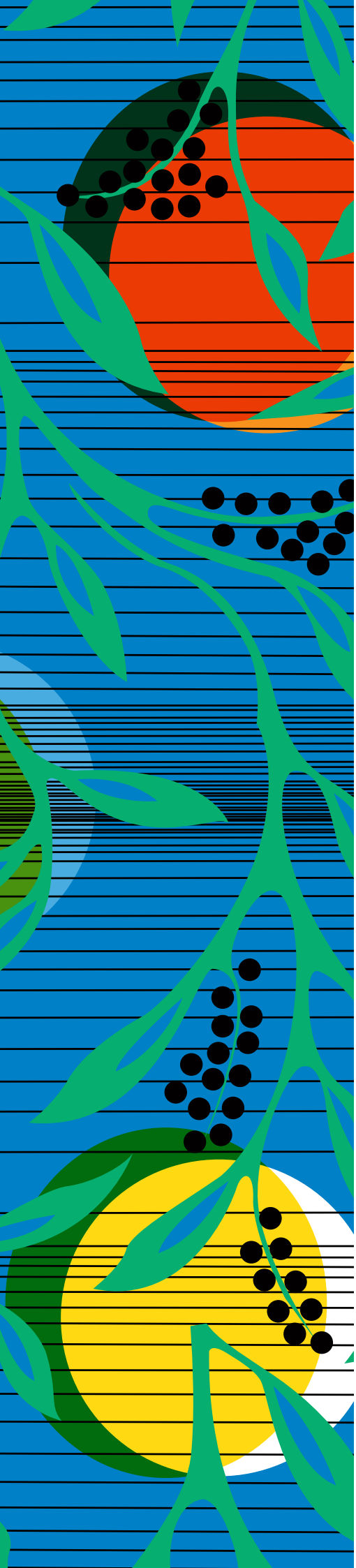

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CITIES AND SPATIAL INTERACTIONS IN WEST AFRICA

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March 2017 **No. 05**

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CITIES AND SPATIAL INTERACTIONS IN WEST AFRICA:

A CLUSTERING ANALYSIS OF THE LOCAL INTERACTIONS OF URBAN AGGLOMERATIONS

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The West African Papers series is designed to share studies with a wide audience of specialists, practitioners, decision-makers and the informed public. The series explores the nature, dynamics and characteristics of African social, economic and political transformations from a regional and multidisciplinary perspective. It seeks to stimulate discussion and gather information to better anticipate the changes that will shape future policies. Papers are available in English and/or French, and summaries are available in both languages. Initiated by the Sahel and West Africa Club (SWAC) to highlight and promote West African issues, the work presented is prepared by its Secretariat, Members and partners; other OECD departments; related international organisations; and associated experts.

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ABSTRACT

Over the past 60 years, urbanisation and cities have fundamentally transformed the social, economic and political geography of West Africa. The number of people living in cities increased from 5 million in 1950 to 133 million in 2010. During the same period, the number of towns and cities with more than 10 000 inhabitants grew from 159 to close to 2 000. A large majority of these agglomerations are secondary cities and small towns that act as hubs and catalysts for local and regional production and supply chains, as well as for the transfer of goods, people and information, linking the local and regional economies to the global economy. The intensity of the spatial interactions of cities has strongly increased with population growth, urbanisation and higher urban density. This paper, part of ongoing work within the Sahel and West Africa Club Secretariat to integrate urbanisation and city growth into analyses of major trends in the region, lays the foundation for the development of a systematic method to capture and describe these spatial interactions. It does so by examining four variables: *city size, market potential, urbanisation level and local dominance*. These variables, in turn, help to define seven different city groups that can be used to classify West African agglomerations. The initial results of this work reveal the diversity and distinctive behaviours of cities in the region, providing a new perspective on urbanisation dynamics and the influence of spatial variables on urban growth rates, the emergence of new agglomerations and the clustering of cities.

Keywords: secondary towns, urbanisation, mega cities, metropolitan areas, West Africa
JEL classification: C31, C38, J11, R12, R58

RÉSUMÉ

Au cours des 60 dernières années, l'urbanisation et les villes ont fondamentalement transformé la géographie sociale, économique et politique de l'Afrique de l'Ouest. Le nombre d'urbains est passé de 5 millions en 1950 à 133 en 2010. Au cours de cette période, le nombre de villes de plus de 10 000 habitants a crû de 159 à 2 000. Ces villes, à grande majorité secondaires et petites, sont des nœuds et des catalyseurs aussi bien des chaînes de production et d'approvisionnement locales et régionales, que des mouvements de biens, personnes et informations. Elles lient les économies locales et régionales à l'économie mondiale. L'intensité des interactions spatiales des villes a fortement augmenté avec la croissance démographique, l'urbanisation et la densité urbaine. Ce papier participe aux travaux plus vastes du Secrétariat du Club du Sahel et de l'Afrique de l'Ouest/OCDE visant à intégrer les dimensions urbanisation et démographie dans les analyses des transformations de la région. Il propose une méthode systématique pour saisir et décrire les interactions spatiales à travers quatre variables - *taille de la ville, potentiel de marché, niveau d'urbanisation et dominance locale*. Sept groupements urbains sont ainsi obtenus pour la région. Les premiers résultats révèlent la diversité et les comportements spécifiques des villes, apportant un regard nouveau sur la dynamique d'urbanisation et l'influence des variables spatiales sur les taux de croissance urbaine, l'émergence de nouvelles agglomérations et le regroupement des villes.

Mots clés : villes secondaires, urbanisation, mégapoles, régions métropolitaines, Afrique de l'Ouest
Classification JEL : C31, C38, J11, R12, R58

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EXECUTIVE SUMMARY

Over the past 60 years urbanisation and cities have fundamentally transformed the social, economic and political geography of West Africa. The number of people living in cities increased from 5 million in 1950 to 133 million in 2010. During the same period the number of towns and cities with more than 10 000 inhabitants grew from 159 to close to 2 000, the large majority of which are secondary cities and small towns. These secondary cities act as hubs and catalysts for local and regional production and supply chains, and the transfer of goods, people and information, linking the local and regional economies to the global economy.

Cities are not isolated points of observation; they are linked to their surrounding regions and to each other through flows of information, people and goods. The intensity of these spatial interactions has strongly increased with urbanisation and higher urban density. Regional features and network interactions increasingly influence the characteristics and functions of cities and these attributes cannot be captured by city size alone. The spatial analysis developed in this paper is a first attempt to develop a systematic way of capturing the regional interactions that define cities and impact city growth and urbanisation.

Four variables, taking into consideration regional and local metrics, were constructed to integrate spatial interactions into a quantitative analysis of cities. The four variables - *city size, market potential, urbanisation level and local dominance* - include population-based variables, distance-based variables and the interaction between both. In a first step, the variables were used to inform and compare the profiles of each of the 1 939 identified urban agglomerations above 10 000 inhabitants in Africapolis (Moriconi-Ebrard, Harre and Heinrigs, 2016), highlighting the large variations in regional and local variables across the city size gradient, but also across cities with similar sizes. In a second step, a clustering algorithm was carried out to identify frequently repeating patterns across the 1 939 agglomerations and to group cities based on their profile. The clustering procedure provides two results: first, it classifies every agglomeration into the group that has the highest degree of similarity and second, it provides a definition of an average city profile for each of the seven groups identified. The analysis reveals the diversity and distinctive behaviour of cities. The results provide unique descriptions of urbanisation dynamics in West Africa, offering insights into the influence of spatial variables on urban growth rates, the emergence of new agglomerations and the clustering of cities.

The reality is of course more complex and more diverse than that captured in this analysis. There is a need and a huge potential to further refine the analysis by integrating more detailed information. Much of this will depend on the availability of more reliable data. African urban growth will continue for decades to come and a better understanding of the spatial and economic transformations that are inherent to this process will be crucial to inform the planning challenges faced by governments.

CITIES AND THE SHAPING OF HUMAN AND ECONOMIC GEOGRAPHY

The pace of urbanisation in West Africa has been spectacular. The number of people living in cities increased from 5 million in 1950 to 133 million in 2010 (Map 1.). The urban population increased by 50 million people between 2000 and 2010 alone, similar to adding the equivalent of four times the population of Dakar each year (OECD, 2016). In 2010, 41% of West Africans lived in an urban agglomeration, compared to only 9% in 1950. The same urban transformation took a century to achieve in the United States, where the level of urbanisation increased from 7% in 1810 to 42% in 1910, and almost three centuries (1600-1880) in Europe (Bairoch and Goertz, 1986). And yet, time is crucial. Time to plan, finance and build the physical infrastructure of towns and cities, time to develop the skills adapted to urban activities and to develop new institutions and services (Jacobs, 1969). In short, time to operate the rural-urban transition, or "urbanisation... the most fundamental change that has ever occurred in the lives of the mass of the people" (Encyclopaedia Britannica, 1929).

In 1990, *The West Africa Long-Term Perspective Study* launched a ground-breaking reflection on the interlocking factors of population, urbanisation, market dynamics, and social and political change (Cour and Snrech, 1999). This work led to the development of a programme on local economies (OECD/SWAC, 2002) that highlighted the crucial role of secondary cities in local economic development and the need to integrate urban and rural areas into one integrated and spatial analysis. Building on these foundations, the work carried out by the Sahel and West Africa Club in 2011-12 on the links between settlement, markets and food security (OECD, 2013), further confirmed the central role of urban agglomerations of all sizes in stimulating agricultural transformations and developing the food economy (Allen and Heinrigs, 2016). All of these analyses, however, have faced the same problem: a lack of urban statistics. The completion of the first homogenous geospatial database on urban agglomerations in West Africa in 2008, funded by the *Agence Française de Développement* and the *Agence Nationale de Recherche* (AFD, 2008), was a major step forward as was its update in 2015 (Moriconi-Ebrard, Harre and Heinrigs, 2016).

Although there is growing interest in African cities, the urbanisation discourse tends to be limited to the aggregate level, looking at the overall rate of urbanisation and focusing on the continent's mega-cities (Christiaensen and Kanbur, 2016). Little policy attention is given to the thousands of secondary cities and small towns, their number and location, their spatial interactions and their connectivity to the network of cities.

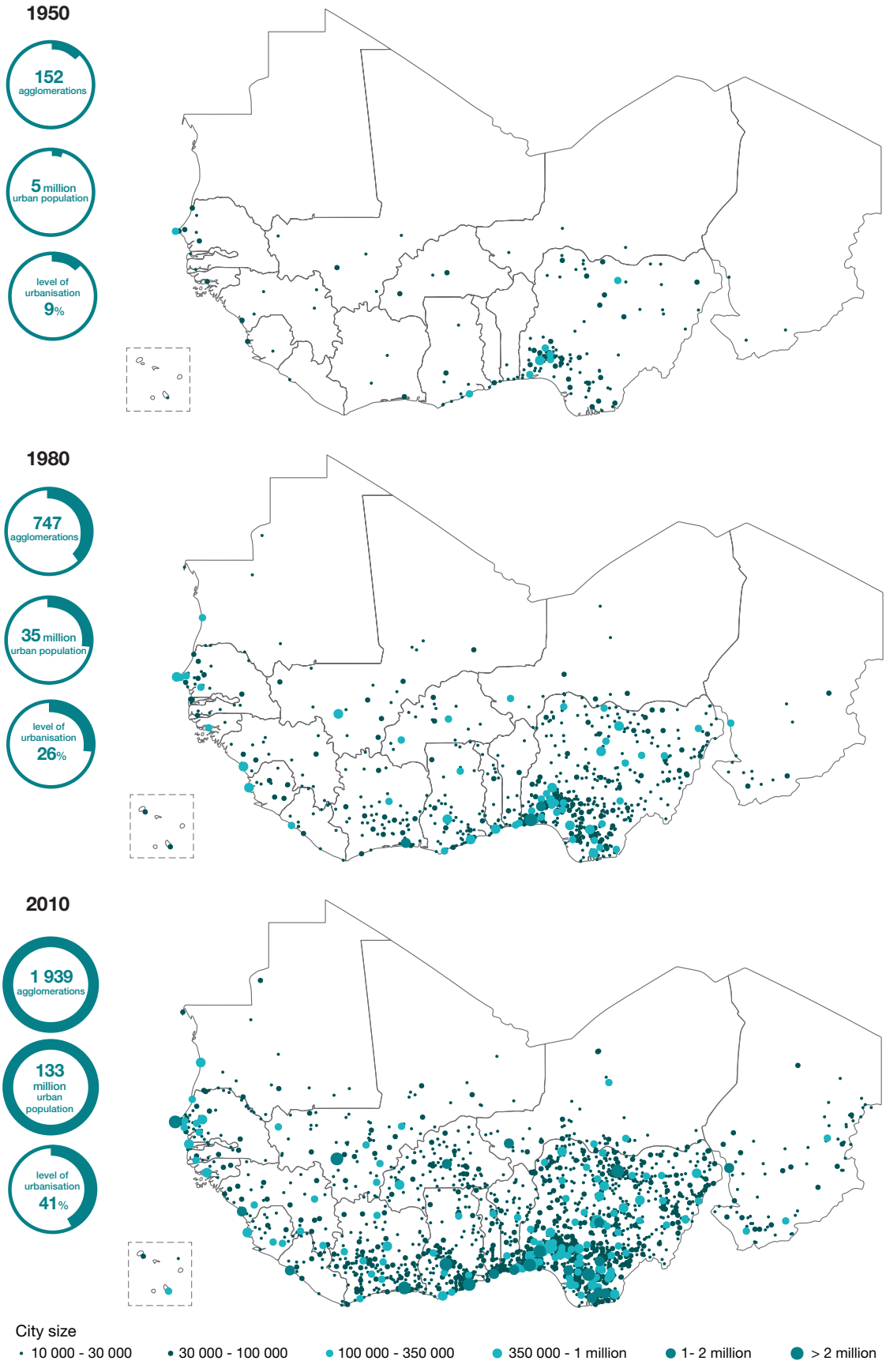
CITIES, NETWORK OF CITIES AND SPATIAL INTERACTIONS

One major feature of the urbanisation dynamic in West Africa is the constant emergence of new towns and cities. In 1950, the region had 152 urban agglomerations with more than 10 000 inhabitants. By 2010, this had grown into a dense urban network[1] of close to 2 000 towns and cities (Moriconi-Ebrard, Harre and Heinrigs, 2016) (Map 1). This network is composed of towns and cities of very different size, ranging from 10 000 inhabitants to 10.4 million (Lagos), in different locations with different functions and different levels of connectivity.

The function of a city depends on its place within the network of cities, its interactions across the network and with its surrounding region. The functions of primary cities[2] are largely determined by size. The largest urban centres are globally well connected through flows of information, people, goods and finance, and act as hubs between national economies and the global economy. However, for the large majority of cities, characteristics and functions are defined regardless of size (Roberts and Hohmann, 2014; Walther, 2008). Functions, such as public administration and government services, education and health services, and economic activities are shaped by the positioning of a city within the national

Map 1

Emergence of a network of cities in West Africa 1950, 1980 and 2010



Source: OECD 2015

and regional urban system, by economic geography and other spatial, administrative and political features. Hence, the function of a city, which also defines its attractiveness, depends as much on the city itself as on the attractiveness of the cities within the urban network and its proximity to other cities. This relationship is not unidimensional; proximity to a more 'attractive' city can have positive as well as negative spill-over effects. In the context of agglomeration economies, proximity to nearby larger cities positively affects the productivity of a city, implying that cities benefit from the agglomeration economies of their neighbours (OECD, 2015).

Two main drivers have massively increased the intensity of spatial interactions of cities: density and distance (World Bank, 2009). Between 1950 and 2010 the region's population increased from 72 million to 323 million. This strong increase in population size, besides driving the urbanisation process, has also led to an increase in rural population, from 66 million to 172 million, and in rural density. Yet, the increase in rural density has been very uneven across the region – rural densities have increased most significantly in proximity to cities (OECD, 1998; OECD, 2013). This correlation between rural and urban settlements highlights the spatial interactions and dynamic relationship between the two environments. In 2010, 88% of the rural population lived within 40 kilometres of an urban agglomeration, reducing the distance between urban and rural populations.

Distances between cities have also dropped. The emergence of new cities has cut the average distance[3] between them from 71 kilometres in 1950 to 22 kilometres in 2010. The greater proximity between cities and between urban and rural populations also reveals the intensity of interactions. 'Market potential' or market attractiveness, often measured as the total population living within a given distance, can provide a measure of the spatial variations in the intensity of potential interactions. These interactions also depend on a variety of other variables, such as accessibility and geography, economic size and diversity, administrative status and position of the agglomeration within the urban network (Cour and Snrech, 1999).

Clearer and more complete metrics can help to detect and differentiate between emerging patterns of agglomerations, their growth and interactions across the region. The complex networks of agglomerations, markets and human mobility patterns are influenced by local and regional dynamics that should be integrated in analyses of West African cities.

CITY SIZE, MARKET POTENTIAL, URBANISATION LEVEL AND LOCAL DOMINANCE

With urbanisation and higher urban density, regional features and network interactions increasingly influence the characteristics of cities. To integrate these into a quantitative analysis of cities, four variables were constructed, taking into consideration regional and local metrics. The four variables - *city size, market potential, urbanisation level and local dominance* - include population-based variables, distance-based variables and the interaction between both. To maintain a balance between local and regional metrics, two variables capture local features (city size and local dominance) and two variables (market potential and urbanisation level) take into consideration regional features. With these four variables it is possible to build upon and distinguish between the different profiles of the 1 939 identified West African urban agglomerations.

An important feature of regional variables is that they have a smooth spatial transition, meaning their values change little over small distances. One example of this type of variable is mean temperature which tends to be very similar for two cities located within a short distance from each other. Local variables on the other hand might not have a smooth spatial transition from one place to another, such as the population of a city.

Table 1
Local and regional features informed by variables

	City size	Market potential	Urbanisation level	Local dominance
Local features	X			X
Regional features		X	X	

The region which surrounds a city is defined here as a distance of 40 kilometres from the centre of the agglomeration (i.e. a radial buffer with a 40 km radius equal to an area of 5 026 km2).[4] The size of the region is kept constant for all cities. In reality, the 'catchment area' or 'hinterland' of a city is influenced by its size and variables such as geography and the ease, speed, and cost of transportation. In gravity models, like Reilly's law, the influence of a city on its region is proportional to its size and inversely proportional to the distance between them. However, since the focus of this analysis is to inform the profile of each agglomeration and to capture the influence of variables beyond city size, integrating an additional variable that depends on city size would further increase the impact of city size on the results. Given that 92% of all urban agglomerations in West Africa have less than 100 000 inhabitants, adding more gravity-related variables would result in further differentiating the largest cities without significantly affecting the results for the vast majority of agglomerations. The distance of 40 kilometres was chosen for three reasons. First, larger distances tend to 'smooth over' spatial attributes. For example, market potential would provide the same values for Lagos and Ibadan when there is a strong difference between both cities. Smaller distances, on the other hand, tend to ignore any regional behaviour. Therefore, a radius of 40 kilometres captures the regional behaviour of cities without flattening their individual attributes. Second, it can be considered that the population living within this distance has reasonable access in terms of travel cost and time to facilities such as health clinics, markets or ports. The third reason relates to the intensity of economic spill-over effects from urban economies. Although economic spill-over effects are measurable over longer distances for large urban centres[5] (OECD, 2015), the effects are much stronger over shorter distances, and in the case of smaller cities these effects can only be measured within a short distance.

The four variables in this analysis were carefully constructed to consider data availability, comparability and data biases. There is a natural constraint in the type of data available, its reliability, its periodicity and its level of geographic resolution. In general, very little data is available on African cities. The situation is better for the continent's large cities, but this is rarely the case for secondary cities and is almost non-existent for the smallest agglomerations. Thus, comparing objects that vary in size as much as agglomerations creates a strong bias towards large cities, beginning with the data itself.[6] The metrics constructed in this analysis are, therefore, based on only two data sources which allow for a geospatial regional analysis of urban agglomerations in West Africa. However, they should be interpreted as proxy for a more complex reality and should be further refined once more detailed and reliable geospatial information becomes available.

The data on urban agglomerations is from the Africapolis database (OECD, 2016), the only existing geospatial database that uses one homogenous definition for urban for all countries in West Africa and that covers all 1 939 agglomerations above 10 000 inhabitants. Beyond population-based variables, the spatial co-ordinates also allow for measuring distance-based variables, that is, the regional attributes and spatial attributes of an agglomeration. The Africapolis definition of urban agglomerations is based on two criteria, land use and population:

1. An agglomeration is a continuously built-up and developed area, with less than 200 metres between two buildings.

2. An agglomeration is considered urban if it has a minimum of 10 000 agglomerated inhabitants.

In addition, the LandScan Global Population Database[7] is used to calculate non-agglomerated population. LandScan provides spatial population estimates for all surveyed countries at a resolution of one square kilometre.

City size

The city size variable corresponds to the number of inhabitants of an agglomeration in 2010. In general, city population variables are highly skewed, meaning in this case that almost 90% of the agglomerations had fewer than 75 000 inhabitants and more than 50% of the agglomerations in West Africa had fewer than 20 000 inhabitants in 2010 (Figure 1). Therefore, city size is transformed in logarithm base 10 to reduce the weight of cities with the largest population.[8] City size is expressed as S_i for the i-th city where P_i is the population of the i-th city, then:

$$S_i = log\ P_i.$$

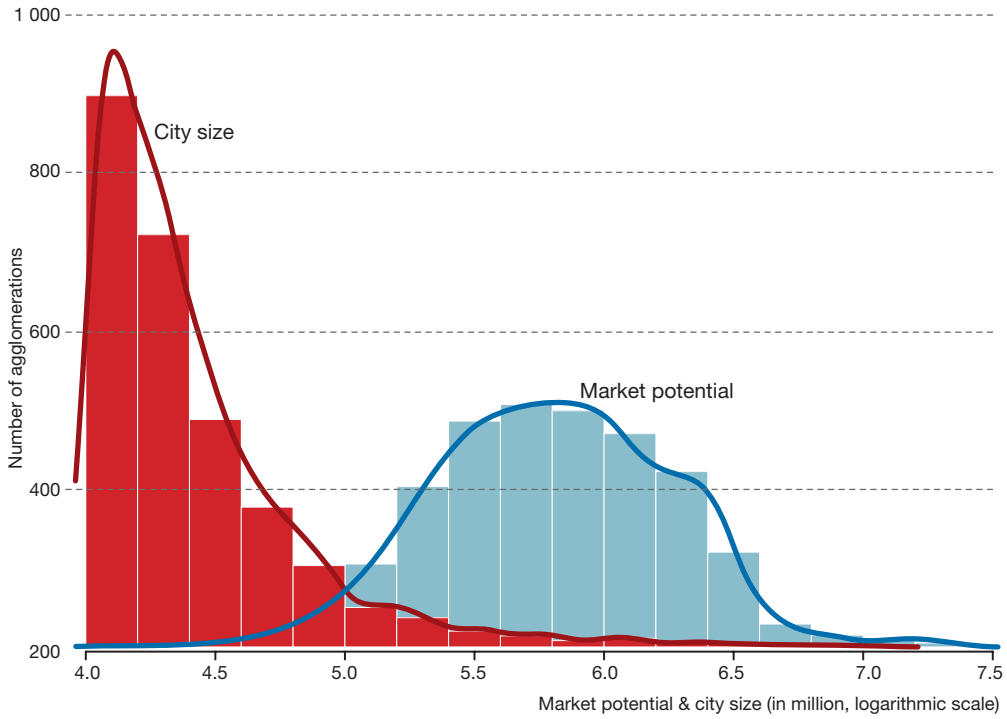
A number of urban characteristics, such as the availability of public services and amenities, economic density and diversity, and connectivity are closely related to city size. In particular, cities at the top of the urban hierarchy, national capitals and large urban centres, will benefit from their size in terms of political and financial power, infrastructure provision and regional and international connectivity. However, this relationship is much weaker further down the urban hierarchy. Differences between agglomerations of say 100 000 and 200 000 inhabitants are more difficult to see with city size.

Market potential

Market potential is a regional variable based on the total population of the region. The region is defined as a radial buffer with a 40 km radius around the centre of the agglomeration. The regional population R_i includes the population of the i-th agglomeration, P_i, the population of other urban agglomerations in the 40 km buffer and the rural, or non-agglomerated, population in the region. The market potential variable is also highly skewed, therefore, it is transformed in logarithm base 10 of the regional population. Formally, for the i-th agglomeration, we consider its regional population R_i and we define its market potential, expressed as M_i, as :

$$M_i = log\ R_i.$$

Figure 1
Distribution of the city size and market potential variables of West African agglomerations



Source: OECD 2015, LandScan and authors' calculations

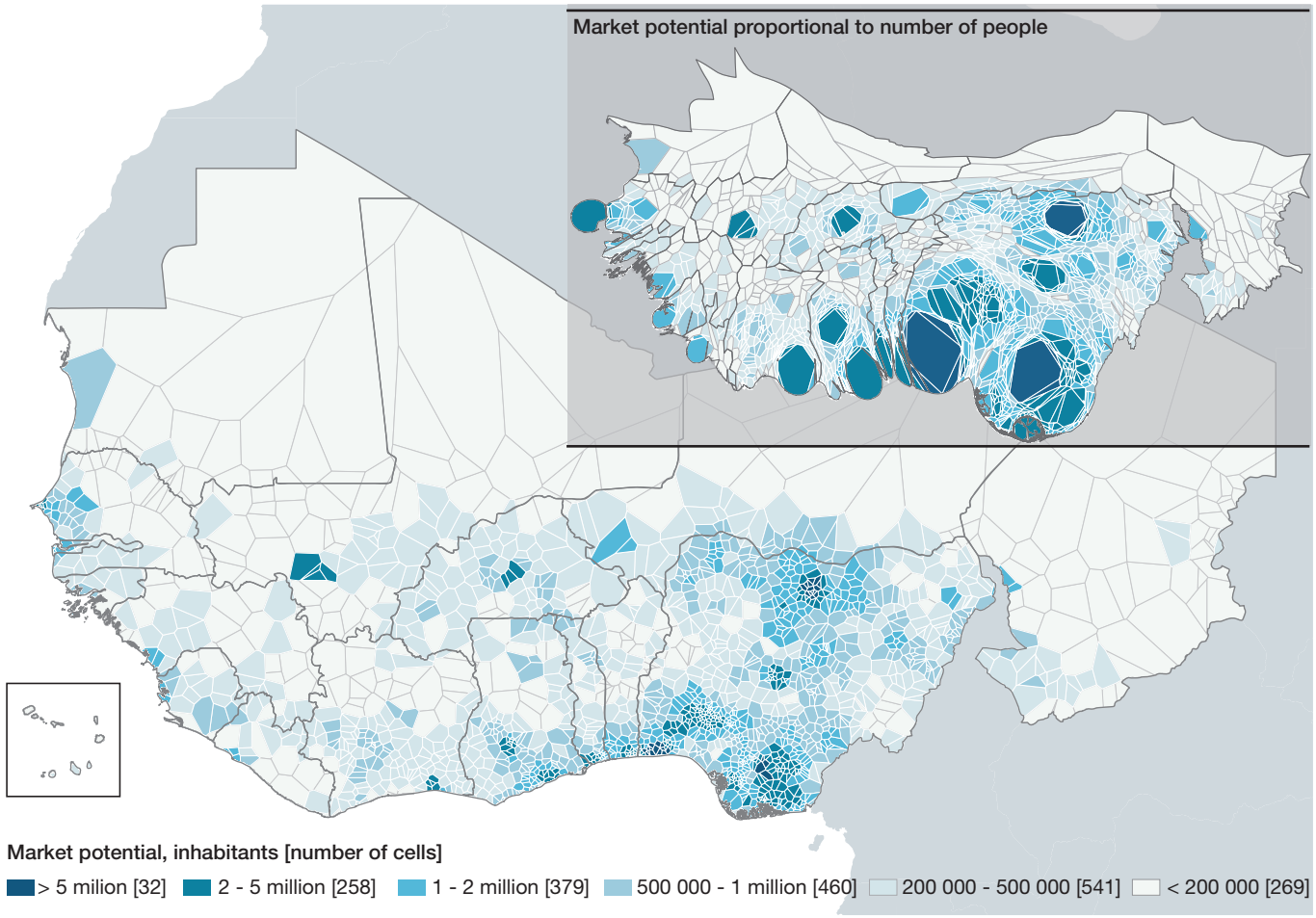
Values for market potential (M_i) have a range from just above 10 000 inhabitants, observed for a few highly isolated agglomerations in Chad and Mali, to nearly 16 million for Lagos. The average value for market potential is 630 000 people (Figure 1). Fifteen per cent of West Africa's agglomerations (290 agglomerations) have a market potential above 2 million people. Yet, only 70 agglomerations (3.6%), mostly distributed in Chad and Mauritania, have a market potential of less than 100 000 people.

The market potential variable is used to provide an estimate for potential interactions between an agglomeration and its surrounding area. The population size of a region is a good measure for spatial variations in economic density in terms of size, diversity and potential markets and can be interpreted to determine the economic attractiveness of the region (OECD, 2015; OECD, 1998; West, 2015; Rich, 1978). The market potential variable also provides an indication of the intensity of potential interactions within a region. In denser regions with higher market potential, the intensity of interactions are greater and the spill-over effects of agglomeration economies to surrounding regions stronger (OECD, 1998). In addition, high market potential is associated with greater availability and accessibility to services and facilities generally associated with larger city size, such as hospitals, schools or universities. However, the reality is more complex and market size and economic attractiveness also depend on a variety of features such as availability of infrastructures, accessibility in terms of time and cost, the extent of economic and social networks often established over decades, and the existence and quality of regulations and trade agreements which are not captured (OECD, 2017). Therefore, the way that market potential is measured here is just a proxy for a more complex reality which is difficult to measure given the available data.

An agglomeration that is located in a region with a high market potential of two million people, for instance, implies that it is a large city or is in close proximity to a large city. Out of the 1 939 agglomerations, 290 agglomerations have a market potential above two million people, however only nine agglomerations have a city size above two million inhabitants. In these cases, regardless of the size of the agglomeration, a high market potential is associated with greater accessibility to services and facilities and greater economic attractiveness. On the contrary, a low market potential implies that the agglomeration suffers from isolation with lower access to facilities and services.

Map 2

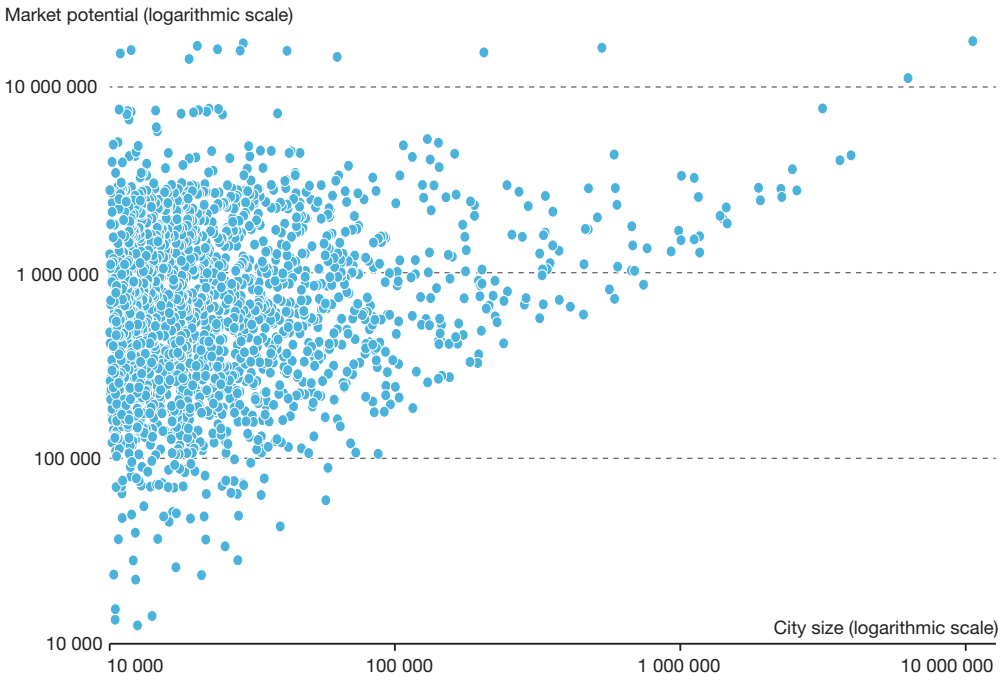
Market potential in West Africa, per Voronoi cell for each agglomeration[9], 2010



Source: OECD 2015, LandScan and authors' calculations

In addition, the market potential measure provides a spatial smoothing from city size meaning that an agglomeration with a high market potential is also surrounded by agglomerations with high market potential (Map 2). For example, Sokomey, a small town in southern Benin with a population of 30 000 inhabitants is located within 10 kilometres of Porto Novo with 400 000 inhabitants, and both have the same market potential value with a regional population of nearly 2.8 million inhabitants. This also shows that market potential and city size capture different attributes of an agglomeration and are independent of one another. The correlation between the two variables is only 0.2 (Figure 2). However, when an agglomeration's city size is large, its market potential cannot be small.

Figure 2
City size and market potential, distribution in 2010



Source: OECD 2015, LandScan and authors' calculations

Urbanisation level

The urbanisation level is the ratio between the urban population and the total population in the region. Formally, let Q_j be the population of all agglomerations located within 40 kilometres of the i-th city, with j between 1 and *n*, where *n* is the number of neighbouring agglomerations and consider the total regional population R_i as defined in market potential. Since the regional population from the region R_i includes the population from the i-th city (P_i) and the population from neighbouring agglomerations (Q_j), then the remaining population is the non-agglomerated rural population in the region. The variable U_i then is a ratio between 0 and 1, where numbers close to zero indicate a low urbanisation level and numbers close to 1 a high urbanisation level. Thus, the urbanisation level U_i is computed as:

$$U_i = \frac{P_i + \sum_{j=1}^{n} Q_j}{R_i}.$$

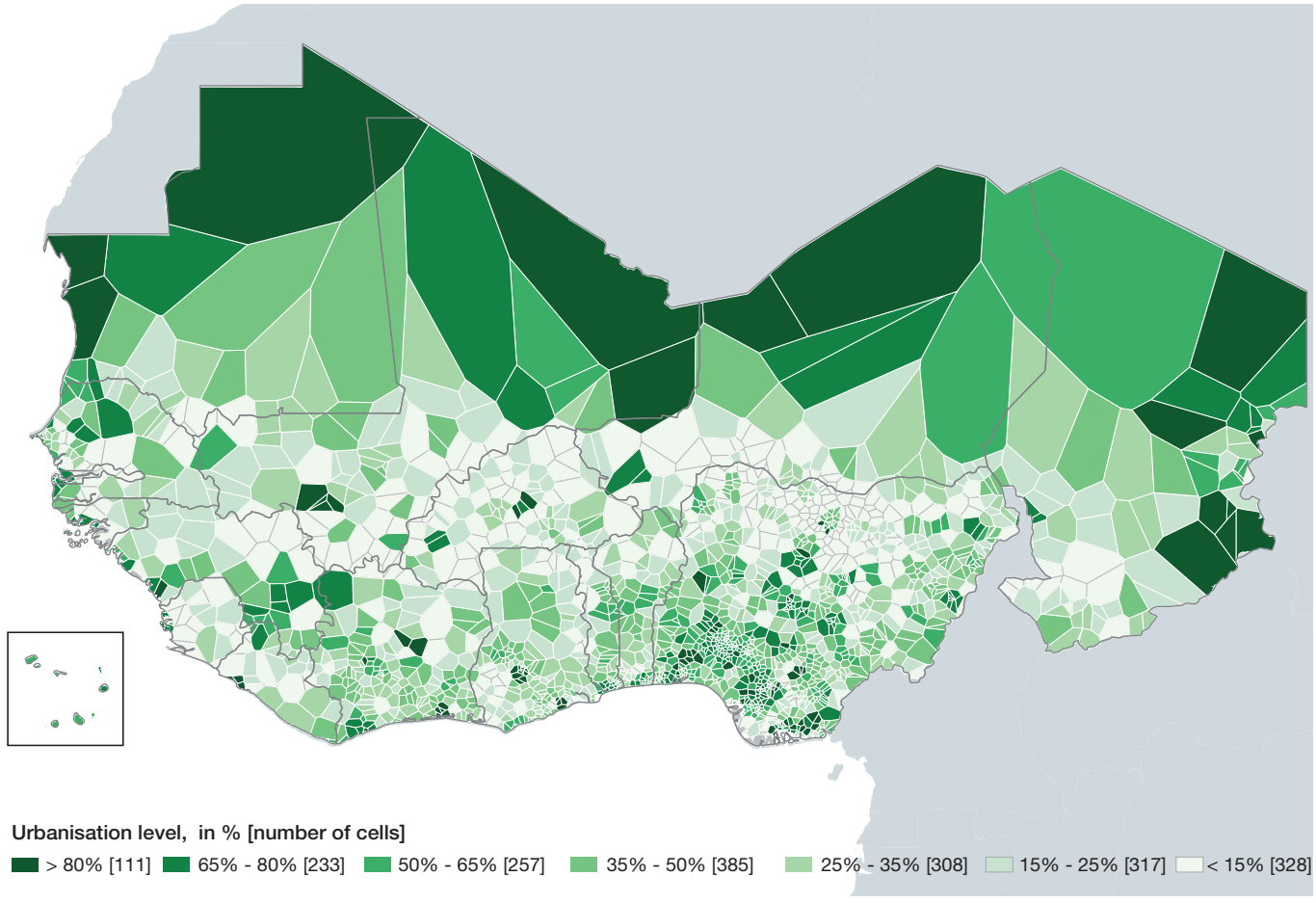
The urbanisation level is a regional variable and differentiates between regions of high urban density and low urban density. Independent of city size, lower levels of urbanisation are present in regions with a higher share of rural population and therefore a greater share of economic activities linked to agriculture. It thus identifies regions with high shares of rural population, for example, southern Côte d'Ivoire and Ghana, southern Niger and northern Nigeria (Map 3). A high level of urbanisation is associated with less agricultural-based local economies.

However, high urbanisation levels are observed in two different scenarios. First, a high urbanisation level might be the result of high urban population density in regions with a dense and developed urban network. These regions are likely to have more diversified urban-based local economies with higher shares of industry and service activities and are

likely to be better connected to the urban network. This is the case, for example, of Kati (Mali), with a level of urbanisation of 0.96, indicating that 96% of its market potential - of 2.5 million inhabitants live in an urban agglomeration, of which only 5% in live Kati itself and the remaining 95% live in Bamako.

Second, a high level of urbanisation might also be the result of very low rural population densities, like in the desert regions of Sahelian countries (Map 3). For example Kidal in northeast Mali with 30 000 inhabitants, has a level of urbanisation close to one. In such cases a high level of urbanisation reflects a high degree of isolation rather than a high urban density.

Map 3
Urbanisation level in West Africa, 2010



Source: OECD 2015, LandScan and authors' calculations

The average value for urbanisation level is 0.4. Six hundred and one agglomerations (31% of all agglomerations) have an urbanisation level above 0.5, of which 111 agglomerations (6%) have a high level of urbanisation of 0.80 or above. These 111 agglomerations account for 20% of the total urban population. On the opposite end of the distribution, 328 agglomerations have an urbanisation level below 0.15, these agglomerations account for only 5% of the total urban population.

Local dominance

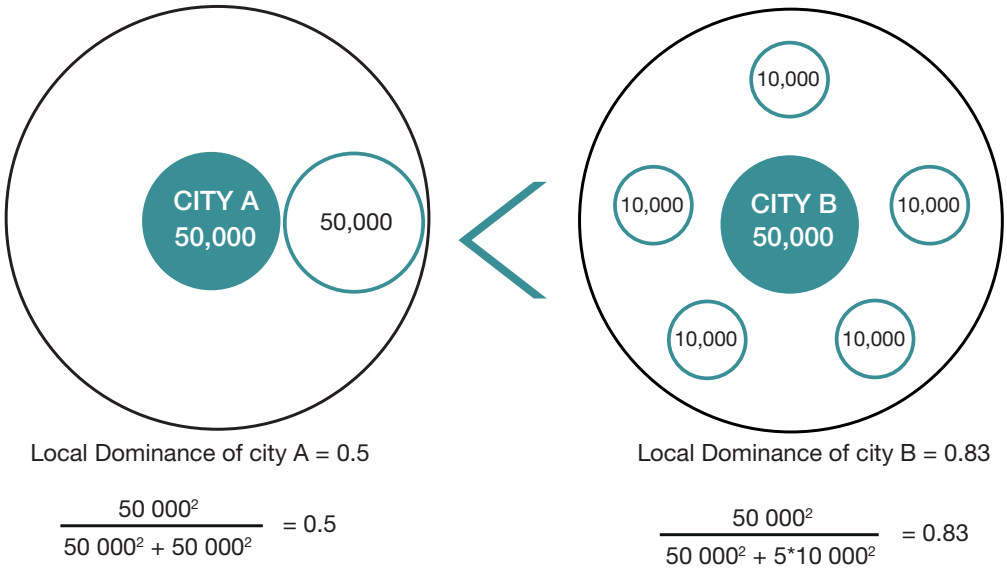
Local dominance is a measure of the size of an agglomeration relative to the size of other agglomerations in its region. It thus captures the quantitative and qualitative differences of an agglomeration's position and interactions within its region. Formally, let Q_j be the population of the agglomerations located within 40 kilometres of the i-th city, with j between 1 and n, where n is the number of neighbouring agglomerations (that is, the agglomerations which belong to the i-th region) and let P_i be the population of the agglomeration. Then, the local dominance D_i is given by:

$$D_i = \frac{P_i^2}{P_i^2 + \sum_{j=1}^{n} Q_j^2}.$$

Local dominance (D_i) is a ratio between 0 and 1, with a value closer to zero meaning that the agglomeration belongs to a region in which there are other, much larger agglomerations, and a value closer to one meaning that the agglomeration is the largest in its region. However, local dominance is an attribute of the agglomeration and not the region since its value can change with each agglomeration even when they are close to each other.

The squared terms P_i and Q_j are needed to help differentiate between two different scenarios (Figure 3). Consider two cities A and B, both with 50 000 inhabitants. In the region of the city A, there is another city with the same population of 50 000 inhabitants, whereas in the region of the city B there are five cities which have 10 000 inhabitants each. A simple ratio, without the squared terms would give the same result for both cities A and B, 0.5. The square of the population sizes, P_i^2 and Q_j^2, provides weights (the population itself) and helps distinguish between the two scenarios.

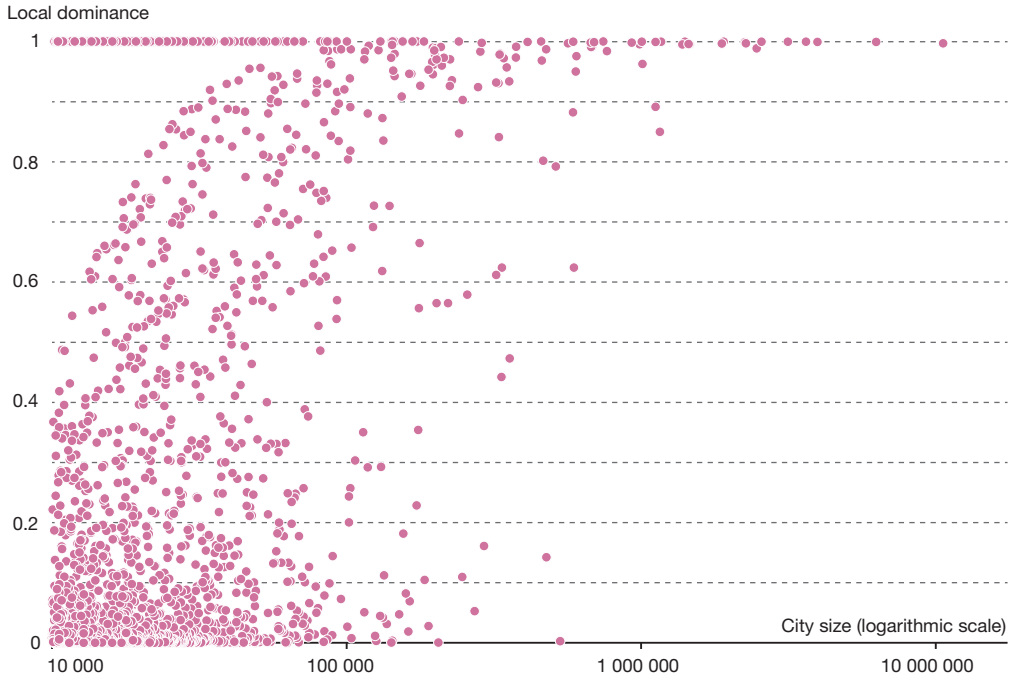
Figure 3
The measurement of local dominance



An agglomeration with high local dominance acts as the main centre of attraction for the region. For example, city B in Figure 3 is five times bigger than any other agglomeration in its region and is likely to 'dominate' in terms of economic, social and political relevance.

Agglomerations with low local dominance are distinguishable because they are surrounded by larger urban agglomerations which are likely to act as the pole of attraction of the region. Some of the smallest agglomerations with a population of 10 000 inhabitants have a local dominance of 1, indicating that they are the only agglomerations in their respective regions, while other, larger cities have a small local dominance as they are surrounded by even larger cities (Figure 4). For example, Ikorodu, located 20 kilometres east of Lagos, with a population of 530 000 inhabitants in 2010, has a local dominance of 0.003. A similar-sized city located in almost any other country in West Africa, would be the second largest city in most of the other countries in West Africa.

Figure 4
City size and local dominance in West Africa, 2010



Source: OECD 2015, authors' calculation

Overall, 313 agglomerations have a local dominance of over 0.9, of which 210 agglomerations have a local dominance of one. Of the 210 agglomerations with a local dominance of 1, 174 have less than 50 000 inhabitants. However, 848 agglomerations (45% of the total) have a very low local dominance of less than 0.05, indicating that a large share of agglomerations are located in a region with at least one mid-sized city.

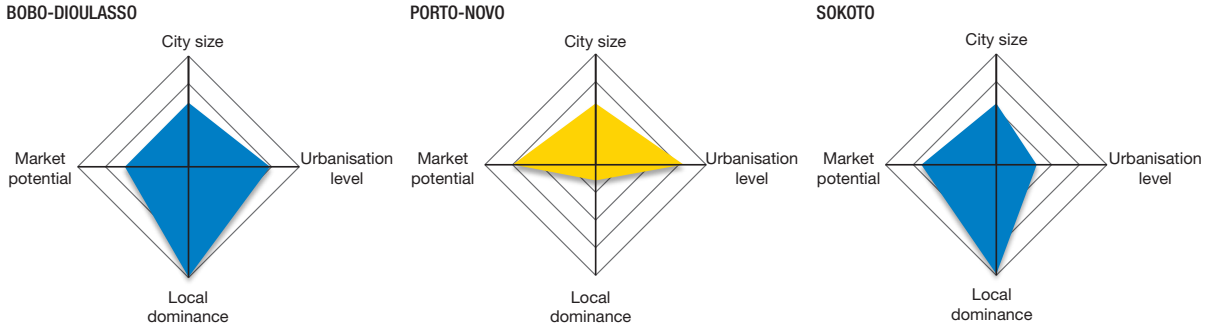
Building profiles of agglomerations

The four variables -city size, market potential, level of urbanisation and local dominance - provide information on local and regional attributes which can be used to inform and compare the profiles of each of the 1 939 urban agglomerations. The four variables have a high degree of interaction meaning that changing one variable would lead to changes in the others. For example, changes in city size automatically imply changes in market potential and in level of urbanisation, while increases in city size will lead to increases in local dominance (with the exception being when local dominance is already 1). Therefore, although these inform different aspects of a city, they are interconnected and should be analysed in combination.

The profile of each agglomeration - made up of the four metrics, city size, market potential, urbanisation level and local dominance ($C_i=\{S^i,M^i,U^i,D^i\}$) - can be used as a quantitative tool to compare different cities. For example, comparing three cities with similar city size highlights the quantitative differences that are influenced by their local and regional attributes (Figure 5). Bobo-Dioulasso (Burkina Faso), Porto-Novo (Benin) and Sokoto (Nigeria) have between 480 000 and 560 000 inhabitants each, yet they show very different attributes for the other three variables. Two cities (Bobo-Dioulasso and Sokoto) have a local dominance of 1 and one city (Porto Novo) has a local dominance of 0.14. Their regional attributes also show significant variation. Market potential ranges from 800 000 people in the case of Bobo-Dioulasso, to 2.8 million in Porto Novo. Sokoto has a market potential of 1.7 million people, yet a level of urbanisation of only 0.36 compared to above 0.74 for the two other cities.

Figure 5

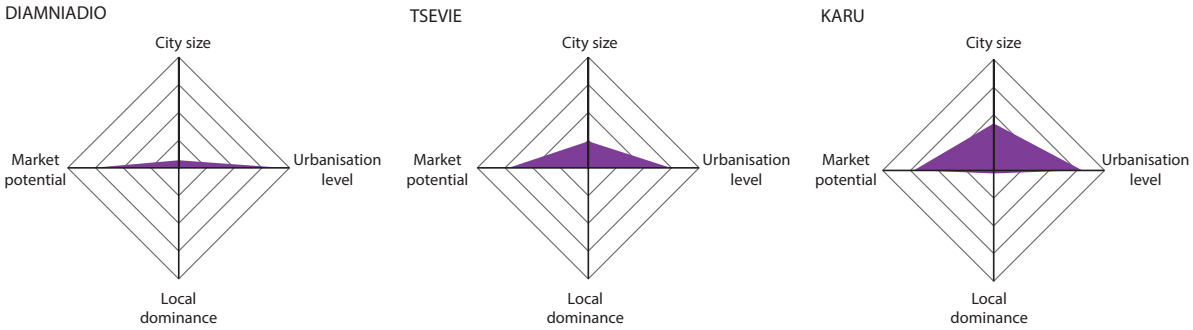
The local and regional differences between Bobo-Dioulasso, Porto-Novo and Sokoto



Source: authors' calculation

The analysis also makes it possible to detect cases in which cities may have very different city sizes, yet their other local and regional attributes show a high degree of similarity. For example, Karu (Nigeria) has a population of 190 000 inhabitants, Tsévié (Togo) has 54 000 inhabitants and Diamniadio (Senegal) has 13 000 inhabitants, yet they all have a local dominance below 0.03, an urbanisation level above 0.75 and a market potential between 2.3 and 3.4 million people (Figure 6).

Figure 6
The local and regional similarities of Karu, Tsévié and Diamniadio



Source: authors' calculation

These few cases highlight the large variations in regional and local variables across cities. Building profiles that integrate multidimensional variables helps to compare and distinguish cities in a methodological manner.

A CLUSTERING ANALYSIS OF AGGLOMERATIONS IN WEST AFRICA

Certain profiles are characteristic of distinct types of agglomerations. In order to identify frequently repeating patterns across the 1 939 agglomerations and to group cities based on their profile, a clustering algorithm was carried out using a K-means clustering procedure. [10] The clustering algorithm provides two results. First, it classifies every agglomeration into the group that has the highest degree of similarity. Each agglomeration is grouped with other agglomerations that have the highest possible similarity with one another. The second result of the clustering procedure is the definition of an average city profile for each group. The profiles highlight the relevant attributes and distinct profile of each group, making it possible to quantitatively differentiate between groups. Seven groups or clusters have been identified and named. The main attributes of each cluster are defined by the unique quantitative behaviour and the spatial distribution of the agglomerations belonging to each group:

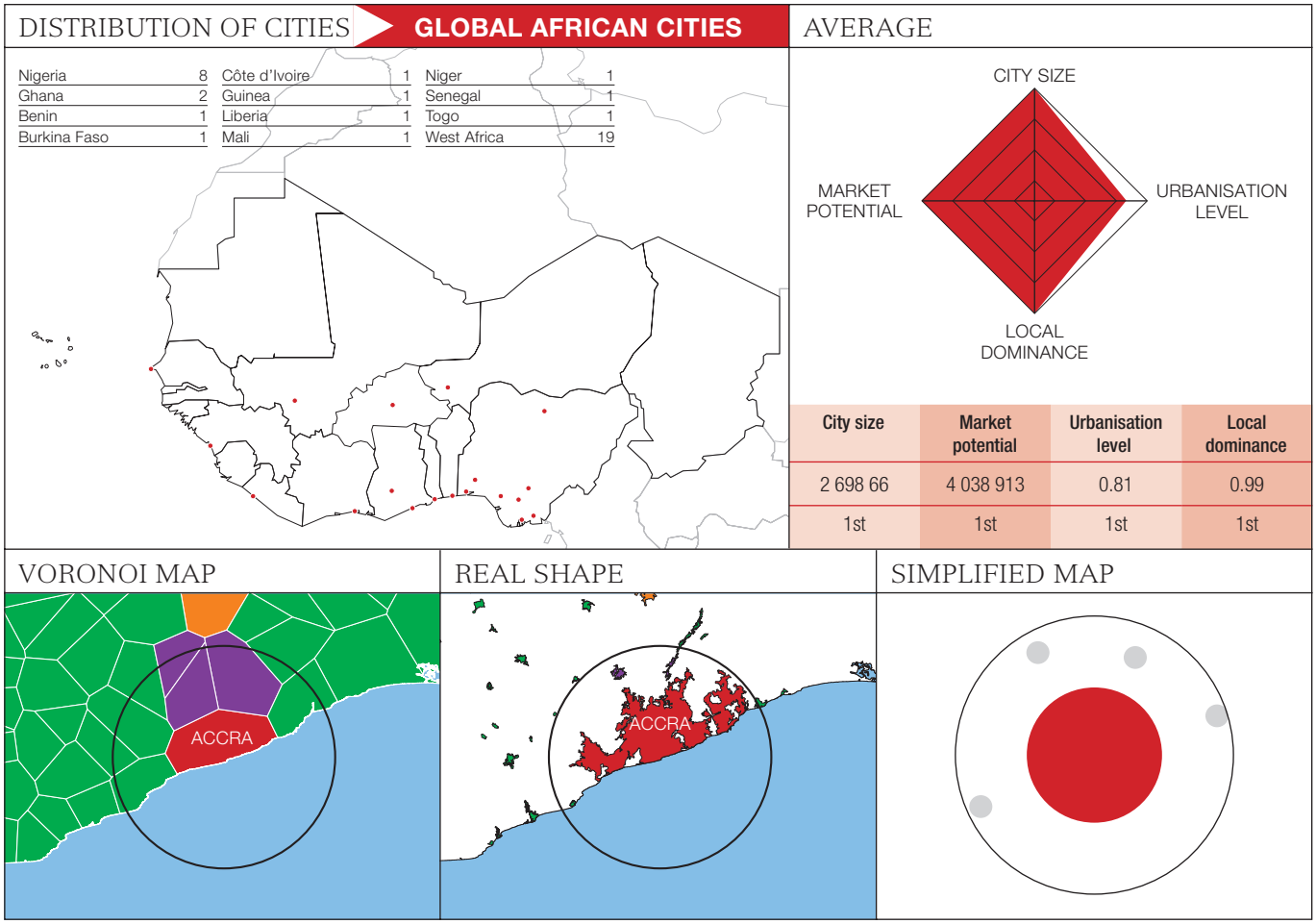
1. Global African cities
2. Regional cities
3. Metropolitan areas
4. Satellite towns
5. Local cities
6. Rural clusters
7. Rural towns

West Africa's seven city clusters

Global African cities (19 agglomerations)

Global African cities group the 19 largest West African cities, including eight national capitals plus Abidjan and Cotonou.[11] The other nine cities in this group are in Nigeria (eight) and Ghana (Kumasi). It is the largest group in terms of population, accounting for 40% of the region's total urban population (51.2 million people), although it accounts for less than 1% of the total number of cities. Global African cities have the highest values for all four variables, with an average city size of 2.7 million people, an average market potential of 4 million, a local dominance of 0.99 and a level of urbanisation of 0.81 (Figure 7).

Figure 7
Profile of global African cities

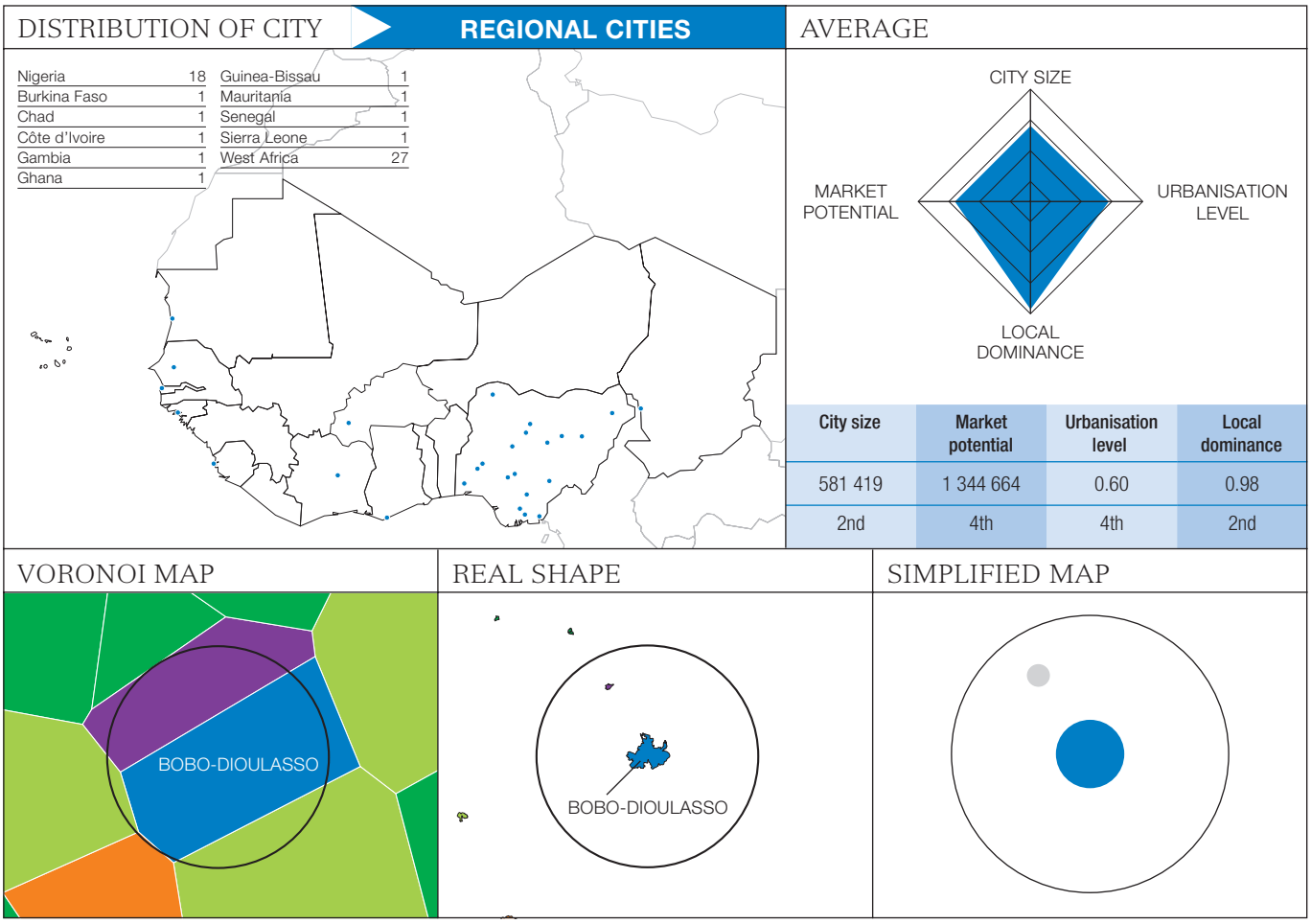


The term global African cities is chosen to reflect the heterogeneity of the 19 cities. Whereas Lagos, Accra, Abidjan and Dakar correspond to one widely-used aspect of defining global cities - global economic integration - other cities in this group such as Kano, Kumasi, Bamako and Ouagdougou have a continental rather than global reach.

Regional cities (27 agglomerations)

The regional cities group is made up of 27 agglomerations, including four national capitals (Bissau, Freetown, N'Djamena, Nouakchott), some countries' second largest cities (Touba, Bouaké, Bobo-Dioulasso) and 18 Nigerian cities. This group accounts for 12% of the total urban population in West Africa. Regional cities rank just below global African cities in terms of average city size and local dominance with an average city size of 580 000 inhabitants and a local dominance of 0.98. However, the values of the regional variables are significantly different from the global African cities group. Regional cities have an average market potential of 1.3 million inhabitants (40% of the market potential for global African cities) and a level of urbanisation of 0.60, ranking fourth out of the seven groups on both (Figure 8).

Figure 8
Profile of regional cities

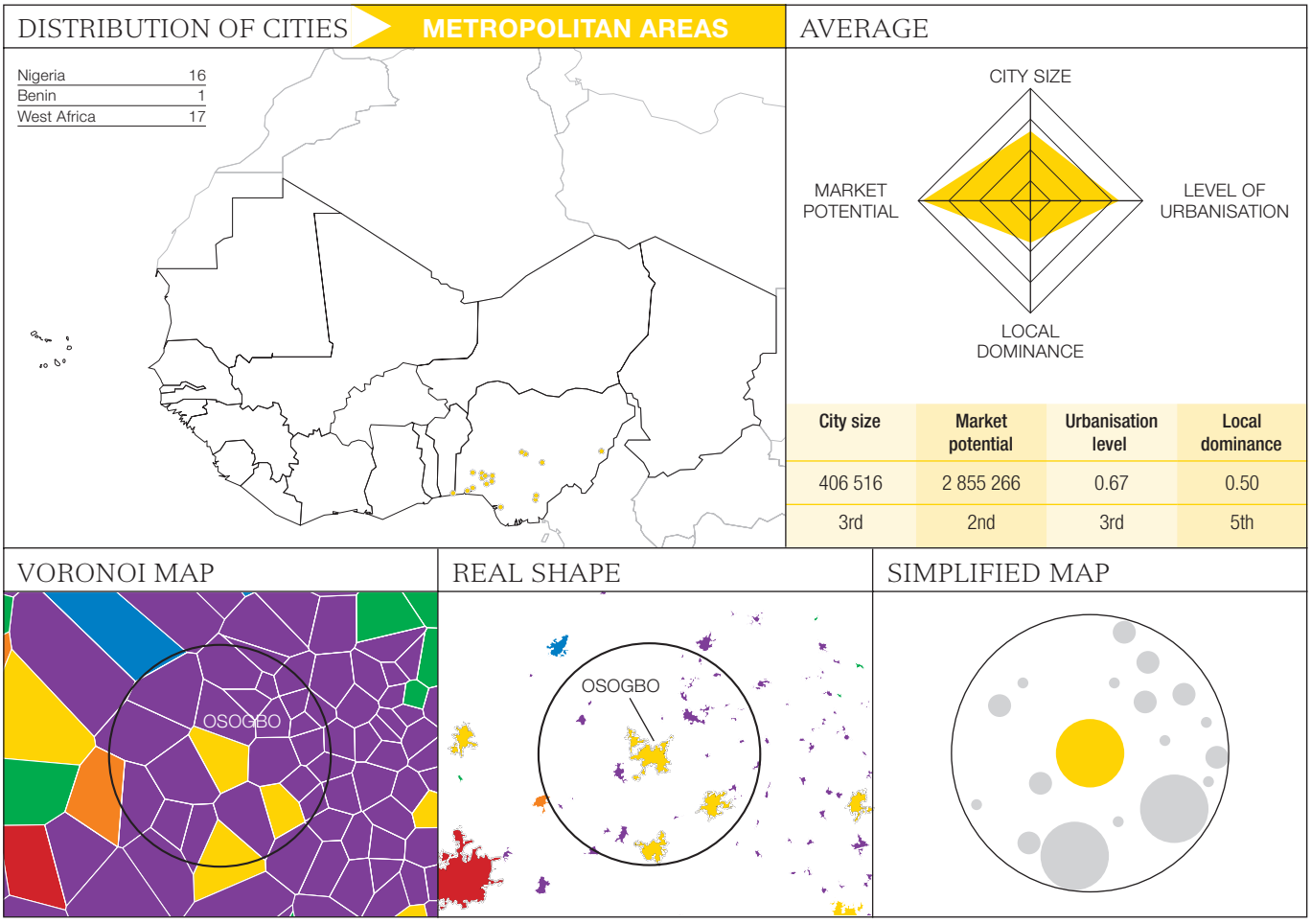


Regional cities, like N'Djamena, Kaduna or Freetown play a dominant role in their regions and in a simplified way, regional cities are a smaller-scale version of global African cities. Only five countries in West Africa have at least one city in both groups (Burkina Faso, Côte d'Ivoire, Ghana, Nigeria and Senegal). In some cases regional cities are almost as big, almost as urbanised and have almost the same market potential as global African cities, yet there is a marked quantitative difference between the cities assigned to each group. And indeed it is the sum of these differences in local and regional attributes which differentiates regional cities from global African cities.

Metropolitan cities (17 agglomerations)

With the exception of Porto-Novo, all metropolitan cities are located in Nigeria, including Abuja, Osogbo and Warri. This group accounts for 8% of the urban population in Nigeria (5% at the regional level). Metropolitan cities are similar to regional cities in terms of average city size (410 000 inhabitants) and average level of urbanisation (0.67). However, in terms of local dominance and market potential, they differ significantly. Metropolitan cities have an average local dominance of 0.5 (compared to 0.98 for regional cities), indicating the presence of other large(r) cities in their region (Figure 9). The presence of more than one large city or urban core in one region is often referred to as polycentrism. Intra-metropolitan polycentrism has been observed in Europe and other regions. The presence of other cities also explains why metropolitan cities have the second highest average market potential (2.9 million people).

Figure 9
Profile of metropolitan cities

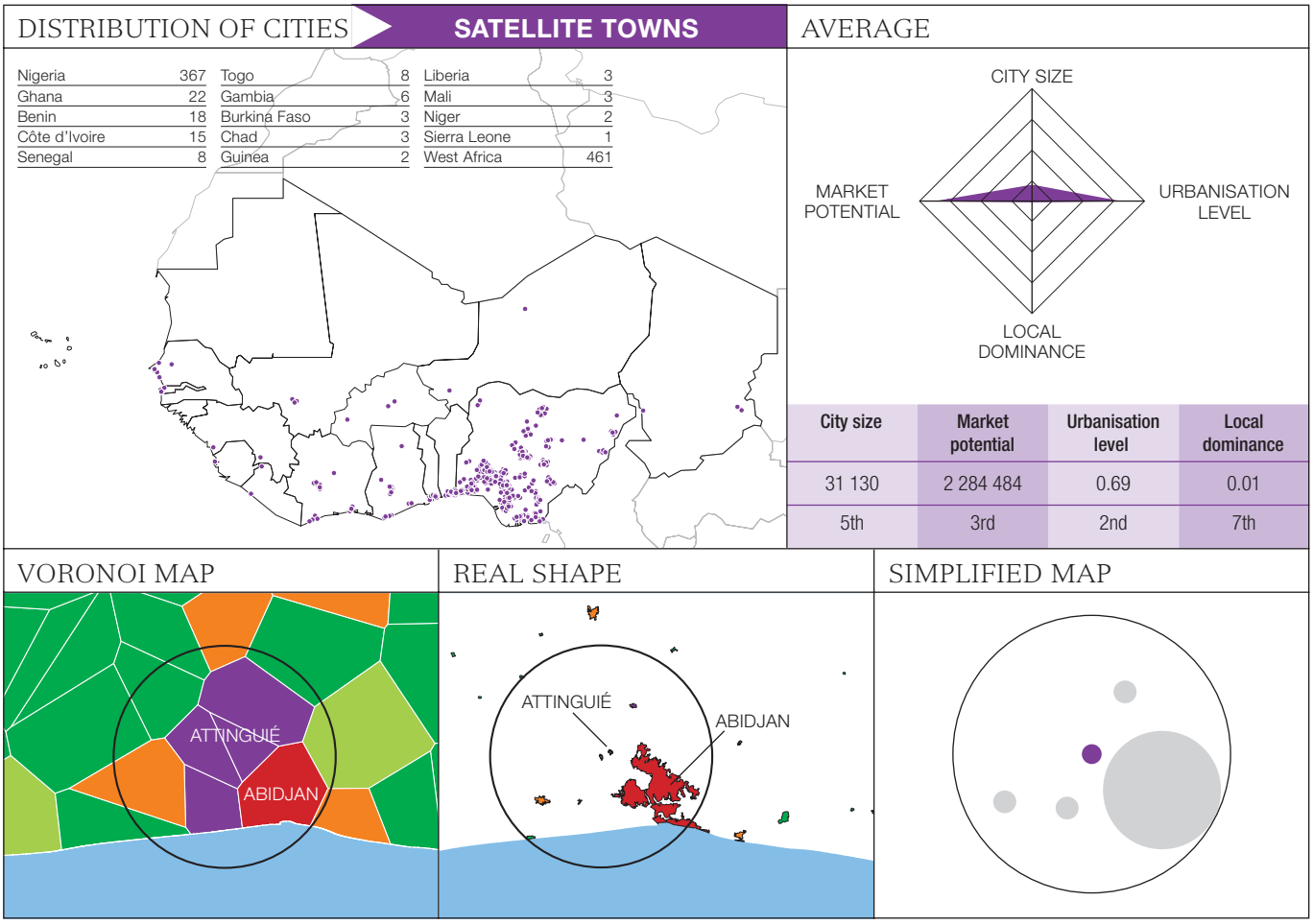


Metropolitan cities are located in very dense urban and metropolitan areas, which explains their particular presence in Nigeria. The emergence of polycentric areas appears to be very context-specific and related to their functional roles and ties (interrelations) and/or specific morphological forms (structure of urban form and built-up areas) (Champion, 2001; METREX, 2010). With current patterns of urban growth and spatial sprawl, this group is likely to grow significantly over the coming decades, particularly in Benin, Côte d'Ivoire, Nigeria and Senegal (Moriconi-Ebrard, Harre and Heinrigs, 2016).

Satellite towns (461 agglomerations)

The group satellite towns is composed of 461 agglomerations, the second largest in terms of number of agglomerations (25%). The group has a combined total urban population of 14.4 million, 11% of the total. Satellite towns have an average city size of 31 000 inhabitants and are located in the peripheral region of larger cities. Seventy-five per cent of satellite towns are in the region of a global city, regional city or metropolitan area. Their distinctive attribute is a local dominance close to zero (0.01), the lowest of all groups. At the same time, given their proximity to larger cities they have a high average level of urbanisation (0.69) and a high average level of market potential (2.3 million people) (Figure 10).

Figure 10
Profile of satellite towns

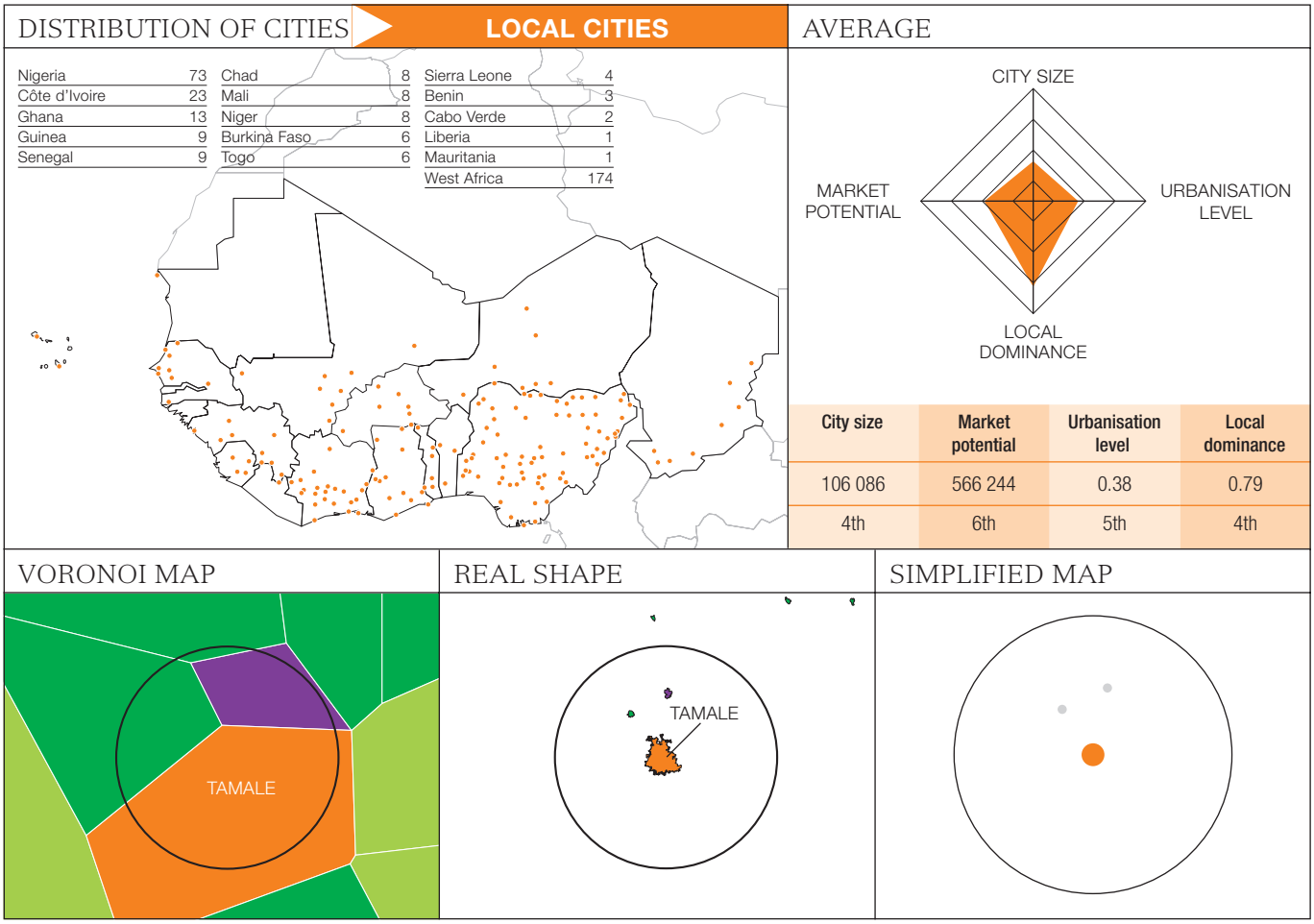


Nigeria is the country with the highest number of satellite towns with 367 towns, 36% of all agglomerations in the country. This can be linked to Nigeria also having the largest number of global African cities, regional cities and metropolitan areas in whose proximity satellite towns develop. However, the Gambia is the country with the highest share of agglomerations in this group 60% (6 agglomerations).

Local cities (174 agglomerations)

The local cities group is composed of 174 agglomerations, with a combined population of 18.5 million inhabitants, or 14% of the total urban population. Local cities have an average city size of 110 000 inhabitants, with a relatively high local dominance (0.79). Compared to regional cities, they have a significantly lower market potential (570 000 people) and a low level of urbanisation (0.38) (Figure 11). In other words, local cities are dominant cities in low market potential areas. Two national capitals are in this group, Yamoussoukro (Côte d'Ivoire) and Praia (Cabo Verde). Other examples of cities within this group are Kayes (Mali), Cape Coast (Ghana) and Maradi (Niger).

Figure 11
Profile of local cities

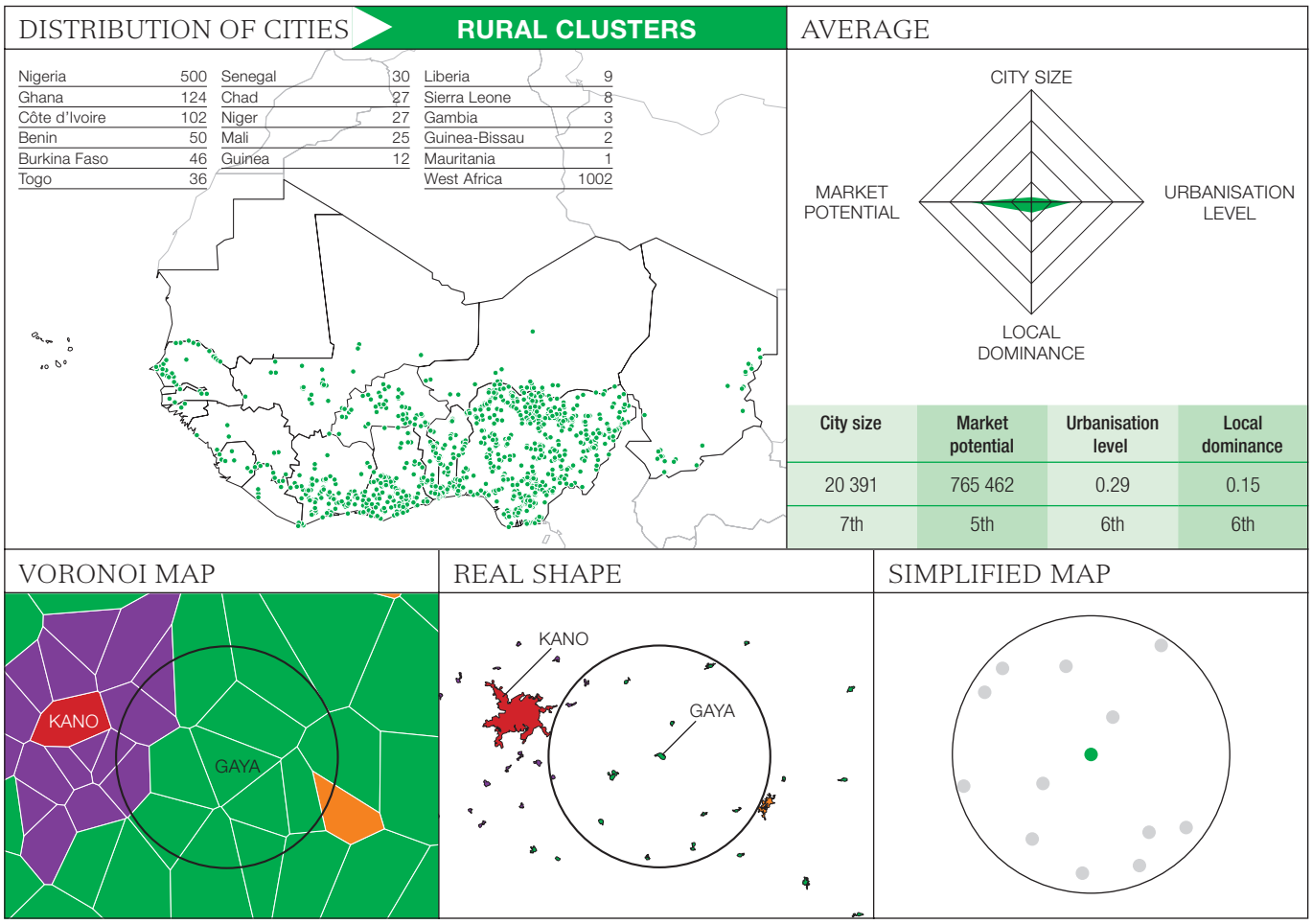


In Cabo Verde, 87% of the urban population lives in a local city which is linked to the country's geography composed of a group of islands of which nine are inhabited. Other countries where a high share of the urban population lives in local cities are Guinea (33%), Niger (30%) and Sierra Leone (29%).

Rural clusters (1 002 agglomerations)

The rural clusters group is the largest in terms of number of agglomerations, with nearly 52% of all agglomerations and the second largest group in terms of total urban population with 20.4 million inhabitants, 15% of the total urban population. Rural clusters have an average city size of 20 000 inhabitants, the smallest of the seven groups. They have an average market potential of 770 000 inhabitants, a low average local dominance (0.15) and a low average level of urbanisation (0.29) (Figure 12). The combination of a relatively high market potential, with small city size and low local dominance highlights the particular attribute of agglomerations in this group; they tend to cluster around each other. The low level of urbanisation underlines that they are located in areas with relatively high rural densities, often within the main agricultural production areas of Benin, Côte d'Ivoire and Ghana, for example.

Figure 12
Profile of rural clusters



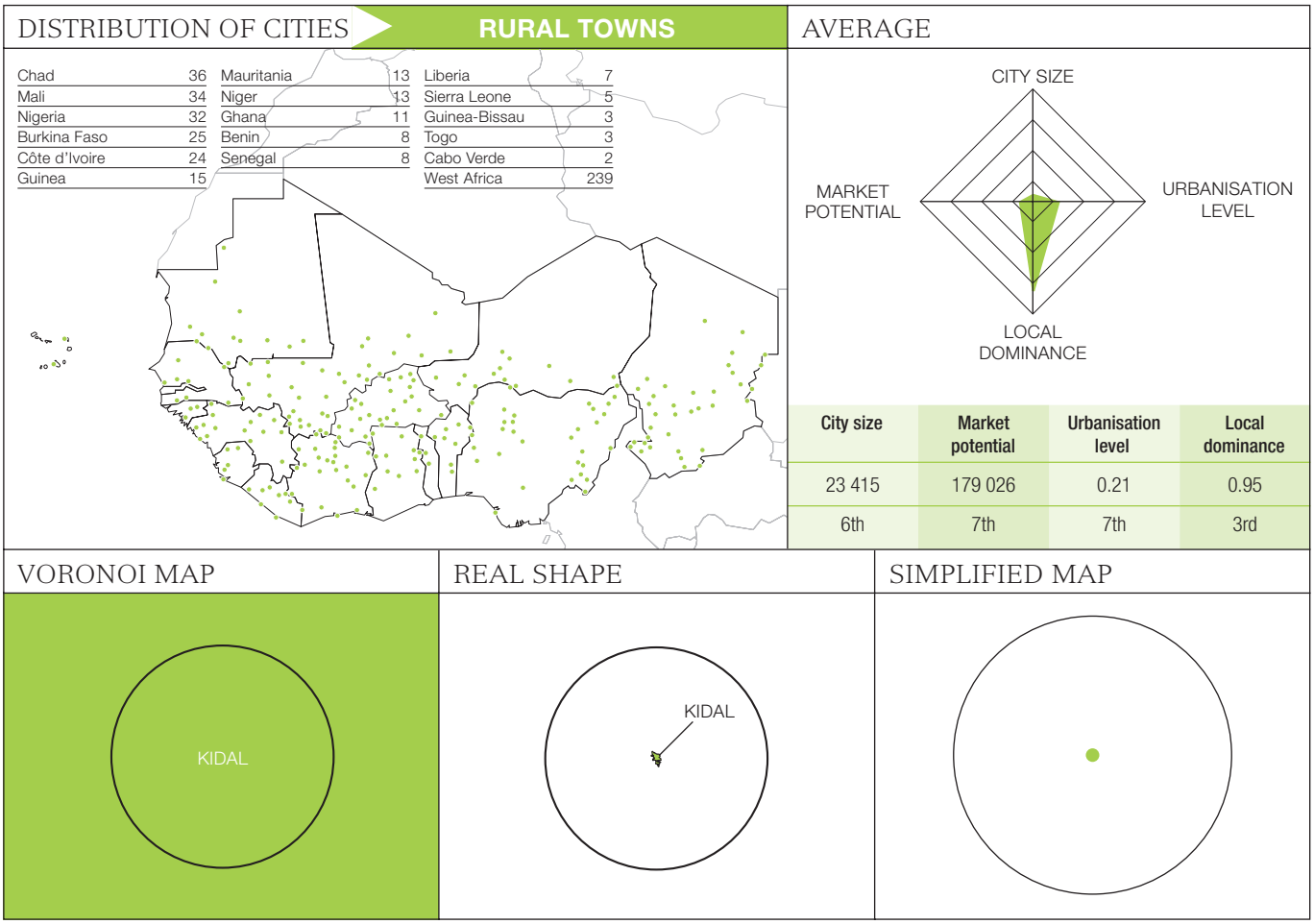
In terms of local metrics (city size and local dominance), rural clusters and satellite towns are very similar. However, their regional attributes are very different since satellite towns share the regional attributes of their large neighbours.

The countries with the highest share of urban population in rural clusters are Benin (26%), Ghana (23%), Togo (22%) and Côte d'Ivoire (20%). The high number of agglomerations in this group can be linked to a process of in situ urbanisation, a key characteristic of the urbanisation dynamic and emergence of new agglomerations in West Africa (Moriconi-Ebrard, Harre and Heinrigs, 2016).

Rural towns (239 agglomerations)

The rural towns group is the smallest group in terms of its share of the total urban population (4%), and the average city size of rural towns is 23 000 inhabitants. Rural towns have three relevant attributes. First, they have the lowest average market potential (180 000 people) second, they have the lowest level of urbanisation (21%) and third, they have a high level of local dominance (0.95) (Figure 13). The combination of low market potential with high local dominance indicates that rural towns are located in more isolated areas with low population densities. These two variables and are also the main distinction with respect to rural clusters.

Figure 13
Profile of rural towns



Rural towns are also geographically more isolated than any other group. They are common in the northern regions of Sahelian countries and in the forest areas of coastal countries such as Guinea Bissau and Liberia. In Chad, Mauritania and Guinea Bissau, rural towns account for 29%, 23% and 20% of the total urban population respectively, the second most important group in these countries. Although Chad, Mauritania and Guinea Bissau, account for only 6% of the total urban population in West Africa, they account for 28% of the urban population in the rural towns group.

The average profile of city groups

The average profile of each group demonstrates the relevant attributes and distinct profile of each and highlights the quantitative differences across groups (Table 1). Global cities have the greatest market potential, the highest local dominance and the highest level of urbanisation. However, for the other groups the average profile highlights the distinct role of each of the four variables and how their combination helps distinguish the attributes of each group. For example, the main difference between cities in the metropolitan areas group and in the satellite towns group is in their local dominance and their city size, hence they are different in their local variables but similar in their regional attributes since the values of their market potential and level of urbanisation are similar (Figure 14). The additional information captured by the four variables is particularly revealing when comparing groups with very similar average city size. The average city size of satellite towns and rural towns is 31 000 and 23 000 inhabitants respectively, yet the differences in their profile are striking: market potential of 2.3 million versus 180 000, urbanisation level of 0.69 versus 0.21, and local dominance of 0.01 versus 0.95 (Table 2.). Similarly, the profile of the average rural cluster group is distinct from the rural town group.

Table 2
Average profile of city clusters

City group	Number of agglomerations	Total population	Average City size	Average Market potential	Average Urbanisation level	Average Local dominance
Global African cities	19	51 300 000	2 700 000	4 000 000	0.81	0.99
Regional cities	27	15 700 000	580 000	1 300 000	0.60	0.98
Metropolitan areas	17	6 900 000	410 000	2 900 000	0.67	0.50
Satellite towns	461	14 400 000	31 000	2 300 000	0.69	0.01
Local cities	174	18 500 000	110 000	570 000	0.38	0.79
Rural clusters	1002	20 400 000	20 000	770 000	0.29	0.15
Rural towns	239	5 600 000	23 000	180 000	0.21	0.95

The correlation between the four variables is considerably low (see Annex 3) which means that each variable measures distinct properties of agglomerations. However, some urban metrics are usually observed simultaneously, for instance, high market potential and low local dominance (Figure 15). The surprising negative correlation between market potential and local dominance (c= -0.53) is explained by the fact that having a high market potential implies that a city is large, or is in a region with a large city. Since there are only a few large cities, the more common case is for a small city to be in the same region as a large city. This scenario results in a low local dominance. In the same sense, high market potential also explains high levels of urbanisation. Thus, the four metrics reflect qualitative and quantitative attributes that help differentiate between the cluster groups.

Figure 14
Profile of the seven average city types

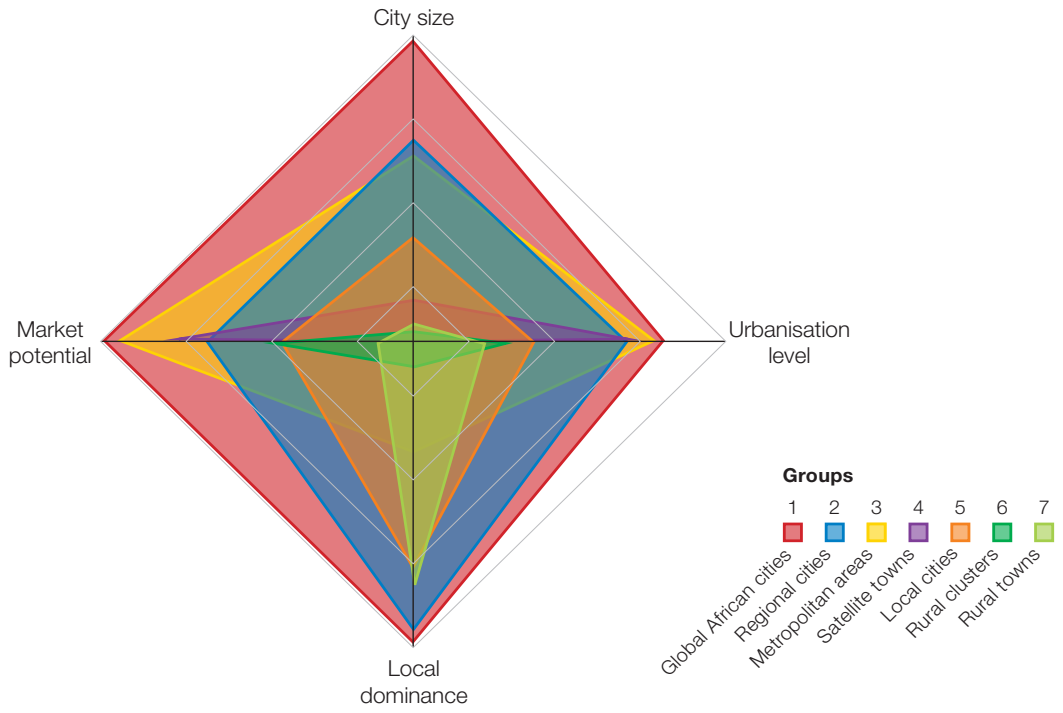
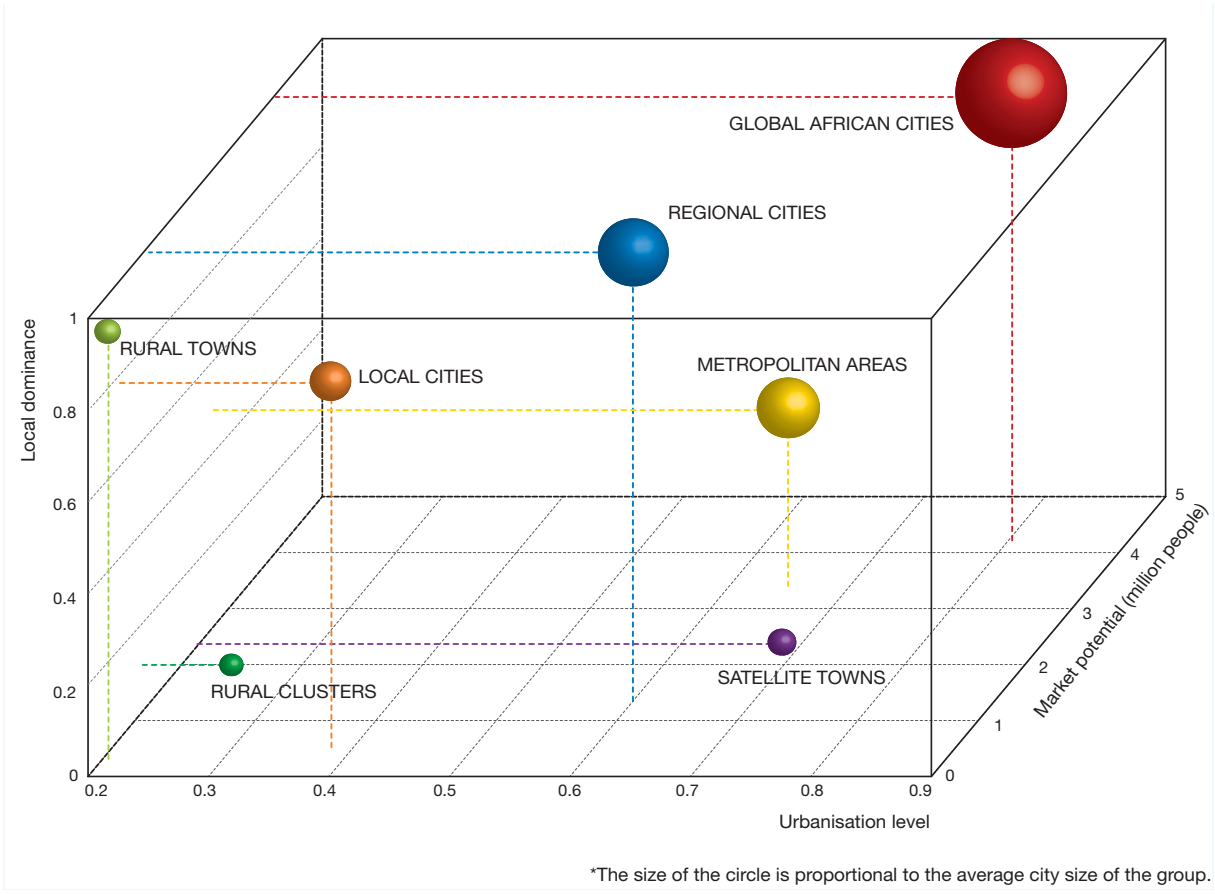


Figure 15
Diagram of the average profile of each group (city size, market potential, level of urbanisation and local dominance)



*The size of the circle is proportional to the average city size of the group.

GROWTH, EMERGENCE AND CLUSTERING OF AGGLOMERATIONS

The results of the clustering exercise provide a range of original information on the regional attributes of cities and on certain population dynamics. Indeed, when comparing agglomeration data collected at different intervals, it is possible to identify trends, such as city growth, patterns of emerging agglomerations and their spatial interaction.

The influence of spatial variables on urbanisation dynamics is highlighted when comparing population growth rates, a key variable in urban planning. The average urban population growth over the 2000-10 period for all agglomerations was 4.3%. However, looking at the average annual growth rates for the seven groups reveals astonishing variations (Table 3). The variations in average growth rates range from 5.6% for global cities to 3.2% for regional cities. This difference of 2.4 percentage points for a city with 580 000 inhabitants (average city size for a regional cities) translates into a difference of 200 000 inhabitants over a ten year period (600 000 inhabitants over 20 years). Metropolitan areas with an average city size of 410 000 inhabitants have the second highest average growth rate (4.9%) and thus appear to benefit from their particular spatial features (polycentricity). The results also show that differences in growth rates are significant for city groups with similar city size too, although the averages can mask significant variations at individual city or town level.

Table 3
Population growth between 2000 and 2010

Group	Average annual growth	Average city size (2010)	Number of agglomerations (2010)
Global African cities	5.6%	2 700 000	19
Metropolitan areas	4.9%	410 000	17
Satellite towns	3.8%	31 000	461
Rural towns	3.8%	23 000	239
Rural clusters	3.6%	20 000	1 002
Local cities	3.5%	110 000	174
Regional cities	3.2%	580 000	27
West Africa	4.3%		1 939

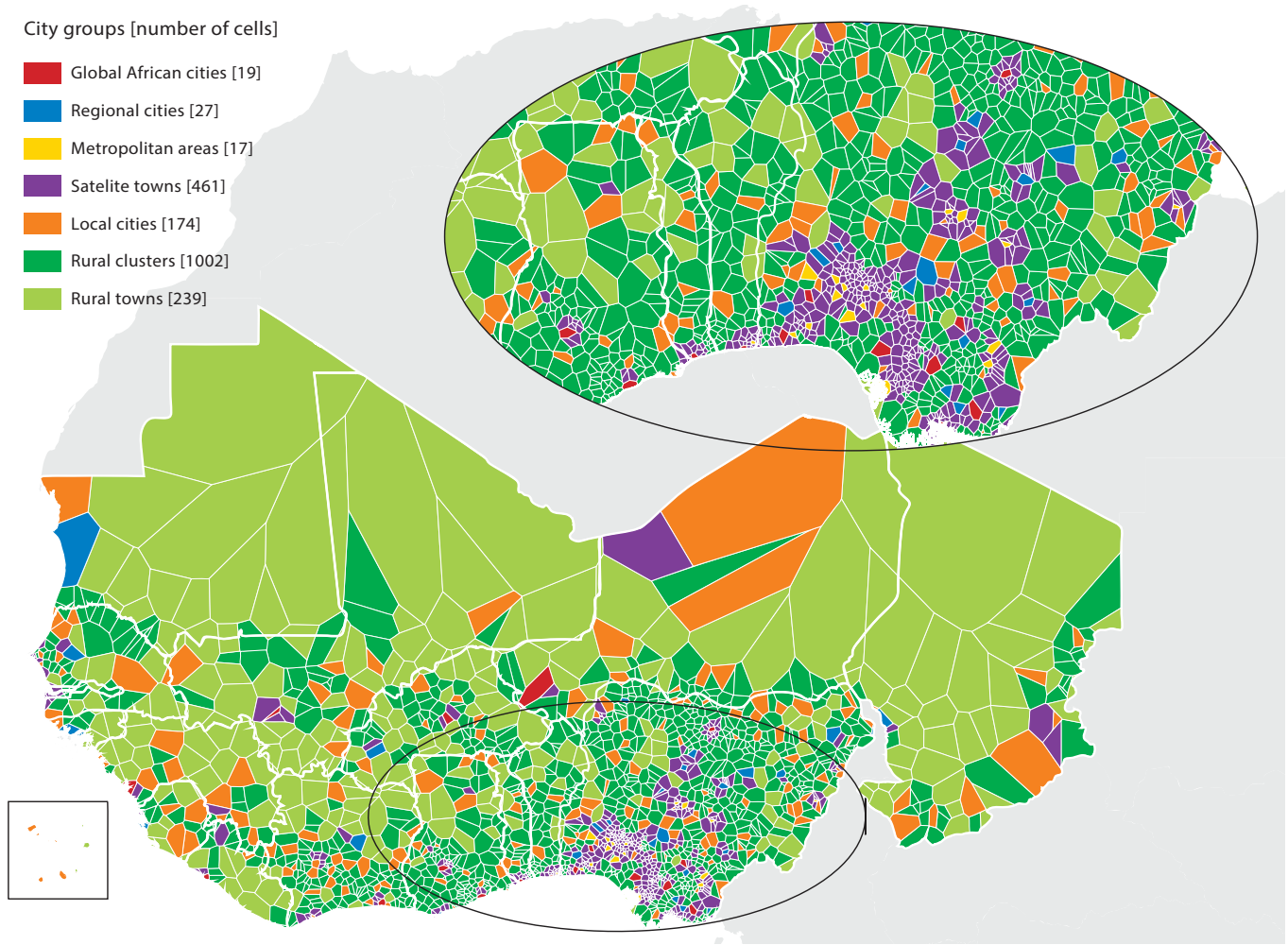
Source: OECD 2015, DIVA-GIS (www.diva-gis.org) and authors' calculations

As already mentioned, one characteristic of the urbanisation dynamic in West Africa is the emergence of new agglomerations.[12] This trend will continue, albeit slowing down in some countries, until the region has completed its demographic and settlement transition. Over the 2000-10 period, 566 new urban agglomerations 'emerged'. Yet, this emergence occurred in particular locations. Ninety per cent of the new agglomerations (502) emerged

in either the rural cluster (375) or in the satellite towns group (127). The two groups have the lowest level of local dominance, but a relatively large market potential. Hence, 90% of the new agglomerations emerged in more attractive market potential regions.

The emergence of agglomerations in the two groups with the lowest local dominance also reveals another important feature: cities tend to cluster. One indication for the clustering or proximity between agglomerations is the high frequency of very low local dominance in the sample (848 agglomerations, or 45% of the total, have a local dominance of less than

Map 4
Spatial distribution of city groups



0.05). This clustering trend is further confirmed by looking at other distance measures. For example, there are an average of eight urban agglomerations within the 40 kilometre radial buffer of one agglomeration.

The clustering or density of the urban network can be illustrated by Voronoi cells. Voronoi cells define the geographic region of a particular agglomeration that is the closest to the (i-th) agglomeration. In other words, if a person is located anywhere within the Voronoi cell of agglomeration A, then agglomeration A is the nearest agglomeration to that person.

This means that the smaller the area of a Voronoi cell, the closer other agglomerations are (Map 4). Metropolitan areas and satellite towns have the smallest cells due to their proximity to other cities. Local cities and rural towns have much larger Voronoi cells due to their greater isolation (Table 4). The three fastest growing city groups (global cities, metropolitan areas and satellite towns) have the smallest average Voronoi cells, accounting for less than 5% of the total area, but more than 50% of the urban population. The clustering of agglomerations and the importance of distance and connectivity have also been observed in other regions (Mansury and Shin, 2015). Furthermore, irrespective of city group and city size, cities located in smaller Voronoi cells grow faster. Therefore, agglomerations within dense urban networks gain additional attractiveness and gravity based on the diversity and density of the economic, social and political activities that they share.

These initial results illustrate the relevance of integrating population-based, distance-based and interaction variables in analyses of African cities and urbanisation. They capture some of the underlying mechanisms that generate city growth, urbanisation and agglomeration economies. African urban growth will continue for decades to come and a better understanding of the spatial and economic transformations that are inherent to this process will be crucial to inform the growing planning challenges faced by governments.

Table 4
Area covered by the city groups

Group	Average area of Voronoi cell (in km²)	Share of total area covered	Number of cities	Total area (in 1 000 km²)
Rural towns	18 940	59.2%	239	4 530
Local cities	5 120	11.7%	174	891
Regional cities	2 690	0.9%	27	73
Rural clusters	1 810	23.7%	1 002	1 810
Global African cities	1 320	0.3%	19	25
Satellite towns	670	4.0%	461	310
Metropolitan areas	390	0.1%	17	7
Total	3 940	100%	1 939	7 640

Source: authors' calculation

CONCLUSION

The spatial analysis developed in this paper is a first attempt to develop a systematic way of capturing the regional interactions that define cities and impact city growth and urbanisation. Urbanisation and the growth of cities are undoubtedly two of the major opportunities and challenges of 21st century Africa. The analysis carried out in this paper reveals the diversity and distinctive behaviours of cities that are not captured by simply looking at the size of a city. The results provide unique descriptions of urbanisation dynamics in West Africa, offering insights into the influence of spatial variables on urban growth rates, the emergence of new agglomerations and the clustering of cities. The reality is of course more complex and more diverse than can be illustrated by the four variables developed in this analysis. There is a need and a huge potential to further refine the analysis by integrating more detailed reliable data. The population-based variables should include more time and cost measures. The distance-based measures need more spatial and connectivity variables such as distance, density and quality of road networks; distances to coasts and other transport infrastructure; and frictions such as physical geography and borders. However, integrating socio-economic variables, administrative settings and interactions between agglomerations across national and regional urban networks, are important first steps in better capturing the complexity of the urbanisation dynamic.

NOTES

1. The definition of urban used in this paper comes from Africapolis where an agglomeration is a continuously built-up and developed area with less than 200 meters between two buildings and is considered urban if it has a minimum of 10 000 inhabitants (Moriconi-Ebrard et.al., 2016).
2. A primary city is generally defined as a leading city in a region or country and is disproportionately larger than any other in the urban hierarchy (Roberts and Hohmann, 2014).
3. Average distance is calculated as the average of the distance between each agglomeration to its nearest neighbouring agglomeration.
4. In 2% of cases, a larger or smaller distance (as high as 60 km and as low as 30 km) is considered based on certain attributes of the city. For instance in Onitsha (Nigeria), the continuously built-up urban area extends beyond 40 km.
5. In 2% of cases, a larger or smaller distance (as high as 60 km and as low as 30 km) is considered based on certain attributes of the city. For instance in Onitsha (Nigeria), the continuously built-up urban area extends beyond 40 km.
6. On average data availability and reliability is better for large cities so that in data-driven analyses, an additional bias would be added towards large cities. For instance, according to publicly available data on Google (2011) and Open Street Map, 65% of West African cities do not have schools. This is known to be inaccurate, but only affects cities with less than 40 000 inhabitants.
7. LandScanTM 2014 Global population database by Oak Ridge National Laboratory, available at http://web.ornl.gov/sci/landscan.
8. In the city size distribution, the largest cities could be considered as statistical outliers. After the logarithmic transformation, the variable S_i ranges from a value of 4 for an agglomeration with P_i=10 000 inhabitants, to a value just above 7 for the largest city, Lagos, with a population of 10.4 million inhabitants.
9. Voronoi cells define the geographic region of a particular agglomeration that is the closest to the (i-th) agglomeration. In other words, if a person is located anywhere within the Voronoi cell of agglomeration A, then agglomeration A is the nearest agglomeration to that person. See Annex A5 for a description of how Vornoi cells are defined.
10. K-means clustering, frequently used in data mining and machine learning, is used to assign each agglomeration into the group with which it shares the most similarity. Annex 4 provides more data on the principal component analysis (PCA) and the results.
11. The official capitals of Côte d'Ivoire and Benin are Yamoussoukro and Porto-Novo respectively.
12. The Africapolis methodology detects three processes in the emergence of new agglomerations: i) an existing agglomeration grows to reach a population of 10 000 inhabitants and will then be considered urban; ii) 'rural-infill' in which a previously dense area develops to form a continuously built-up area (with a minimum of 10 000 agglomerated inhabitants); iii) 'merging' in which two initially separated agglomeration with less than 10 000 inhabitants merge through growth of the built-up area and form one single agglomeration with more than 10 000 inhabitants.

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ANNEX 1. DESCRIPTIVE STATISTICS FOR CITY GROUPS

Table A1.1
Number of agglomerations per group by country

	Global African cities	Regional cities	Metropolitan areas	Satellite towns	Local cities	Rural clusters	Rural towns	Total by country
Benin	1	0	1	18	3	50	8	81
Burkina Faso	1	1	0	3	6	46	25	82
Côte d'Ivoire	1	1	0	15	23	102	24	166
Cabo Verde	0	0	0	0	2	0	2	4
Ghana	2	1	0	22	13	124	11	173
Guinea	1	0	0	2	9	12	15	39
Gambia, the	0	1	0	6	0	3	0	10
Guinea-Bissau	0	1	0	0	0	2	3	6
Liberia	1	0	0	3	1	9	7	21
Mali	1	0	0	3	8	25	34	71
Mauritania	0	1	0	0	1	1	13	16
Niger	1	0	0	2	8	27	13	51
Nigeria	8	18	16	367	73	500	32	1014
Senegal	1	1	0	8	9	30	8	57
Sierra Leone	0	1	0	1	4	8	5	19
Chad	0	1	0	3	8	27	36	75
Togo	1	0	0	8	6	36	3	54
Total by group	19	27	17	461	174	1 002	239	1 939

Table A1.2
Share of agglomerations per group by country

	Global African cities	Regional cities	Metropolitan areas	Satellite towns	Local cities	Rural clusters	Rural towns
Benin	1%	0%	1%	22%	4%	62%	10%
Burkina Faso	1%	1%	0%	4%	7%	56%	30%
Côte d'Ivoire	1%	1%	0%	9%	14%	61%	14%
Cabo Verde	0%	0%	0%	0%	50%	0%	50%
Ghana	1%	1%	0%	13%	8%	72%	6%
Guinea	3%	0%	0%	5%	23%	31%	38%
Gambia, the	0%	10%	0%	60%	0%	30%	0%
Guinea-Bissau	0%	17%	0%	0%	0%	33%	50%
Liberia	5%	0%	0%	14%	5%	43%	33%
Mali	1%	0%	0%	4%	11%	35%	48%
Mauritania	0%	6%	0%	0%	6%	6%	81%
Niger	2%	0%	0%	4%	16%	53%	25%
Nigeria	1%	2%	2%	36%	7%	49%	3%
Senegal	2%	2%	0%	14%	16%	53%	14%
Sierra Leone	0%	5%	0%	5%	21%	42%	26%
Chad	0%	1%	0%	4%	11%	36%	48%
Togo	2%	0%	0%	15%	11%	67%	6%

Table A1.3
Share of city groups by country

	Global African cities	Regional cities	Metropolitan areas	Satellite towns	Local cities	Rural clusters	Rural towns
Benin	5%	0%	6%	4%	2%	5%	3%
Burkina Faso	5%	4%	0%	1%	3%	5%	10%
Côte d'Ivoire	5%	4%	0%	3%	13%	10%	10%
Cabo Verde	0%	0%	0%	0%	1%	0%	1%
Ghana	11%	4%	0%	5%	7%	12%	5%
Guinea	5%	0%	0%	0%	5%	1%	6%
Gambia, the	0%	4%	0%	1%	0%	0%	0%
Guinea-Bissau	0%	4%	0%	0%	0%	0%	1%
Liberia	5%	0%	0%	1%	1%	1%	3%
Mali	5%	0%	0%	1%	5%	2%	14%
Mauritania	0%	4%	0%	0%	1%	0%	5%
Niger	5%	0%	0%	0%	5%	3%	5%
Nigeria	42%	67%	94%	80%	42%	50%	13%
Senegal	5%	4%	0%	2%	5%	3%	3%
Sierra Leone	0%	4%	0%	0%	2%	1%	2%
Chad	0%	4%	0%	1%	5%	3%	15%
Togo	5%	0%	0%	2%	3%	4%	1%

ANNEX 2. DESCRIPTIVE STATISTICS FOR URBAN POPULATION

Table A2.1
Urban population per city group (by country)

	Global African cities	Regional cities	Metropolitan areas	Satellite towns	Local cities	Rural clusters	Rural towns	Total by country
Benin	1 158 625	-	476 780	375 048	459 186	920 161	194 203	3 584 003
Burkina Faso	1 907 666	564 806	-	66 319	446 033	770 093	581 377	4 336 294
Côte d'Ivoire	3 966 553	588 533	-	236 816	2 156 523	1 900 755	613 117	9 462 297
Cabo Verde	-	-	-	-	200 175	-	29 413	229 588
Ghana	5 882 101	376 833	-	466 103	1 415 866	2 522 862	265 651	10 929 416
Guinea	1 408 632	-	-	29 093	1 046 700	292 414	415 048	3 191 887
Gambia, the	-	603 066	-	178 741	-	56 358	-	838 165
Guinea-Bissau	-	458 074	-	-	-	23 978	118 835	600 887
Liberia	1 170 000	-	-	36 000	45 453	190 926	145 237	1 587 616
Mali	2 269 862	-	-	156 039	1 019 455	374 896	771 179	4 591 431
Mauritania	-	743 715	-	-	87 373	37 574	264 943	1 133 605
Niger	1 169 829	-	6 434 000	48 698	852 573	486 695	257 127	2 814 922
Nigeria	28 330 000	9 737 000	-	12 302 500	7 766 600	11 074 000	716 400	76 360 500
Senegal	2 562 152	692 136	-	205 561	1 375 544	532 863	214 714	5 582 970
Sierra Leone	-	928 592	-	41 612	485 533	135 854	75 141	1 666 732
Chad	-	1 005 570	-	50 038	611 218	488 471	862 170	3 017 467
Togo	1 449 284	-	-	158 192	490 755	624 249	71 699	2 794 179
Total Clustering	51 274 704	15 698 325	6 910 780	14 350 760	18 458 987	20 432 149	5 596 254	132 721 959

Table A2.2
Share of urban population per city group (by country)

	Global African cities	Regional cities	Metropolitan areas	Satellite towns	Local cities	Rural clusters	Rural towns
Benin	32%	0%	13%	10%	13%	26%	5%
Burkina Faso	44%	13%	0%	2%	10%	18%	13%
Côte d'Ivoire	42%	6%	0%	3%	23%	20%	6%
Cabo Verde	0%	0%	0%	0%	87%	0%	13%
Ghana	54%	3%	0%	4%	13%	23%	2%
Guinea	44%	0%	0%	1%	33%	9%	13%
Gambia, the	0%	72%	0%	21%	0%	7%	0%
Guinea-Bissau	0%	76%	0%	0%	0%	4%	20%
Liberia	74%	0%	0%	2%	3%	12%	9%
Mali	49%	0%	0%	3%	22%	8%	17%
Mauritania	0%	66%	0%	0%	8%	3%	23%
Niger	42%	0%	0%	2%	30%	17%	9%
Nigeria	37%	13%	8%	16%	10%	15%	1%
Senegal	46%	12%	0%	4%	25%	10%	4%
Sierra Leone	0%	56%	0%	2%	29%	8%	5%
Chad	0%	33%	0%	2%	20%	16%	29%
Togo	52%	0%	0%	6%	18%	22%	3%

Table A2.3
Share of urban population per city group (by city group)

	Global African cities	Regional cities	Metropolitan areas	Satellite towns	Local cities	Rural clusters	Rural towns
Benin	2%	0%	7%	3%	2%	5%	3%
Burkina Faso	4%	4%	0%	0%	2%	4%	10%
Côte d'Ivoire	8%	4%	0%	2%	12%	9%	11%
Cabo Verde	0%	0%	0%	0%	1%	0%	1%
Ghana	11%	2%	0%	3%	8%	12%	5%
Guinea	3%	0%	0%	0%	6%	1%	7%
Gambia, the	0%	4%	0%	1%	0%	0%	0%
Guinea-Bissau	0%	3%	0%	0%	0%	0%	2%
Liberia	2%	0%	0%	0%	0%	1%	3%
Mali	4%	0%	0%	1%	6%	2%	14%
Mauritania	0%	5%	0%	0%	0%	0%	5%
Niger	2%	0%	0%	0%	5%	2%	5%
Nigeria	55%	62%	93%	86%	42%	54%	13%
Senegal	5%	4%	0%	1%	7%	3%	4%
Sierra Leone	0%	6%	0%	0%	3%	1%	1%
Chad	0%	6%	0%	0%	3%	2%	15%
Togo	3%	0%	0%	1%	3%	3%	1%

ANNEX 3. DESCRIPTIVE STATISTICS FOR CITY SIZE, MARKET POTENTIAL, LOCAL DOMINANCE AND LEVEL OF URBANISATION

Table A3.1
City size

City size	Number of agglomerations	Cumulative percentage	Total population	Cumulative percentage
10 000 ~ 30 000	1 355	69.9%	22 794 146	17.2%
30 000 ~ 100 000	433	92.2%	21 967 731	33.7%
100 000 ~ 350 000	103	97.5%	18 604 273	47.7%
350 000 ~ 1 million	26	98.9%	14 945 535	59.0%
1 million ~ 2 million	13	99.5%	17 239 606	72.0%
above 2 million	9	100.0%	37 170 668	100.0%
Total	1 939		132 721 959	

Source: OECD 2015

Table A3.2
Market potential

Market potential	Number of agglomerations	Cumulative percentage	Total population	Cumulative percentage
12 543 ~ 100 000	70	3.6%	1 387 013	1.0%
100 000 ~ 300 000	409	24.7%	10 412 328	8.9%
300 000 ~ 500 000	331	41.8%	10 395 747	16.7%
500 000 ~ 1 million	460	65.5%	21 051 533	32.6%
1 million ~ 2 million	379	85.0%	29 325 998	54.7%
2 million ~ 5 million	258	98.3%	38 712 540	83.8%
5 million ~ 17.6 million	32	100.0%	21 436 800	100.0%
Total	1 939		132 721 959	

Source: OECD 2015, LandScan and authors' calculations

Table A3.3
Local dominance

Local dominance	Number of agglomerations	Cumulative percentage	Total population	Cumulative percentage
0.00 ~ 0.05	848	43.7%	19 488 887	14.7%
0.05 ~ 0.20	351	61.8%	10 559 795	22.6%
0.20 ~ 0.40	171	70.7%	5 202 103	26.6%
0.40 ~ 0.60	105	76.1%	4 493 401	29.9%
0.60 ~ 0.80	101	81.3%	6 033 855	34.5%
0.80 ~ 1.00	155	89.3%	79 106 401	94.1%
1	208	100.0%	7 837 517	100.0%
Total	1 939		132 721 959	

Source: OECD 2015, LandScan and authors' calculations

Table A3.4
Level of urbanisation

Urbanisation level	Number of agglomerations	Cumulative percentage	Total population	Cumulative percentage
0% ~ 10%	176	9.1%	3 138 053	2.4%
10% ~ 20%	302	24.7%	7 539 746	8.0%
20% ~ 30%	322	41.3%	10 482 996	15.9%
30% ~ 40%	305	57.0%	11 315 287	24.5%
40% ~ 50%	233	69.0%	14 576 552	35.5%
50% ~ 60%	166	77.6%	8 898 934	42.2%
60% ~ 70%	194	87.6%	32 509 594	66.7%
70% ~ 80%	130	94.3%	18 423 344	80.5%
80% ~ 90%	58	97.3%	9 406 248	87.6%
90% ~ 100%	53	100.0%	16 431 205	100.0%
Total	1 939		132 721 959	

Source: OECD 2015, LandScan and authors' calculations

The relationship between attributes

Table A3.5
Correlations of variables

	City size	Market potential	Urbanisation level	Local dominance
City size	1.000	0.214	0.258	0.441
Market potential	0.214	1.000	0.368	-0.530
Urbanisation level	0.258	0.368	1.000	-0.311
Local dominance	0.441	-0.530	-0.311	1.000

Table A3.6
City size and market potential

Market potential \ City size	10 000 ~ 30 000	30 000 ~ 100 000	100 000 ~ 350 000	350 000 ~ 1 million	1 ~ 2 million	above 2 million	Total
less than 100 000	63	7					70
100 000 ~ 300 000	314	87	8				409
300 000 ~ 500 000	245	71	15				331
500 000 ~ 1 million	300	117	37	6			460
1 million ~ 2 million	251	88	20	14	6		379
2 Million ~ 5 Million	159	60	21	5	7	6	258
above 5 million	23	3	2	1		3	32
Total	1 355	433	103	26	13	9	1 939

Source: OECD 2015, LandScan and authors' calculations

Table A3.6
City size and level of urbanisation

Urbanisation level \ City size	10 000 ~ 30 000	30 000 ~ 100 000	100 000 ~ 350 000	350 000 ~ 1 million	1 ~ 2 million	above 2 million	Total
0% ~ 10%	164	12					176
10% ~ 20%	237	59	6				302
20% ~ 30%	220	91	10	1			322
30% ~ 40%	215	69	18	3			305
40% ~ 50%	151	59	19	2	1	1	233
50% ~ 60%	105	39	19	3			166
60% ~ 70%	119	45	17	9	2	2	194
70% ~ 80%	77	32	8	6	7		130
80% ~ 90%	34	14	5	2	1	2	58
90% ~ 100%	33	13	1		2	4	53
Total	1 355	433	103	26	13	9	1 939

Source: OECD 2015, LandScan and authors' calculations

Table A3.7
City size and local dominance

Local dominace \ City size	10 000 ~ 30 000	30 000 ~ 100 000	100 000 ~ 350 000	350 000 ~ 1 million	1 ~ 2 million	above 2 million	Total
Less than 0.05	714	120	13	1			848
0.05 ~ 0.20	255	86	9	1			351
0.20 ~ 0.40	118	44	9				171
0.40 ~ 0.60	64	35	5	1			105
0.60 ~ 0.80	47	44	8	2			101
0.80 ~ 0.99	10	55	49	19	13	9	155
1	147	49	10	2			208
Total	1 355	433	103	26	13	9	1 939

Source: OECD 2015, LandScan and authors' calculations

ANNEX 4. K-MEANS CLUSTERING

The K-means clustering procedure divides the set of 1 939 observations C_i, each of them with their $C_i=\{S_i,M_i,U_i,D_i\}$ profile, and divides the observations into K distinct groups; estimates the average city of each group, x_j, with j between 1 and K and then determines the 'distance' between each observation C_i to the average city of each group, x_j. By an iterative procedure, the K-means clustering gives the partition that minimises the sum of all the distances between each agglomeration to the average city of the group to which it is assigned.

Two relevant parts of the K-means clustering are that first, it considers the 'distance' of each observation to the average observation of the group, which in the four-dimensional case means that the four variables have the exact same assigned weight. This highlights the importance of considering a set of variables $\{S_i,M_i,U_i,D_i\}$ which have a similar range. If the city size were not transformed with the logarithm, then much more relevance would be assigned to city size than to any other variable.

Second, the number of groups, K, is pre-selected. Different numbers of groups could have been considered, however, fewer groups were not useful in terms of the results obtained and more groups were not useful in terms of interpreting and differentiating between groups. Five groups were initially considered and the largest city group was further divided into three groups, giving a of total seven clusters or groups. Each agglomeration is assigned to one of the seven groups.

By reducing the four dimensions into two dimensions following the principal component analysis (PCA) procedure, the distinction between groups becomes more obvious. Level of urbanisation, market potential and local dominance are assigned to the first component, x-axis, and city size is assigned to the second component, y-axis (Figure A4.1). For example, regional cities and metropolitan areas have a similar city size, similar range on the y-axis, yet metropolitan areas locate further left on the (x-axis) than regional cities, meaning that metropolitan areas have a lower local dominance and higher level of urbanisation and market potential than regional cities on average. However, since the PCA figure only represents two dimensions and the clustering analysis is based on four dimensions, two distinct groups might appear to overlap in Figure A4.1, for instance rural clusters and satellite towns.

The box plot is a standardised way of displaying the distribution of the data based on five attributes: minimum, first quartile, median, third quartile, and maximum (Figure A4.2). The central rectangle spans the first quartile to the third quartile (the interquartile range or IQR). A segment inside the rectangle shows the median and the 'whiskers' above and below the box show the locations of the minimum and maximum quartiles.

Figure A4.1
Principal component analysis (PCA)

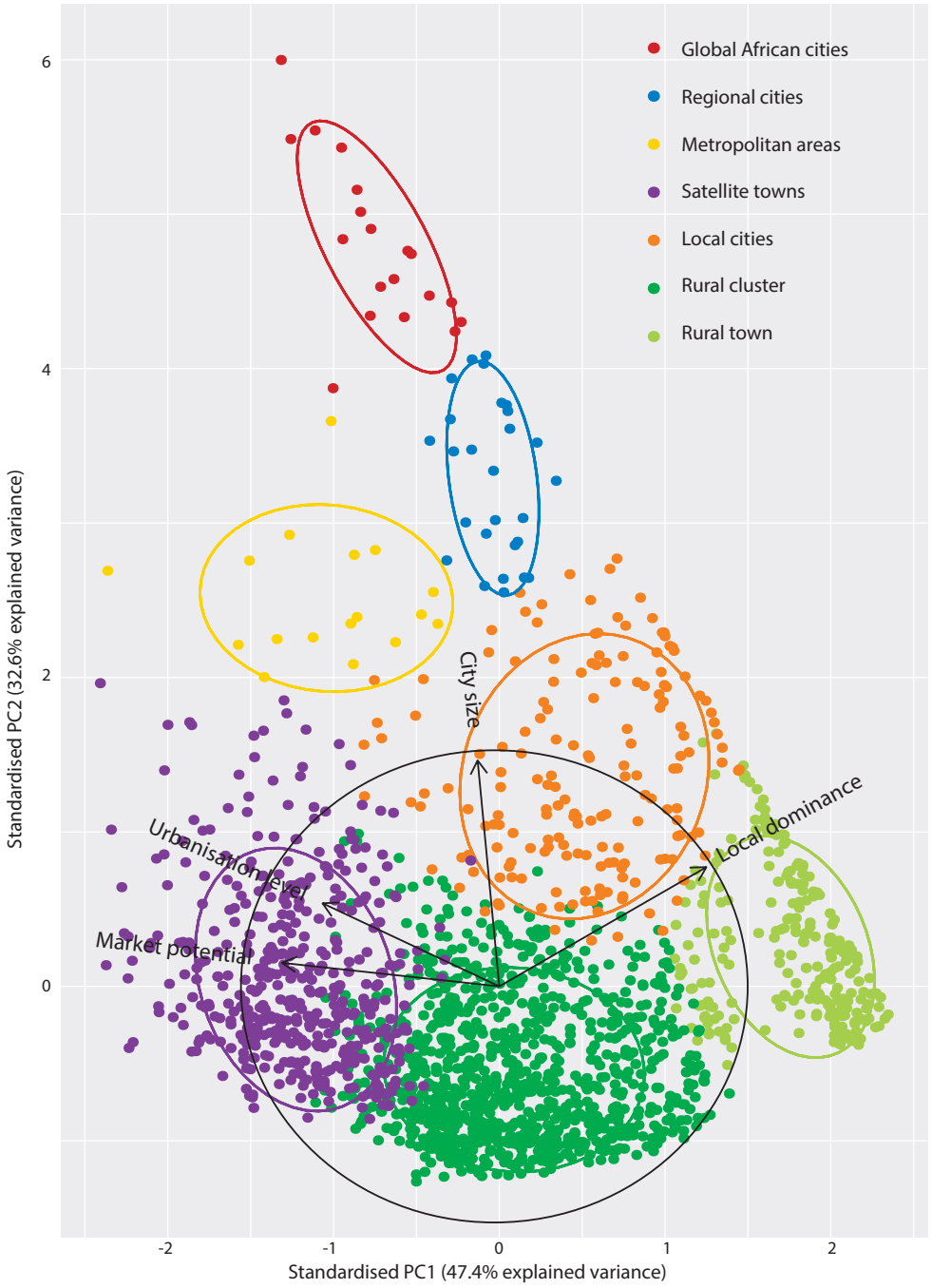
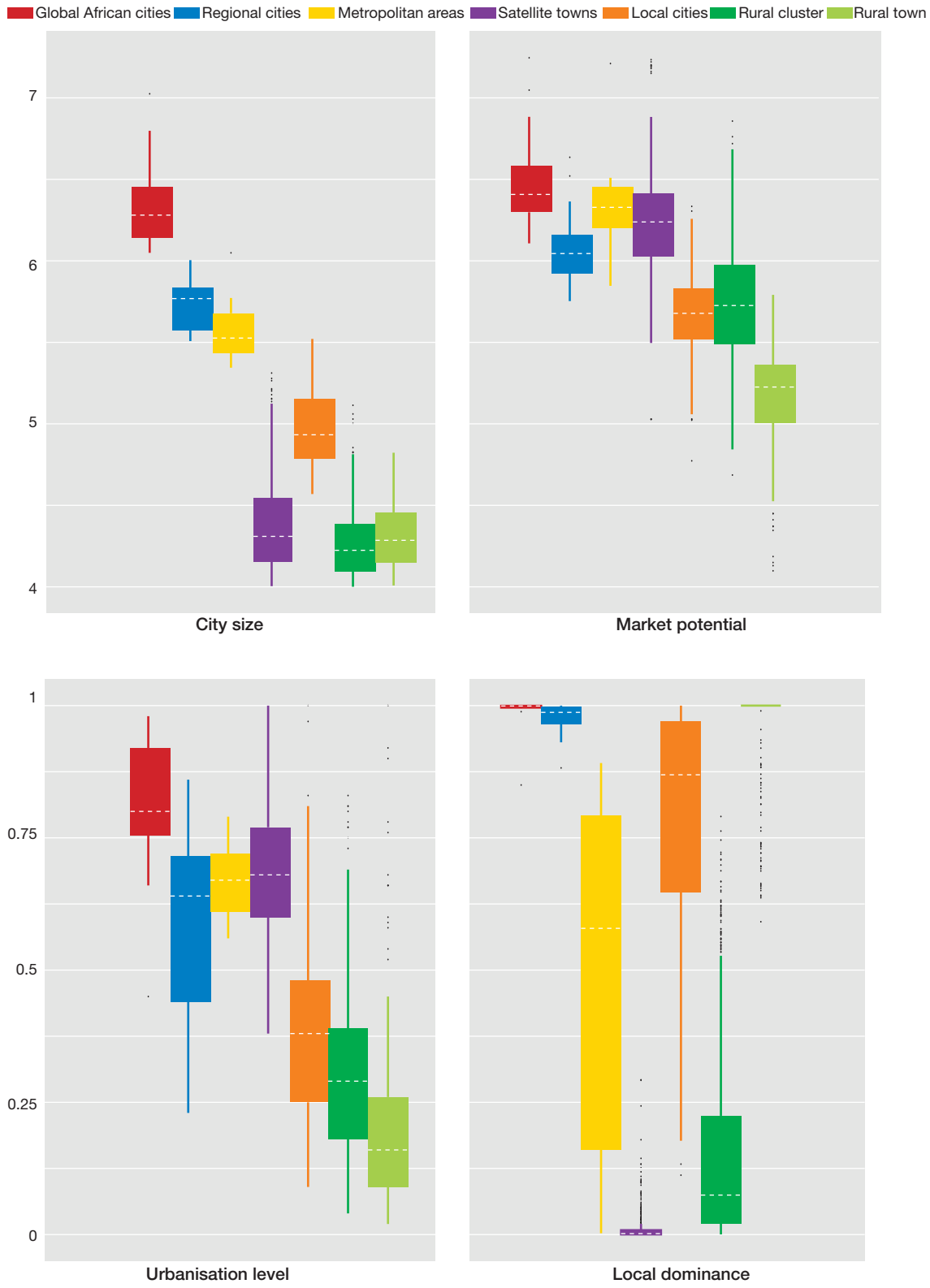


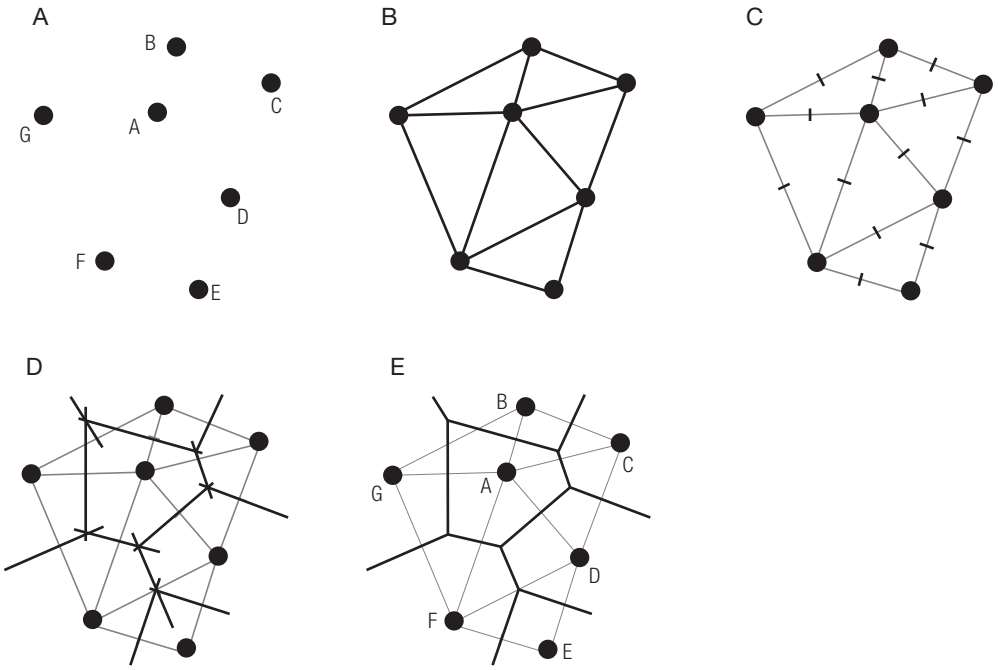
Figure A4.2
Box plot of city group



ANNEX 5. VORONOI DIAGRAMME

The Voronoi diagramme is a partition of the space into non-overlapping cells such that each point (except for the points lying on the boundaries of the cells) is identified with a unique cell. For a given set of points in space, which in our case are the (x,y) co-ordinates of the 1 939 agglomerations in West Africa, the resulting partition identifies the region that is closest to each point. The boundaries between two tiles are the set of points that are equidistant to the corresponding points on the cells. The Voronoi partition is easily interpreted as the region that is closest to each point. For the 1 939 agglomerations, each location on the map is identified with its closest city. For the interpretation, larger Voronoi cells usually correspond to regions that have fewer agglomerations and smaller Voronoi cells correspond with regions in which there is a high density of points or cities.

Figure A5.1
Voronoi cells



Source: authors' calculation

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