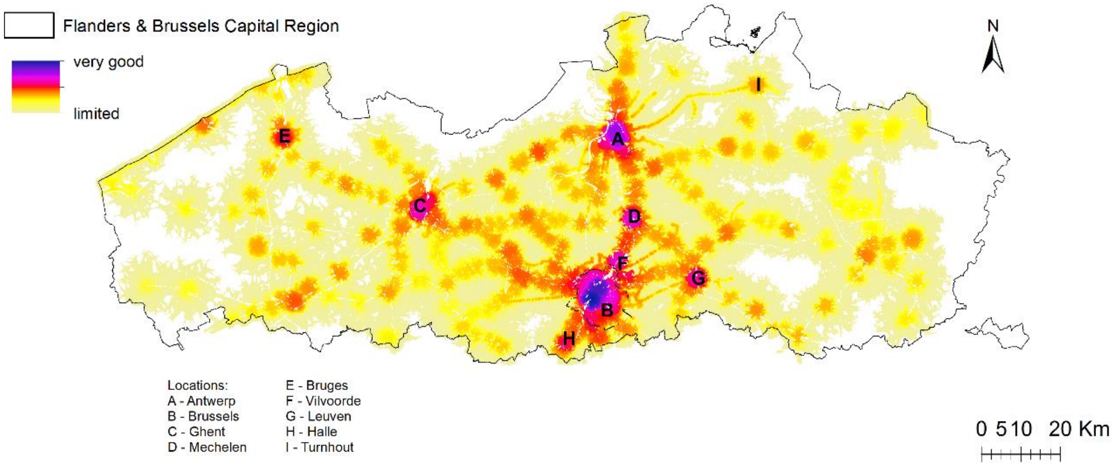
Table 2 gives a short overview of the accessibility scores, based on the composite indicator, for the different public transport networks in Flanders and the BCR. The transit scores vary between 1.17 and 9.00 with a median score of 3.64. Of the 3417 stops, 75% has a score lower than or equal to 4.27. Forty-five stops have a value of 6 or more. All Flemish stops in the latter group belong to three nodes (Antwerp-Central, Antwerp-Berchem and Mechelen station). The median and mean values are the highest for the tram/metro stops, that are mostly situated in the BCR, followed by the bus stops. Lowest median and mean values are found for the train stops. This is mainly due to the fact that only the main bus stops are included in the analysis, while all train stops, so including train stops that only serve smaller lines, are included.

*Table 2: Accessibility of public transport networks in Flanders and the Brussels-Capital Region (2015)*

| | Min. | 1st quartile | Median | Mean | 3rd quartile | Max. |
|---|---|---|---|---|---|---|
| ALL | 1.17 | 3.07 | 3.64 | 3.70 | 4.27 | 9.00 |
| Train | 1.17 | 2.76 | 3.23 | 3.46 | 3.96 | 9.00 |
| Tram, metro | 2.85 | 4.01 | 4.50 | 4.54 | 4.90 | 9.00 |
| Bus | 1.51 | 3.06 | 3.58 | 3.63 | 4.18 | 9.00 |

Figure 5 shows the result of the translation of the accessibility scores of the individual nodes to all cells of 1 hectare using the distance decay function presented in Figure 1. In general, the presence of a railway station with a high accessibility score is clearly visible as red to purple spots on the map. The locations in and surrounding Brussels, Antwerp, Ghent, Vilvoorde, Mechelen and Leuven have high scores. Also, Bruges and Halle perform well. By including the main bus stops, a number of locations in the neighbourhood of the latter stops score somewhat higher than locations outside their sphere of influence. An example is the axis between Antwerp and Turnhout. The bus stops are very close to one another hence show up as a thin red ribbon on the map. The choice to include the main bus stops only implies that some locations do not fall inside the influence sphere of any transit node. Those locations are illustrated in white on the map.

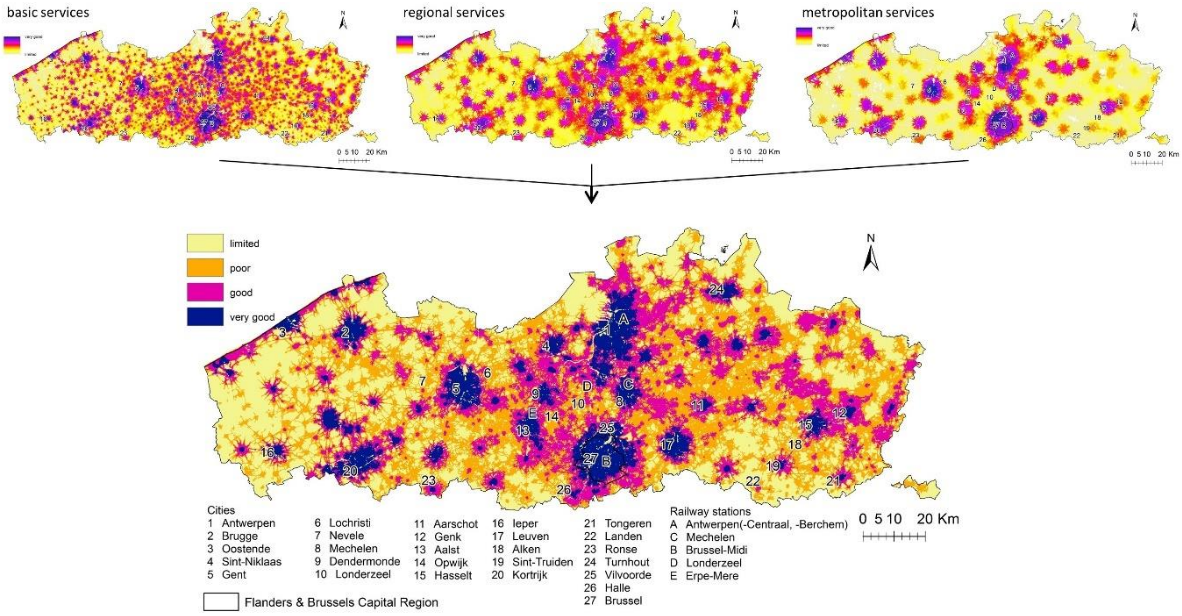
*Figure 5: Accessibility of public transport (2015)*




## 5.2 Accessibility of services

Flanders is well-served in terms of basic services (Figure 6, top - left) provided by a relatively dense network of small centres. Due to the distance decay with short travel times (7 minutes for the 'close' distance) applied for this category of services, the well-served areas do not extend far beyond the locations of the services. For regional services (secondary education, swimming pools, hospitals, larger shops, etc.), some 40 centres stand out, including the largest cities as well as the centres of smaller cities (Figure 6, top - middle). Because many metropolitan services are strongly concentrated, only about 20 centres show up with a high score for the accessibility of metropolitan services (Figure 6, top -right). As a result, major parts of the territory show up with very low to average accessibility of metropolitan services. These findings are in line with earlier studies on the hierarchy of settlements in Flanders (Loopmans et al., 2011; van Hecke, 1998). However, in line with Storme et al. (2015), the metropolitan services are not limited to the largest urban agglomerations, but due to the specific type of services (e.g. niche services such as museums, locations of pop festivals etc.), they can be found at specific locations throughout the region.

*Figure 6: total accessibility of services (bottom), classified in 4 classes, comprised by accessibility of basic services (top - left), regional services (top - middle) and metropolitan services (top - right)*




According to the bottom map of Figure 6 , depicting the total accessibility to services, Flanders' Metropolitan Core Area (MCA) attains high scores. This MCA comprises roughly the functional space between Brussels, Leuven, Antwerp and Ghent (Boussauw et al., 2018). Besides the large urban agglomerations in the MCA, all regional urban agglomerations according to Van Hecke's (1998) definition (Kortrijk, Bruges, Ostend, Sint-Niklaas, Mechelen, Leuven, Hasselt, Genk and Turnhout) are among the better served centres of Flanders and the BCR. The accessibility to services is limited near the Western, North-eastern and South-eastern borders of Flanders. This can be partly explained by the fact that services in the bordering regions outside Flanders and Brussels (Walloon region, the Netherlands and France) are not taken into account due to a lack of data. However, given the relatively low travel times assigned to the different categories of services and the fact that trips performed on foot or bicycle, the underestimation due to the omission of services in these regions is expected to be relatively small. Moreover, a study for the province of Antwerp shows that retail customer streams across the border are relatively small, even in the municipalities close to the border (Idea Consult et al., 2014).

## 5.3 Urban development potential

The urban development potential map (Figure 7) shows the combined score of the accessibility of public transport and of services for every 1-ha location in Flanders.

In the urban development potential map the MCA stands out again with many of the locations pertaining to category A (purple in Figure 7). This is certainly the case for Brussels, Antwerp, Ghent, Mechelen and Leuven, whose centres belong to the top of category A. Their suburbs as well as smaller urban centres score lower, but are still within category A. The more distant suburbs pertain to category C. At the given walking or bicycling distances, the effect of the high accessibility of public transport of the centre ceases, but, the suburbs can still benefit from good to very good accessibility of services. Beyond the MCA, the railway and bus lines radiating out of the central part of the region can be recognized easily. Thus, regional urban agglomerations stand out. They all have good accessibility of public transport and good to very good accessibility of services, hence pertain to category A, but except for Bruges, are not part of the absolute top.

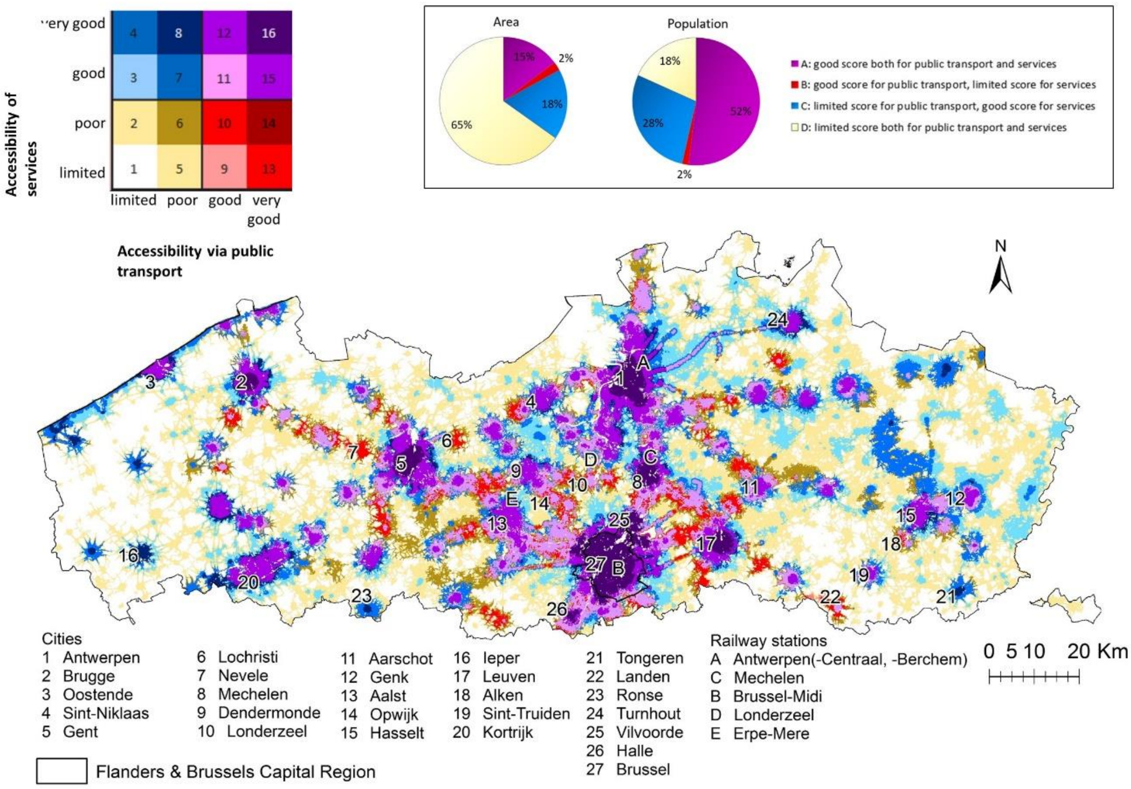
This category A generally corresponds to Bertolini's ideal-typical situation of a 'balance' where the node and place perform equally strong at the location (Figure 3). At the top of this category are 'stressed' areas in Bertolini's model. In these stressed areas, a further intensification or densification can easily create conflicts caused by the multiple claims on the limited space. However, a large number of studies already demonstrated that typical population densities in Flemish cities are quite low compared to the densities in other European urban regions (e.g. EEA & FOEN, 2016; Pisman et al., 2018) and most of the category A locations in Flanders still have room for further densification.

There are a limited number of locations with a good accessibility of public transport but limited service accessibility (category B, red in Figure 7), the so-called 'unsustained nodes' in Bertolini's Node-place model (Figure 3). These are areas in the proximity of railway station of smaller municipalities, or, suburbs of smaller centres. For the former, the centres have not generated sufficient accessibility of services in the course of time. The latter are within an acceptable walking or biking distance to the railway station but too far outside the town centres to benefit from its available services. Locations with a (very) good accessibility of public transport, but with limited service accessibility (types 13 and 14 in Figure 3) do not occur in Flanders. This is because railway stations with a high accessibility score were either originally located in bigger towns, hence coincided with good to very good service accessibility, or, were located in more remote locations, but, a well-serviced centre developed in their close vicinity in the course of history. They thus became part of category A.

Similarly, there are two types of locations with a high service accessibility, but limited public transport availability (category C, blue in Figure 7); the so-called 'unsustained place' in Bertolini's Node-place model. These are the suburbs of the larger towns discussed above and the centres of smaller towns, which are located on secondary lines or at the end of major lines and thus have a reduced offer of public transportation.

Large zones with both a limited access to public transport as services (category D, yellow in Figure 7) mainly exist in the more decentralized rural areas near borders, away from the dense centre of Flanders. The areas in white on the map have almost no access to public transport and/or services (by foot and/or bicycle). In the remainder of the discussion, they are considered to be part of category D.

*Figure 7: Urban development potential map of Flanders and Brussels-Capital Region, combining accessibility of public transport and of services. Inset top right: area and population for each quadrant.*




In total, 15% of the area of Flanders and the BCR belongs to category A, 2.2% to category B, 17.8% to category C and 65% to category D Figure 7, upper right corner, left chart). Thus, however Kompil et al. (2019) conclude that Belgium as a country has a high level of service accessibility, this is not equally spread over the (northern part of the) country since almost two thirds of the total territory has a limited offer of either services or public transport or both. Category B is very limited in spatial extent. Except for category B, the distribution of the population (Figure 7, upper right corner, right chart) strongly differs from the areal distribution. Almost half (52%) of the inhabitants of Flanders live in locations pertaining to category A, 28% to category C and 18% to category D. Thus, 18% of the population living on 65% of the territory depends largely on the car or lesser quality public transport for most of its travel to services found at larger distances.

Hence, with the aim to halt the expansion of settlement area in Flanders and concentrate new growth in areas with good public transport and services, the urban development potential map is a rich instrument as it enables to pinpoint areas requiring policy intervention to meet the given ambition. Indeed, category A locations are most desirable to accommodate the future growth as they have both the public transport and service accessibility required. Future urban development in category A locations, however, poses other policy challenges than providing access to public transport and services. Densification can have negative environmental impacts (such as urban heat islands, air pollution and noise), which in term can lead to negative health effects. These negative impacts can be partly counterbalanced by providing sufficient green spaces that deliver ecosystem services such as temperature regulation, water uptake, recreation, etc. (WHO, 2016). Also in Flanders, certain zones within category A are suffering from negative environmental impacts, such as increased air pollution (Lauwaet et al., 2018). Densification projects should therefore be implemented with caution bearing in mind the quality of urban living.

Because of these environmental and health challenges in the category A locations and since category A locations are not distributed evenly throughout Flanders, category B and category C locations can offer possibilities for future development. Verachtert et al. (2022) expect a growth of almost 300,000 households (10%) towards 2035. This expected growth is taking place in all regions within Flanders, including those regions that lack sufficient category A locations. In order to accommodate all these households, a selection of category B and category C locations could play a role. Category B locations are very few in total but would require to bring in services, which in many cases will have the undesirable effect of new land take, hence, the creation of more settlement area. Category C locations require an investment in expensive public (rail) transport, which will take time and space to develop. Therefore, other guiding spatial principles, such as safeguarding valuable open space and strengthening existing village centers, should be taken into account to select the best possible locations for urban development within the B and C category.

Further development of category D locations should be discouraged as they are deprived of both good public transport and services.

# 6 Conclusions and policy use

Decisions on land use are long term commitments which are difficult and costly to reverse. They should be taken with a proper prior analysis of the possible economic, social and environmental impacts. Planning support systems (PSS) are often used by decision makers involved in planning for evaluating the possible trade-offs between these different impacts (Geertman & Stillwell, 2009; Geertman et al., 2013). Although there are many key elements that are essential for making a successful PSS, such as the user-friendliness or the communicative value of the tool, the quality of the data and models that make up the content of the PSS are crucial for its adoption by and usefulness for spatial planners (Vonk & Geertman, 2008). This study generated a substantial amount of geographically detailed model output, combining the analysis of service accessibility, public transport and the presence of walking and cycling infrastructure. The resulting urban development potential map presents valuable information for decision makers in the spatial planning process. Not only do the resulting maps identify locations where accessibility is high and therefore suitable for (further) developments, the mapping at regional scale also gives insight in the less suitable or even unsuitable locations due to the low accessibility scores. This offers steering handles to formulate strategies and measures to guide urban development at suitable locations.

Transit-oriented spatial planning policy should go hand in hand with a mobility policy. An appropriate offer in public transport and walking/cycling traffic infrastructure is essential to gain all the advantages of living in well serviced urban centres. In particular in the areas with the highest urban development potential (good to very good accessibility of public transport and services) the capacity should be adapted to the planned and realized urban developments. But also the intensification of the usage of space in areas with a good to very good service accessibility but limited to low accessibility of public transport, should be combined with a vision on green mobility to lower the car dependency in these areas.

The urban development potential map as presented for Flanders has been calculated within a research project under the authority of the Environment Department of the Flemish government and published online in 2016. The method has been developed in close collaboration with the Environment Department and a number of other stakeholders who are responsible for policy making at the regional level. Van Delden et al. (2011) stress the importance of such a participatory approach when building PSS in order to bridge the science-policy gap. Although such a participatory approach may have some scientific pitfalls, such as a lacking theoretical or empirical justification for some of the parameters that are used, the results of this study have shown its value as a policy tool. The urban development potential map has been used in several PSS, applied at several scales, to formulate advice for spatial planning. At the regional scale, for example, the indicators underlying the analysis have been used to provide information and guidance to people who want to move and to raise their awareness of the transport (and associated environmental) implications of their residential choice (e.g. Van Den Bergh et al., 2018). The high resolution (1 hectare) of the map facilitates zooming in and identifying local 'hotspots' for development. In most European countries, including Belgium, three or more levels of administration have some sort of competence in spatial planning (Nadin et al., 2018). In Belgium, these three levels are the regions (Flanders, Wallonia, Brussels-Capital Region), provinces (NUTS2 regions) and municipalities. In such countries, with a distribution of competences among several levels, this full-scale, but yet high-resolution map allows to bridge the gap between the different levels. In Flanders, for example, the map has been used at the municipal scale to support the making of spatial implementation plans ('Ruimtelijke UitvoeringsPlannen' or RUP) that are the Flemish instrument for changing zoning designations. In these spatial implementation plans, the urban development potential map is often used as one of the spatial criteria to assign new housing or mixed areas. Other examples of PSS developed by planning bureaus -derived from the development potential map and used at the local level are the StationsRadar (UGent, 2019, Caset, 2019) and the Kernenkompas (BUUR, 2020).

Using the urban development potential map at the municipal scale or local scale does require a careful interpretation. The map needs to be related to the existing land use and local spatial dynamics. Moreover, spatial policy plans often present policymakers with a larger set of principles to guide future urban development: principles about the value of open space, about energy-efficiency, etc. Therefore, projects or plans at such scale are always tailormade. But they can benefit from the urban development potential map as a starting point.

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