Assessment of Land Use Efficiencies of Ghanaian Cities: Case Study of Sekondi-Takoradi Metropolis

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DOI: http://dx.doi.org/10.4314/sajg.v12i1.6

Abstract

Urban land use efficiency is a key indicator of the resilience of a city and its sustainability. However, in Africa and Ghana, information on land use efficiency in cities is lacking. There is little to no understanding as to how urban development is affecting the lives of people, the economy and the environment. In this study, geospatial techniques were used to estimate urban land use efficiency (LUE), the changes in the built-up area per capita and urban sprawl speed (SS) for the Sekondi-Takoradi Metropolitan area. Multi-temporal land use maps and population data were used for this purpose. The results indicate that generally land use efficiency in the city has improved since 2002, from a value of 0.67 between 2002 and 2008 to 0.88 between 2008 and 2016, and that it deteriorated slightly above one (1) between 2016 and 2021. The city has also become more built up over the period, with the rate of sprawling also declining. However, the study shows that land in the city that was either agricultural land or grassland has been converted to built-up land use/land cover, which is indeed a challenge for urban agriculture. The results of this study can be used by city authorities as a guide to urban development.

Key words: land use efficiency, multi-temporal, sprawling, sustainability, urban

1. Introduction

In 2018, 55% of the global population lived in urban areas, and by 2050, the figure is projected to increase to 68% (UN, 2019). Furthermore, in many countries, the rate of urbanisation has outpaced the population growth rate (Koroso et al., 2021). Urbanisation in Africa is also increasing at a faster rate. As of 2019, 43% of the people in Africa were living in urban areas (UN, 2019). According to the Ghana Statistical Service (GSS, 2021), the rate of urbanisation is high as 57% of the people were living in urban areas in 2021 and in seven out of the 16 regions of Ghana, more than 50% of the people were living in urban areas.

Urbanisation leads to changes as people move from rural to urban settlements, with a significant increase in the urban population and changes in job types, lifestyle and culture being the ensuing results (Schiavina *et al.,* 2019; UN, 2019). The permanent changes to the natural environment through rapid urbanisation can impact negatively on agriculture and food security, water resources, biodiversity and health (Li *et al*., 2021; Vogler and Vukomanovic, 2021). Sustainable urbanisation has therefore been recognised as an important concept for sustainable development and has been captured as one of the 17 Sustainable Development Goals (SDG) (UN, 2021). Sustainable urbanisation (SDG11) is focused on achieving safe, inclusive, resilient and sustainable human settlements (Schiavina *et al*., 2019). As more than 60% of the world population will be living in urban areas in the near future (UN, 2019), the attainment of SDG11 will be crucial, as will be the attainment of many other SDGs, as there are interactions between many of the goals (Pradhan *et al.,* 2017). Land use efficiency (SDG11.3.1) is one of the most important indicators for attaining the sustainability of the city (Cai et al., 2020) and an understanding of land use efficiency stresses the necessity to support effective planning systems towards achieving sustainable cities.

Although the deadline for the attainment of the SDGs is only eight years away, there is, to the best of our knowledge, limited information on assessing the progress that has already been made towards alleviating the challenges in Africa, as listed under SDG11.3.1. As part of an effort to track the progress of the implementation of the SDGs in Ghana, this study aims to determine and analyse multi-temporal changes in urban LUE for the Sekondi-Takoradi Metropolitan Area (STMA), by using multi-temporal maps of the built-up area, derived from Earth Observation (EO) data. The study also analyses urban sprawl speed (SS), city densification (D) and built-up area per capita ((BpC_t), to clarify the nature of urban expansion and how it relates to land use efficiency in the city.

2. Methods

2.1. Study Area

Sekondi-Takoradi Metropolis (Figure 1) is the capital of the Western Region of Ghana. The metropolis is located between latitudes 4° 52′ to 5° 02′ North and longitudes 1°39′ to 1°49′ West. With an area of approximately 209 km^2 , it is the most urbanised area in the Western region of Ghana, with 96% of its citizens living in urban settings (GSS, 2010). The twin city has an average annual temperature of about 22 °C. Rainfall on the other hand is bi-modal, peaking between March and July, with a minor season between August and November. Mean annual rainfall peaks at about 1380 mm and the natural vegetation has mostly been degraded over the years. Three rivers systems, namely, the Anankwari River in the east, the Whin and the Kansawora Rivers to the west, as well as the Essei and the Butre lagoons, drain the metropolis. The indigenous communities on the outskirts, as well as along the coast, engage in subsistence farming, producing crops such as maize, plantain, cassava, cocoyam, oil palm, vegetables, and coconut. Marine fishing is an activity also worth mentioning.

Economic activities in the metropolis have increased tremendously since 2007, when crude oil was discovered in commercial quantities atCape Three Points, off the coast of Ghana. Sekondi-Takoradi has served as the base for the oil companies and service providers. As a result of the introduction of the petroleum industry, commercial activities have increased, which in their turn have also resulted in a high demand for accommodation and other services. A visit to the city revealed that rapid expansion is taking place in terms of the number of buildings, especially on the outskirts, and the remodelling of several old buildings near the city centre.

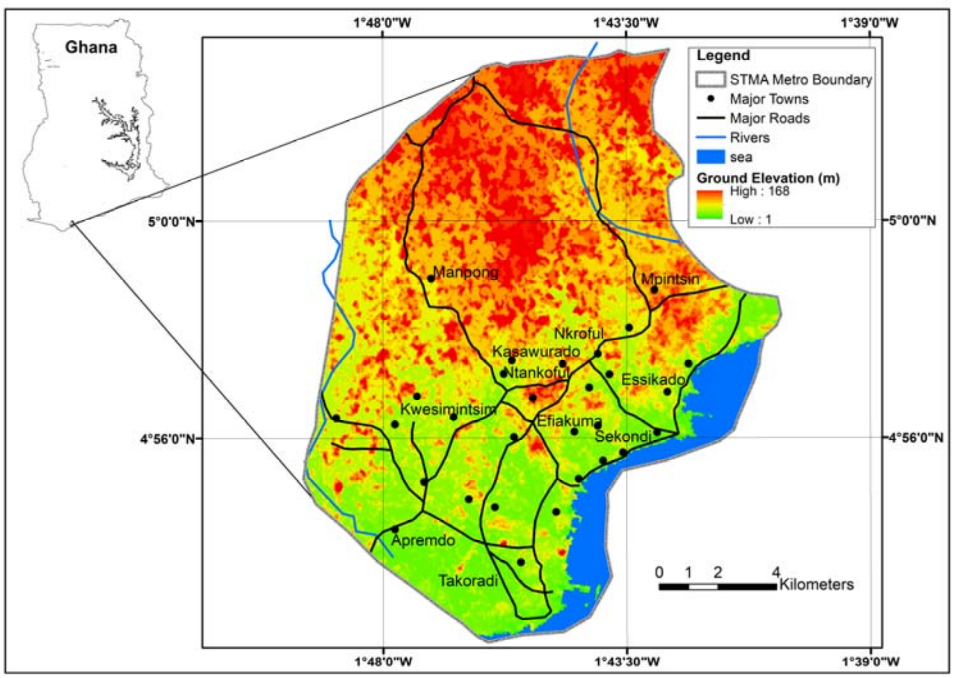

Figure 1 Map of Study Area

2.2. Data Acquisition

The data used for the study consisted of satellite images from Sentinel 2, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 5 Thematic Mapper (Table 1). The images were downloaded from the European Space Agency (ESA) and the United States Geological Survey (USGS) websites. Other data included the Digital Elevation Model (DEM), and shapefiles of the study area depicting the boundary of the metropolis, road networks, rivers and the coastline. The latter were, obtained from several sources, including the Survey of Ghana, Google Earth and the USGS EarthData portal. The study also used human population data from the STMA for the 2000, 2010 and 2021 census years, which were obtained from the Ghana Statistical Service (GSS, 2005, 2014, 2021).

Table 1: Satellite Images used in the Study

Sensor	Spatial resolution (m)	Number of Bands	Date of Acquisition
Sentinel 2	10 (band 2,3,4,8), 20 (band 5,6,7, 8a, 11, 12) and 60 (band 1, 9.10)	13	26th January, 2021
Landsat 7 ETM+	30 (band 1 to 5, 7), 60(band 6), 15 (band 8)	8	15th January, 2002 6th January 2016
Landsat 5 TM	30 (band 1 to 5, 7), 120 (band 6)	7	1st February, 2008

2.3. Land Cover Mapping

The land cover of the Sekondi-Takoradi metropolitan area was mapped using satellite images from three sensors (Table 1). The downloaded images were extracted and their subsets were created to cover the study area. The red-blue-green image composites were also created to support the visual identification of various land covers. Line strips on the 2016 Landsat ETM+ image were filled using the gap mask file provided by the USGS. Training samples were extracted from high-resolution Google Earth images, corresponding, where possible, to the year of image. The training data were supplemented with local knowledge of the study area. Five land cover classes (Table 2), corresponding to the level II land cover classification scheme of the USGS, were identified and mapped.

Table 2: Land Cover Nomenclature for Sekondi-Takoradi Metropolitan Area

Land Use	Description
Built-up	Industrial, commercial and public built-up areas, transportation routes, villages, paved/unpaved roads, car/truck parks, bare lands, playing fields
Water	Sea, lagoons, lakes, rivers, ponds
Secondary forest	Degraded/re-growth forest and tree crops (cocoa, palm) and rubber trees, with an open canopy
Evergreen forest	Tall trees, including indigenous species, and mature rubber trees, located mostly in the forest reserves and on the plantation farms
Shrubs/farms	Short tree species and non-tree vegetation, such as herbs, grasses and farmlands (cocoa, palm, plantain, cassava, maize), recently cleared forests

2.4. Land Use Efficiency and Built-up Area per Capita

Urban land use efficiency (LUE) relates to the level of interaction between human economic activities and nature. It is an index which has been used extensively in quantifying the degree of sustainability of urban systems or land (Zitti *et al*., 2015; Yang *et al.,* 2017; Melchiorri *et al*., 2019; Cai et al., 2020). It is commonly defined as an input-output ratio in terms of land, capital and labour. Urban LUE falls under the United Nations' SDG 11.3.1 and is one of the key variables that can be used to track progress towards alleviating the challenges of sustainable human settlement planning. Urban LUE can be estimated as the ratio of land consumption rate (LCR) to population growth rate (PGR) (Schiavina *et al.,* 2019).

Furthermore, the built-up area per capita (BpC_t) and the changes it undergoes (BpC_c), which together indicate whether an urban area is densely or sparsely populated, serve as an additional index that can be used to measure a city's progress towards sustainable development. BpC_t (m^2/year) is the average area that is built up and that is available to an individual in an urban area each year. Built-up area per capita can be estimated as the ratio of urban area at a particular time to the population of the same area. In this study, LUE and BpC_t (equations 1, 2 and 3) were calculated on the basis of meta data from the UN Stats website (https://unstats.un.org/sdgs/metadata).

$$LUE = \frac{LCR}{PGR} = \frac{LN\left(\frac{Urb_{t+n}}{Urb_t}\right)}{LN\left(\frac{Pop_{t+n}}{Pop_t}\right)} \quad (1)$$

$$BpC_t = \frac{Urb_t}{Pop_t} \quad (2)$$

$$BpC_c = \frac{BpC_{t+n} - BpC_t}{BpC_t} x100 \quad (3)$$

Where

LN is the natural logarithm, Urb_t and Urb_{t+n} represent the area of land consumed (built-up) as at the initial year t and the final year t+n, respectively. Pop_t and Pop_{t+n} represent the population of the built-up area as at the initial year and the final year, respectively. BpC_t and BpC_{t+n} represent the built-up area per capita as at the initial year and the final year, respectively, and BpC_c represents the change in the built-up area per capita.

2.5. Urbanisation and SDGs

Urban sprawl is a phenomenon whereby a suburban area is characterised by low-density development and an over-dependence on the automobile for transportation. Urban sprawl is a challenge to the attainment of the United Nations' SDGs (Vogler and Vukomanovic, 2021) on sustainable cities, as it could represent an aspect of unsustainable land use. Since arable lands are converted into low-density, single-use areas, it could also affect the ecology and food security of a region. Understanding the spatial and temporal patterns of sprawl within a city is necessary if effective policies for increasing efficiencies of urban land use are to be developed and implemented.

In this study, urban sprawl was analysed using two indicators (equations 4 and 5), the Sprawl Speed (SS) (Li *et al*., 2021) and Densification (D) (Koroso *et al.*, 2021). Sprawl Speed is the expansion rate of the annual built-up area, measured at different time intervals, while densification measures the area of undeveloped land within the built-up area that has been developed over a period. Densification also contributes to the sustainability of a city's development (Wang *et al*., 2019).

$$SS = \frac{A_{t2} - A_{t1}}{t_2 - t_1} \quad (4)$$

$$D = \frac{built\ up\ area\ t2 - built\ up\ area\ t1}{built\ up\ area\ t1} \times 100 \quad (5)$$

Where

D (%) is built up densification over a period, SS (Km^2/year) is the sprawl speed, At_2 and At_1 are the built-up areas in the final year and the initial year, respectively, while t_1 and t_2 are the initial year and the final year, respectively. Table 3 lists the range of parameters (equations 1 to 5), the range of values and their interpretation.

Table 3 Values of Parameters and their Interpretation

Change Trend	**Interpretation**
$0 \leq LUE \leq 1$	PGR > LCR, densification and efficient land use
$1 < LUE < 2$	PGR < LCR, low density, inefficient land use
$LUE > 2$	LCR at least twice PGR, inefficient land use
$0 \leq D \leq 100$	0: lowest, 100: maximum
$SS \geq 0$	The lower the better
$0 \geq BpC_c \geq 100$	High values: low densification, low values: high densification

3. Results

3.1. Change in the Built-up Area

Figure 2 presents the land use /land cover (LULC) maps of the Sekondi-Takoradi Metropolitan area for 2002, 2008, 2016 and 2021, while Table 4 presents the LULC statistics for the same period. It can be observed from the maps that generally the farmland areas, as well as the vegetation (shrubs, secondary and evergreen forests) in the metropolis have declined, while the built-up area has consistently increased over the period. In 2002, the built-up area covered only 20% of the total area of the city, but it increased to 28% and 30% in 2008 and 2016 respectively. By 2021, the built-up area occupied more than 34% (71.86 km^2) of the city. The LULC of the city of Sekondi-Takoradi experienced transitions in different directions over the study period. Table 5 shows a change matrix which depicts the various land use/ land cover transitions. It can be observed from Table 5 that the built-up area has taken over the space which was previously occupied by shrubs/farms (*i. e.* 10.41% from 2002 to 2008, 5.96% from 2008 to 2016 and 7.18% from 2016 to 2021). This is the reason why the area occupied by shrubs/farms declined over the study period. Overall, secondary and evergreen forests have declined. In fact, some of their space has been taken up by shrubs/farms; this, in spite of small increases, can be attributed to the maturation of the rubber trees located in the north-western portion of the study area.

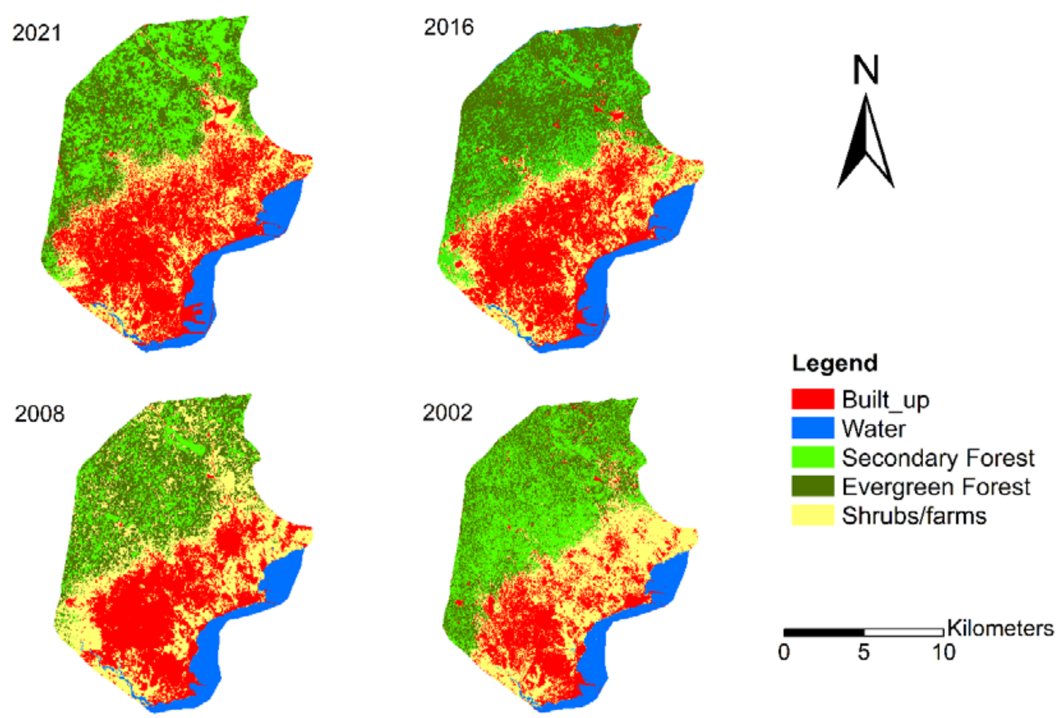

Figure 2 Land Use/Land Cover Maps for the Sekondi-Takoradi Metropolitan Area, Ghana

Table 4 Land Cover Statistics for Sekondi-Takoradi

	2002	2008	2016	2021
Land cover	**Area (Km^2 (%))**	**Area (Km^2 (%))**	**Area (Km^2 (%))**	**Area (Km^2 (%))**
Built-up	41.27 (19.73)	57.78 (27.66)	64.13 (30.67)	71.86 (34.36)
Water	16.38 (7.83)	17.44 (8.35)	16.91 (8.09)	15.70 (7.51)
Secondary forest	54.90 (26.24)	21.34 (10.22)	37.77 (18.06)	39.34 (18.81)
Evergreen forest	44.52 (21.28)	51.39 (24.60)	53.26 (25.47)	42.69 (20.41)
Shrubs/farms	52.12 (24.92)	60.94 (29.17)	37.03(17.71)	39.56 (18.91)

Table 5: Change Matrix (%) for Sekondi-Takoradi Land Cover

(a) 2002-2008

		From 2002				
	Landcover	Builtup	Water	Secondary forest	Evergreen forest	Shrubs/farms
To 2008	Builtup	16.57	0.04	0.31	0.36	10.41
	Water	0.23	7.75	0.01	0.00	0.36
	Secondary forest	0.03	0.00	7.01	2.84	0.07
	Evergreen forest	0.31	0.00	13.02	10.96	0.76
	Shrubs/farms	2.45	0.06	6.14	6.87	13.46

(b) 2008-2016

		From 2008				
	Land Use	Builtup	Water	Secondary forest	Evergreen forest	Shrubs/farms
To 2016	Builtup	23.84	0.42	0.07	0.46	5.96
	Water	0.06	7.80	0.00	0.01	0.12
	Secondary forest	0.05	0.01	5.51	7.83	4.17
	Evergreen forest	0.08	0.00	4.22	15.78	5.96
	Shrubs/farms	3.66	0.12	0.16	0.97	12.76

(c) 2016-2021

		From 2016				
	Land Use	Builtup	Water	Secondary forest	Evergreen forest	Shrubs/farms
To 2021	Builtup	25.75	0.54	0.56	0.60	7.17
	Water	0.13	7.28	0.00	0.00	0.09
	Secondary forest	0.10	0.06	8.06	10.42	0.16
	Evergreen forest	0.46	0.07	6.18	13.25	0.54
	Shrubs/farms	4.27	0.13	2.76	1.75	9.68

3.2. Land Use Efficiency and Urbanisation

Table 6 presents the land use efficiency and the built-up per capita statistics for Sekondi-Takoradi for four time slices (2002-2008, 2008-2016, 2016-2021 and 2002-2021). The table shows that the highest urban expansion or land consumption rate (LCR) of 0.056 occurred between 2002 and 2008, while the lowest occurred between 2008 and 2016. The highest population growth rate (PGR) also occurred between 2002 and 2008, while the lowest was between 2008 and 2016. Furthermore, the metropolis recorded land use efficiency (LUE) statistics of 0.672 between 2002 and 2008, which increased marginally to 0.877 and 1.149 for the second (2008-2016) and third (2016-2021) periods, respectively. Table 6 also presents densification (D) and change in built-up area per capita (BpCc) for the Sekondi-Takoradi Metropolitan area between 2002 and 2021. During the first period (2002-2008), densification (D) was 39.997%, but it declined significantly for the second (2008 and 2016) and third periods (2016 and 2021). The overall densification (urban infilling) between 2002 and 2021 was, however, high (74%). Moreover, BpC_t declined from 121.669 m^2/year in 2002 to 103.262 m^2/year in 2008, further reduced to 101.767 m^2/year in 2016, and increased marginally to 103.284 m^2/year in 2021, indicating that over the 19-year period, built-up space per person in the metropolitan area has generally declined by 15%. Table 6 also shows that urban sprawl speed (SS) declined from 2.751 km^2/year over the first period (2002-2008) to 0.793 km^2/year over the second period, but increased to 1.546 km^2/year over the third period (2016-2021).

Table 6 Land Use Efficiency and Urban Sprawl

	Period			
Parameter	**2002-2008**	**2008-2016**	**2016-2021**	**2002-2021**
LCR	0.056	0.013	0.023	0.029
PGR	0.083	0.015	0.020	0.038
LUE	0.672	0.877	1.149	0.772
D (%)	39.997	10.986	12.054	74.107
BpCc (%)	-15.1	-1.4	1.5	-15.1
Sprawl speed (km2/year)	2.751	0.793	1.546	1.610

4. Discussion

The study has shown that land use/land cover changes in Sekondi-Takoradi city are pervasive as the urban area has undergone substantial changes (more than 40% expansion) over the past 19 years. The built-up area has expanded and taken over spaces previously occupied by shrubs/farms, which is an indication that the land available for urban agriculture in the city has been declining. This could have negative implications for urban food security, especially with regard to vegetables that are grown locally.

Similarly, during the study period, land use/land cover efficiency has varied. In the first period, urban land use efficiency (LUE), which was 0.672, increased to 0.877 and increased again to 1.149, in the second and third periods, respectively. An LUE value of 0.672 is an indication of efficient land use (Table 3), where the population growth rate (PGR) is higher than the urban expansion rate (LCR). Furthermore, during the second period (2008-2016), the LUE improved as the value then came closer to one (1), which is also an indication of efficient land use (Koroso *et al.,* 2021), as the LCR was lower than the PGR. Furthermore, during the third period, the LUE started to deteriorate as its value increased slightly above one (1), since the LCR was greater than the PGR. As shown in this study, efficient land use allocations are achieved when the population growth rate is higher than the urban expansion rate, which should be the objective of all cities and spatial planning departments. However, measures need to be developed to curtail the deterioration of efficient land use allocations, which occurred during the period 2016-2021. Although not very high, they are an indication that the urban expansion rate is beginning to outpace the population growth rate and may, if not managed well, result in low density development.

The declining densification percentage during the study period indicates that the amount of undeveloped land within the city is declining . It suggests that the city is becoming more built up. This trend towards densification may be attributed to several reasons, including the increased economic activities which have resulted in the boom in construction related to the oil industry since 2011, when the potential of the oil reserves in Ghana was first realised. A visit to the city shows that massive construction is currently in progress, especially in those areas which were undeveloped or disused industrial land or sites. Since the discovery of oil, there has also been an increase in the number of hotels along the coast - to cater for the many visitors to the city Additionally, although the urban area has expanded tremendously over the years, the built-up area per capita, which is the space available per person, has not changed much. This is not surprising, since the urban expansion rate is at par relative to the population growth rate, thereby resulting in efficient land use (Table 6). It is also refreshing to note that urban sprawl is slowing down in the Sekondi-Takoradi city as the sprawl speed has declined marginally over the past 19 years. With the slowing down of sprawl, the city authorities will be better placed to plan and provide infrastructure and services to all sections of the city and thus promote the attainment of sustainable development in the city.

5. Conclusion

This study has shown that the city of Sekondi-Takoradi has experienced substantial growth in its built-up area over the 19-year study period; the land in the urban area which was previously occupied by shrubs/farms has been taken over by built-up land use/land cover. The study has also shown that land has generally been efficiently allocated and the city has become denser than it previously was in 2002. There are also indications that the urban sprawl speed is declining. City authorities will need to develop measures to ensure that further outward expansion of the city is managed well, to ensure that the provision of services and infrastructure is effective, as the land consumption rate is beginning to outpace the population growth rate.

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