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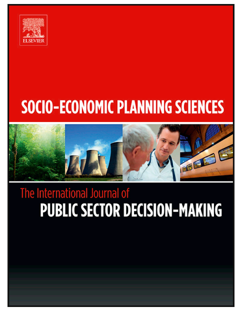

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Easy Come, Easy Go: Short-term Land-use Dynamics *vis à vis* Regional Economic Downturns

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Easy Come, Easy Go: Short-term Land-use Dynamics *vis à vis* Regional Economic Downturns

Abstract

The present study postulates distinctive land-use dynamics along the economic cycle, and tests against diverging trends over time of urban and non-urban land-uses with characteristic economic potential. Short-term land-use changes over seven time windows encompassing the last three decades (1992-2020) were investigated in metropolitan Athens (Greece), a mono-centric region experiencing complex economic downturns. Based on diachronic land-use maps with homogeneous spatial resolution and nomenclature derived from ESA Climate Change Initiative (ESA-CCI), a change detection analysis was run considering mean patch size, distance from downtown, and specific entropy-based metrics of landscape diversification (Shannon-Wiener H' diversity index and Pielou J evenness index). Results of a canonical correlation analysis document differential intensity and spatial direction of change during expansions and recessions associated with distinctive socio-demographic profiles. Metropolitan growth followed a radio-centric (land-saving) model during economic expansions with intense urbanization of fringe land. A more dispersed settlement model – reflecting urban sprawl – was associated with economic stagnations, involving land at progressively distant locations from downtown. Landscape diversification was higher under stagnations and lower during expansions.

Keywords: Metropolitan cycle; Sprawl; Indicators; Partial Least Square regression; Mediterranean Europe.

1. Introduction

New socioeconomic structures and functions emerged and consolidated since the second half of the 20th century, altering – more or less rapidly – the dominant landscape of regions and countries (Seto and Shepherd, 2009; Garcia, 2010; Allan et al., 2022). Urban expansion is undoubtedly the most impactful process at the base of such transformations (Seto and Kaufmann, 2003; Turner, 2005; Lambin and Meyfroidt, 2010). Going together with economic growth, an intense debate on how development levels result in specific urban patterns (e.g. Salvati et al., 2016), and the consequence on land-use change over larger regions (Liu et al., 2018), arose in recent decades. Wealth accumulation, and the subsequent increase in personal incomes, were assumed to fuel rising population inflows in contemporary cities (Wang and Zhang, 2001; Winarso and Firman, 2002; Zhang et al., 2021). As a consequence, cities – especially in advanced economies – begun the most representative agent of change for regions and countries in the last three-four decades (Seto et al., 2011; Morelli et al., 2014; Egidi et al., 2020).

Together with urbanization, other processes of land-use change involving non-urban landscapes (e.g. agricultural intensification, rural depopulation with cropland extensivation, and natural recovery of abandoned/relict land), revealed latent relationships with background conditions (Paulsen, 2013; Kim et al., 2015; Lauf et al., 2016). They exerted, together, relevant environmental impacts and important transformations in socio-demographic structures across regions (Hewitt and Escobar, 2011; Haase et al., 2013; Hongling and Teng, 2013). In this perspective, earlier studies have occasionally identified the stylized facts at the base of complex linkages between economic downturns, socio-demographic processes, and land-use change during economic expansions and recessions (Wang and Monzon, 2016; Tulumello et al., 2020; Tomao, 2021); a comprehensive interpretation of this multivariate relationship is far from being achieved.

Up to now, relatively few studies have identified differential land-use change trajectories associated with the economic cycle at the regional scale (e.g. Baing, 2010; Ceccarelli et al., 2014; Smiraglia et al., 2015; Woestenburg et al., 2018). Comparative analyses at country or continental scales were even scarcer (e.g. Colantoni et al., 2016), depending on the limited availability of spatially coherent, diachronic land-use maps in both advanced and emerging economies (Pérez, 2010; Nevado-Pena et al., 2015; Salvati and Ranalli, 2015). Assumed as a driver of land-use change, economic downturns – reflecting trends over time in relevant variables such as income or unemployment – were heterogeneously defined and operationalized with the use of sometimes incoherent indicators (e.g. Goldblum and Wong, 2000). Building activity in metropolitan areas was another variable frequently considered when defining economic cycles (Millington et al., 2011). Most of these studies, however, were aimed at comparing only two economic periods (Cartier, 2001), the one characterized by income growth, wealth accumulation and activity expansion (Chorianopoulos et al., 2010), and the other one featuring recession or stagnation (Garcia-Coll and Lopez-Villanueva, 2018). The impact of multiple socioeconomic drivers of change over longer (and more differentiated) time periods and scales has been occasionally estimated (Diaz-Pacheco and Garcia-Palomares, 2014; Falco and Chiodelli, 2018; Salvati et al., 2018).

The present study assumes land-use stocks and flows over multiple time intervals as an economically relevant measure associated with metropolitan cycles (Chorianopoulos et al., 2014), and the analysis of the intrinsic correlation with key socioeconomic indicators as a way of investigating the role of economic downturns in landscape transformations (Cuadrado-Ciuraneta et al., 2017). Recent improvements in Geographical Information Systems (GIS), remote sensing and geo-spatial analysis, have contributed to a refined understanding of such changes (Huang and Tang, 2012; Kazemzadeh-Zow et al., 2017; Gounaridis et al., 2019), allowing a diachronic, high-resolution monitoring of land-use spatial structure *vis à vis* local economic dynamics (Jaeger et al., 2010; Orenstein and Hamburg, 2010; Kim et al., 2015), and justifying additional efforts – both theoretical and empirical – in this research direction.

Based on such improvements, landscape science has also introduced indicators that estimate the inherent diversification in land-use spatial distribution (Hasse and Lathrop, 2003), namely Shannon-Wiener H' diversity index and Pielou J evenness index (Colantoni et al., 2015). Earlier studies (e.g. Allen, 2003) demonstrated the potential of such approaches when explaining the latent relationship between landscape transformations, land-use change and economic dynamics – delineating drivers and effects more effectively than other indicator-based approaches (Aguilar, 2008; Cheshire and Magrini, 2009; Wilson and Brown, 2015). By integrating landscape indicators with basic indicators that describe the evolving background context (Wu and Zhang, 2012; Weilenmann et al., 2017; Zambon et al., 2018), our study investigates the socioeconomic implications of land-use change, taken as a function of the economic cycle (Thinh et al., 2002). In other words, we assumed economic expansions and recessions as associated with distinctive land-use change trajectories - with morphologies and spatial structures intimately related with socio-demographic transformations and economic dynamics (Sorensen, 2000; Hoymann, 2011; Oueslati et al., 2015).

Based on these premises, our study investigates short-term land-use changes over seven time windows (four years each) encompassing the last three decades (1992-2020) in metropolitan Athens (Greece), a mono-centric region (Pili et al., 2017) whose recent history reflects economic downturns generalizable to broader socio-demographic contexts in Mediterranean Europe (Maloutas, 2007; Gospodini, 2009; Di Feliciantonio and Salvati, 2015). Diachronic land-use maps with standardized spatial resolution and homogeneous nomenclature system derived from ESA Climate Change Initiative (ESA-CCI), were the main geo-spatial information source of this study. The related land-use and socioeconomic indicators were explicitly analysed, likely for the first time in the recent literature, over a sufficiently long and homogeneous time frame reflective of sequential stages of expansion and stagnation (Salvati et al., 2016), providing insights in the latent mechanisms of contemporary city growth.

2. Methodology

2.1. Study area

We took metropolitan Athens, the largest part of the administrative region of Attica in Central Greece (SM.Figure 1), as the study area (Salvati and Serra, 2016). Hosting the capital city of the Greek state since its formation – approximately two centuries ago – metropolitan Athens extends nearly 3000 km^2 of land administered by 115 municipalities (Di Feliciantonio et al., 2018), and concentrates more than 3.7 million resident inhabitants (2021 census). Being representative of metropolitan Athens (Ciommi et al., 2019), this area coincided with the Athens' Large Urban Zone (Rontos et al., 2016), as defined in the framework of the 'Urban Atlas' European program (European Environment Agency, 2011). Metropolitan Athens' orography consists of 20% lowlands (< 100 m at sea level) and 50% uplands (elevation ranging between 100 and 600 m). Steep areas extend nearly 30% of the area and include Parnitha (1429 m), Pendeli (1107 m), and Imitos (1026 m) mountains (Giannakourou, 2005). Three lowland districts located immediately out of Athens: Marathon plain, devoted to agriculture (Pili et al., 2017), Messoghia plain, characterized by multiple land-use mixing cropland and service settlements including the international Airport 'E. Venizelos' (Morelli et al., 2014), and Thriasio plain - one of the largest industrial sites of Greece (Colantoni et al., 2016). Consisting mostly of residential and industrial settlements, the Greater Athens' area (namely the Athens' compact conurbation) extends 430 km^2 and hosts more than 30% of the Greek population (2021 census).

2.1.1. The recent expansion of metropolitan Athens

Having assumed since the 1950s a mono-centric structure consolidated with compact urbanization in the 1960s and the 1970s (Salvati and Serra, 2016), settlement de-concentration has been observed in the area since the early 1980s (Di Feliciantonio and Salvati, 2015) with the consequent spillover of resident population in neighbouring districts (Di Feliciantonio et al., 2018). In that period, a complex stratification of socioeconomic forces has led Athens evolving toward a three-belts structure (Zambon and Salvati, 2019): (i) a strictly urban zone, within a distance from downtown Athens < 10 km; (ii) a peri-urban zone constituted of fringe municipalities (i.e. with a distance from downtown Athens between 10 and 20 km) displaying intermediate population density, moderate demographic growth, and a medium-low share of built-up areas in the municipal surface area; and (iii) a strictly rural area constituted of remote municipalities, with a distance from downtown > 20 km.

In the last two decades, Attica experienced sequential expansion and recession waves in line with the dominant cycle at both national and macro-regional (Mediterranean) scale (Chorianopoulos et al., 2010). Long-term trends in selected socioeconomic indicators for the whole of Greece were illustrated in SM.Figure 2. After a relatively short stagnation in the early 1990s (Gospodini, 2009), Athens experienced a remarkable 'building boom' between the mid-1990s and the late 2000s (Couch et al., 2007). The announcement of the 2004 Olympics in 1996 kicked off state-driven infrastructural policies fuelling a residual planning deregulation after decades (1950s-1970s) of settlement informality and out-of-plan urbanization (Beriatos and Gospodini, 2004). Impacts of the subsequent recession have probably been stronger in Athens than in any other European city, persisting – at least partially – until few years ago (Chorianopoulos et al., 2014).

2.2. Elementary data and variables

The geo-spatial dataset used in this work has been derived from the Land Cover project within the European Space Agency (ESA) Climate Change Initiative (CCI). CCI is a program of Global Climate Observing System and the Committee on Earth Observation Satellites that provided an adequate, comprehensive, and timely response to the challenging set of requirements for (highly stable) long-term satellite-based products (https://www.esa-landcover-cci.org/?q=node/1). The chosen dataset covers a time frame of 28 years between 1992 and 2020, and consists of global maps at 300m spatial resolution, with a legend based on the United Nations Land Cover Classification System

(LCCS) and a thematic details level consistent with existing (global and regional) geo-spatial land products (European Space Agency, 2017). Maps were obtained from 300 m MERIS (Medium Resolution Imaging Spectrometer), 1 km SPOT-VEGETATION, 1 km PROBA-V (Project for On-Board Autonomy, with the V standing for Vegetation), and 1 km AVHRR (Advanced Very High-Resolution Radiometer) imagery. The Geographic Coordinate System used for the global land database was based on the World Geodetic System 84 (WGS84) reference ellipsoid.

2.2.1. Data preparation and preliminary analysis

CCI timing allows a quantitative analysis of land-use changes over seven consecutive time intervals (four years long) between 1992 and 2020. Based on the 37 original land classes, the available raster files were reorganized into 10 summary classes and four basic groups (SM.Table 1) adopting sequential operations (Colantoni et al., 2016). First, the spatial distribution of land-use classes have been examined at 8 years (1992, 1996, 2000, 2004, 2008, 2012, 2016 and 2020). Second, a land change detection (i.e. a quantification of the surface area undergoing change from a given class to another) was carried out at the seven time intervals derived from the previous time frame (1992-1996, 1996-2000, 2000-2004, 2005-2008, 2009-2012, 2013-2016, 2017-2020).
Based on this rationale, the raster maps were subjected to geo-spatial elaborations (*sensu* Kazemzadeh-Zow et al., 2017) aimed at calculating (i) the surface area of each land-use class at each examined year (n = 8); (ii) the surface area experiencing land-use change, for each time interval (n = 7); (iii) the average distance (km) of pixels undergoing land-use change (by initial and final class) from downtown Athens (Platia Syntagmatos). Moreover, class diversification of pixels experiencing land-use change was estimated, separately for each time interval, using Shannon Diversity Index (H') as follows:

$$H' = -\Sigma pi * ln(pi) \qquad \text{(Equation 1)}$$

where p_i is the proportion of a given land-use in the whole landscape. The higher the value of H', the higher the diversity of land undergoing changes from one class to another. A standardized Pielou evenness index (J) has been additionally calculated (Pili et al., 2017) as follows:

$$J = H/ln(S) \qquad \text{(Equation 2)}$$

where S stands for the total number of land-use classes undergoing change over a given time interval (Ciommi et al., 2019). If all classes are represented in equal numbers in the sample, then J equals 1. If one class dominates the landscape matrix, J is close to zero (Di Feliciantonio et al., 2018). To derive such information, the available raster files, and the related tabular attributes, have been processed using ArcGIS (release 10.0) software and tools.

2.3. Indicators

Based on the spatially explicit analysis illustrated above, the present study made use of two indicators' sets, the former allowing a diachronic and comprehensive assessment of land-use change (based on 12 variables overall, hereafter called block 'a'), the latter providing a coherent picture of economic, demographic and social dynamics in the study area (based on 14 variables overall, hereafter called block 'b'). Both indicators' sets covered the same study period (1992-2020) and were calculated coherently for the seven consecutive time intervals, as defined above. All the selected indicators – both in blocks 'a' and 'b' – were regarded as particularly stable and reliable (Rontos et al., 2016), and are representative of relevant land-use, territorial, demographic, and socioeconomic processes characteristic of the study area (Morelli et al., 2014; Di Feliciantonio and Salvati, 2015; Pili et al., 2017).

2.3.1. Land-use indicators

Indicators quantifying land-use changes (block 'a') include (i) five variables calculated as the per cent surface area of land (in total landscape) experiencing (1a) a generalized change, irrespective of the initial and final land-use class ('Tot'), or a specific conversion to (2a) urban area ('Urb'), (3a) cropland ('Agr'), (4a) forests ('For') or (5a) bare land ('bare'). Although being regarded as a gross rate of change (Colantoni et al., 2016), indicator (1a) provides a generic estimation of the 'rapidity-of-change' characteristic of a given landscape system; indicator (2a) quantifies urbanization processes (Pili et al., 2017); indicator (3a) assesses agricultural intensification (Duvernoy et al., 2018); indicator (4a) represents forest recovery (Colantoni et al., 2015), and indicator (5a) delineates processes of extensivation of rural landscapes, including land abandonment (Ceccarelli et al., 2014). Other five variables quantify (ii) the average distance (km) of the landscape pixels undergoing change from downtown Athens (Ciommi et al., 2019), distinguishing (6a) the whole of pixels experiencing a land-use conversion ('Dtot') from (7a) pixels experiencing conversion to urban area ('Durb'), (8a) cropland ('DAgr'), (9a) forests ('Dfor'), or (10a) bare lands (Frenkel, 2004). Two additional indicators estimate the overall diversification of land-use change considering both (11a) Shannon H' diversity index ('HSha') and (12a) Pielou J evenness index ('JPie') calculated as described above. These twelve indicators were assumed as representative of different dimensions of land-use change, namely (i) the spatial direction and intensity of change, (ii) the economic process behind the change, and the (iii) intrinsic diversification in patterns and trends of change (Grekousis et al., 2013; Chorianopoulos et al., 2014; Salvati et al., 2018; Egidi et al., 2020).

2.3.2. Socioeconomic indicators

Socioeconomic indicators (block 'b') delineate (i) latent processes of wealth accumulation and urban agglomeration (Hoymann, 2011), (ii) job market dynamics (Paulsen, 2013), as well as (iii) demographic growth or decline (Salvati and Carlucci, 2016), taken as important dimensions of change when describing transitional metropolitan systems (e.g. Salvati and Serra, 2016). Indicators' choice also depends on the (more or less) systematic release of official statistics at the regional level that is granted by Hellenic Statistical Authority (ELSTAT). The selected indicators (n = 14) covered homogeneously the investigation period (Ciommi et al., 2018), and were expressed as the per cent rate of change over time at each time interval (n = 7). Indicators include (1b) per-capita income growth (Purchase Power Standard, PPS) from regional accounts of Greece (updated based on Eurostat estimations), (2b) total population growth, (3b) elderly index, and (4b) the per cent share of native Greeks in total population, both derived from the estimation of resident population (ELSTAT) and the national population register (Hellenic Ministry of Interior Affairs). The remaining ten indicators are: (5b) the per cent share of population with tertiary education in total population, (6b-8b) total activity rate, as well as gross employment and unemployment rates, (9b-10b) specific unemployment rates (i.e. long-term (> 12 months) unemployment rate and unemployment rate in services), (11b-12b) per cent shares of workers in both industry and services, as well as (13b) the per cent share of employees in total workers and (14b) the per cent share of highly skilled employees in total employees.

2.4. Statistical techniques

Land-use changes were illustrated using descriptive statistics with tables, maps (location points), and basic graphs (Chelleri et al., 2015). Trends over time in a selection of socioeconomic indicators were illustrated through line graphs and published as supplementary materials. A pair-wise correlation analysis between relevant variables was run using both Parametric (Pearson) and non-parametric (Spearman) coefficients testing for significance at $p < 0.05$ after Bonferroni's correction for multiple comparisons (Duvernoy et al., 2018). The integrated use of Pearson and Spearman coefficients contributes to identify linear and non-linear relationships (Pili et al., 2017). More specifically, a relationship between two variables was regarded as linear when Pearson coefficient is higher than (or comparable to) Spearman coefficient in both value and sign (Zambon et al., 2019). Conversely, a relationship between two variables was regarded as non-linear when Spearman coefficient is distinctively higher than the respective Pearson coefficient in both value and sign (Zambon and Salvati, 2019).

A Principal Component Analysis (PCA) was run on the data matrix including the twelve land-use change indicators (block 'a') with the final aim at summarizing landscape transformations (Salvati, 2014) and decomposing the intensity and spatial direction of change on the base of the specific timing adopted in this study (Egidi et al., 2020). Components with eigenvalues > 1 were selected and analysed computing loadings (i.e. the indicators' dimension) and scores (i.e. the temporal dimension). A biplot summarizing the position of loadings and scores in the same factor plane was finally adopted to illustrate the outcome of this multivariate analysis (Colantoni et al., 2016).

A two-block Partial Least Squares (TPLS) analysis was carried out with the aim at identifying the latent, multi-dimensional relationship between block 'a' and 'b' indicators (Salvati et al., 2018). TPLS is an ordination method mixing advantages of exploratory data analysis and multiple regression techniques, with the objective of maximizing covariance between two (partly redundant) sets of variables on the same spatial unit (Smiraglia et al., 2015). Significant factors were selected according with Rohlf and Corti (2000). Loading coefficients were used to delineate relationships between indicators ('a' and 'b' blocks) and the extracted dimensions, representing the most relevant, latent relationships between the two datasets (Ciommi et al., 2019). The multivariate relationship between 'a' and 'b' indicators' blocks was contextualized along the extracted (latent) dimensions considering the scores assigned to each time interval (Salvati et al., 2018).

3. Results

3.1. Land-use in metropolitan Athens, 1992-2020

Figure 1 illustrates landscape transformations in Athens since 1992, and highlights the unrested radio-centric expansion of settlements mostly based on a progressive development of bare lands. The per cent share of developed land in total landscape grew from 13% (1992) to 21% (2020) of total landscape (Table 1), while bare land decreased from 9.5% (1992) to 5.6% (2020). The relationship between the surface area of the two classes was linear and negative (Pearson r coefficient = -0.98; Spearman r_s coefficient = -0.96), confirming bare land as a key stock of land available for building all over the study period (SM.Figure 3, left). The cropland surface underwent a progressive contraction over the three decades of investigation declining from 34% to 28% of the whole landscape. Natural areas experienced a modest growth (1-2 per cent increase between 1992 and 2020), and remain the dominant land-use in metropolitan Athens still now.

The contraction of forest area, combined with the reduction of traditional cropland, led to more complex semi-natural mosaics representative of the traditional dry landscapes of coastal Greece. In the face of a reduction in the surface area of agricultural mosaics (mixing tree (olives/vineyards) and herbaceous crops), a moderate expansion of natural mosaics made up of bushes, pastures and sparse natural vegetation, was observed (SM.Figure 3, right). Faced with the inherent reduction in forest area, these processes should be interpreted as a progressive degradation of natural, relict landscape mosaics, and denote human pressure and an increased exposure of pervious land to urban expansion.

3.2. Land-use changes in metropolitan Athens, 1992-2020

The spatial distribution of land-use changes was illustrated in SM.Figure 4 indicating the point location of pixels under change in respect with downtown Athens and making the reference time interval fully explicit. The highest frequency of change was observed between 2008 and 2012 at various distances from Athens, while the lowest amount of change was observed between 2016 and 2020 in rural areas West of Athens. Table 2 reports a detailed description of land-use changes detected in the study area, distinguishing among time intervals and quantifying the entity (i.e. surface area) of change by land-use macro-class (cropland, natural, bare and built-up) confronted with the total land under change and the whole landscape area (see also SM.Table 2). The average distance (km) of pixels experiencing land-use conversion from downtown Athens was finally tabulated (see also SM.Table 3).

Table 3 summarizes relevant figures derived from the selected land-use change indicators by time interval. The per cent share of land (both urban and non-urban) under conversion in the total landscape was highest in the first two time intervals (above 3%) and reached its lowest value (1%) at the end of the great crisis (2012-2016). Of these changes, however, those reflecting urbanization (i.e. conversion of non-urban areas to urban areas) were the most frequent in 2000-2004 (75% of total changes), in coincidence with the maximum expansion of the Greek economy culminated in the 2004 Olympics. Despite the low rate of change in 2012-2016, half of these conversions resulted in land development (54%). This percentage remained almost constant (53%) in 2016-2020. This time interval reflected a modest economic recovery and accelerated (non-urban) landscape transformations. Conversely, in a period of moderate economic growth (1992-1996 and 1996-2000) following a long stagnation, urbanization-driven land take accounted for a smaller proportion (34%-44%) of total land-use changes. Finally, the lowest contribution of urbanization to overall land conversions was observed during the most intense recessionary wave (2008-2012).

Changes over time in the average distance of pixels under transformation from downtown Athens reflect a slow but continuous migration towards remote areas. During economic expansion, however, land-use changes (regardless of the macro-class involved) were recorded in more central locations (on average, 23 km from Athens in both 2000-2004 and 2004-2008). Land conversions concentrated in more remote locations during recession (on average, 35 km from Athens in 2012-2016); this may indicate a different human pressure on the landscape resulting from economic downturns. Urban transformations were observed, on average, 27 km far from Athens at the end of the great recession (2012-2016) and only 22 km far from Athens during economic expansion (2000-2004). Following a moderate recovery of the regional economy, land development in the most recent period (2016-2020) has intensified again in central areas, since the average distance from Athens has decreased from 27 km to 26 km (SM.Figures 5).

Two indexes estimating diversification in land-use changes were finally calculated with the aim at quantifying trends toward more homogeneous (or heterogeneous) landscapes. Results of the analysis suggest how economically dynamic waves of the metropolitan cycle, associated with more intense urbanization processes, coincided with homogeneous landscape transformations. The lowest diversification in landscape transformation processes was recorded specifically during economic expansion (2000-2004), when urbanization accounted for the largest proportion of land-use change. On the contrary, economic stagnation seems to fuel land-use diversification; this is particularly evident in Athens since 2008, when the highest values of both indexes (Shannon H' and Pielou J) were observed.

3.3. A multivariate analysis of land-use changes in metropolitan Athens, 1992-2020

Principal Component Analysis summarized land-use indicators (block 'a') in two dimensions explaining 66% of the overall variability in the data matrix. Component 1 (36%) discriminated among economic expansions (positive scores) and stagnation (negative scores). Component 2 (30%) distinguished time waves with landscape transformations dominated by urbanization (negative scores) from those dominated by predominantly non-urban land-use changes (e.g. agricultural intensification/ extensivation, land abandonment/renaturalization).

Similarities in the position of variables (land-use change indicators) and cases (time intervals) in the four quadrants of the biplot illustrated in Figure 2, allow identifying four quadrants with distinctive landscape transformations over economic expansions or recessions. Economic expansion (2000-2004) was associated with homogeneous and intense (urbanization-driven) landscape transformations (Quadrant II). Landscape dynamics typical of the moderate economic expansion preceding the Olympic 'gold' decade were evident in Quadrant I. In particular, the 1992-1996 time interval was dominated by accelerated landscape transformations (Tot) causing a net expansion of bare lands (Bare). Land-use changes involving non-urban macro-classes, especially croplands (Agr) and forests (For), were also intense during 1996-2000. In this period, land-use changes involving forests were observed at greater distances from Athens. Quadrant IV instead highlighted the most frequent landscape transformations in a period of recession, being observed at increased distances from downtown Athens. These results document how economic stagnations coincided with spatially diluted land-use changes, i.e. involving remote areas, where land conversions have been less frequent during expansions. In the same context, landscape diversification increased sharply with economic stagnation.

3.4. Linking land-use change with the evolving socioeconomic background

The results of a multivariate analysis integrating land-use change and socioeconomic indicators were shown in Table 4. A canonical correlations analysis based on Partial Least Square regression has identified three latent relationships between landscape transformations and economic dynamics. The most significant dimension explained 75% of the overall variability in the data matrix, delineating economic dynamics as a process of growth over time in both disposable income and population (both indicators received negative and significant regression coefficients). This process was associated (with the same coefficient sign) to growing rates of (i) university graduates and (ii) workers in the service sector, as well as of (iii) highly skilled workers and (iv) employees as a whole.

Urbanization was the landscape transformation most associated with such economic dynamics (statistically significant coefficient with negative sign). With economic expansion, land take impacted fringe districts, perpetrating a radio-centric expansion of settlements (significant coefficient and positive sign of 'DistU'). Less intense transformations of non-urban landscapes were observed in such a period. In other words, landscape transformations during expansions featured spatial homogeneity and urbanization as the dominant land-use change. The 2000-2004 time interval (reflecting accelerated economic expansion) was the most (negatively) associated with dimension 1 (urbanization prevailing on other land-use transformations). Conversely, the period classified with the highest (positive) score was 2008-2012, representing the peak of the great crisis in Greece.

The second dimension explained 13% of the overall variability and was associated with population growth (significant coefficient with positive sign) decoupled from wealth/income growth, and associated in turn with rising gross unemployment rates, long-term unemployment rates, and unemployment rates in the tertiary sector. The period most associated (significant coefficient with positive sign) with this dimension was 2008-2012, while 2016-2020 received a coefficient with the highest value and negative sign. Taken together, dimension 2 outlined recessionary dynamics with unemployment growth against a stable (or slightly increasing) population. In this period, non-urban land use changes (cropland and natural) moved at greater distances from downtown and changes associated with land abandonment or re-naturalization processes (e.g. forest recovery) were less frequent than the average, suggesting a rising human pressure on remote land.

The third dimension explained 11% of the overall variance and delineate a gradient opposing economic growth to population growth. In this case, per-capita income growth and rising activity rates (positive sign) coincided with aging and the consequent contraction of resident population. The time intervals with the most intense regression coefficients (positive sign) were 1992-1996 and 1996-2000. Economic dynamics, as opposed to demographic dynamics, were also associated with more intense non-urban land conversions (e.g. forests to agriculture).

4. Discussion

Earlier works have occasionally investigated the relation between regional (socioeconomic) structures and the related land-use change over relatively short-time intervals, relying on quantitative measurements of causes and effects only rarely (Díaz-Pacheco and García-Palomares, 2014; Gavalas et al., 2014; Nevado-Peña et al., 2015; Salvati and Ranalli, 2015; Wang and Monzon, 2016; García-Coll and López-Villanueva, 2018). With this limitation in mind, our study delineates an original approach to monitor diachronic land-use change from a socioeconomic perspective (Salvati et al., 2016). By adopting a land-use nomenclature representative of the different economic potential of metropolitan land (Colantoni et al., 2016), a land change detection was run considering together mean patch size (Salvati et al., 2018), distance from downtown (Ciommi et al., 2019), and specific entropy-based metrics of landscape diversification (Shannon-Wiener H' diversity index and Pielou J evenness index) as key indicators of change (Grekousis et al., 2013). To understand the possible impact of recent urban evolution on landscape transformations (e.g. Salvati, 2014), a multivariate analysis was run on multi-domain indicators that quantified representative dimensions of land-use and socioeconomic dynamics in metropolitan Athens (Ciommi et al., 2019).

The adopted timing, based on seven periods of equal length covering almost three decades

(1992-2020), makes it possible to estimate the impact of economic downturns – from moderate/marked expansions to intense recessions and subsequent stagnations – on land-use change (Smiraglia et al., 2015). Landscape transformations associated with economic downturns were recognized to be profoundly different over the study period (Lekakis and Kousis, 2013). Land-use changes were found as barely divergent during the economic expansion (2000-2004) culminated in the Olympic Games, and the subsequent recession (2008-2012). Considering together intensity and spatial direction of change, our analysis demonstrated how urbanization was particularly intense and concentrated on fringe land during economic expansions (e.g. Turok and Mykhnenko, 2007), being in turn much less intense, and more dispersed into remote areas, during stagnations (Simon, 2008). However, going beyond too simplified interpretations, such a relationship highlights a complex environmental-economic trade-off with articulated policy implications (Zhang et al., 2011).

In fact, while it seems reasonable to assume urbanization processes as pro-cyclical (Paulsen, 2013), the same result fails when considering changes over time in the distance of the new developments from inner cities. Assuming Athens as a mono-centric (settlement) model (Maloutas, 2007; Kandylis et al., 2012; Pili et al., 2017), economic expansions have stimulated radio-centric land development fuelled by scale and agglomeration factors (Zambon et al., 2017). Such urbanization patterns resulted in the expansion of medium-high density residential settlements, and perpetuate a (land-saving) spatial structure with indirect environmental advantages (Carlucci et al., 2017). On the contrary, stagnations – being associated with decelerating urbanization rates – pushed land development toward more peripheral areas (Salvati et al., 2018). This process may depend on anti-cyclical land price dynamics, more volatile speculative behaviours, and rational/irrational expectations of future urbanization gains (Salvati et al., 2016).

Compared to what was observed with economic expansions, recession-driven urbanization was demonstrated to be spatially dispersed and with a higher-than-expected environmental impact (Jahanifar et al., 2019). This requires a more articulated interpretation of the net impact of economic cycles on urban sustainability (Tomao et al., 2021), going beyond the simplified assumption linking positive environmental externalities with economic stagnation – just because urbanization rates usually decelerate in this part of the cycle (Pérez, 2010). In-depth studies are increasingly requested to verify the overall environmental impact of new settlements built-up during recessions (Diaz-Pacheco and Garcia-Palomares, 2014), considering together compactness and distance from downtown as the main dimensions of change (Woestenburg et al., 2018). The downward pressure on house and land prices – combined with the rising demand for smaller dwellings and workspaces – may stimulate urban sprawl (Arapoglou and Sayas, 2009), with the consequent increase in per-capita land take rates, causing a negative (environmental) spiral that earlier studies have been rarely explored (Zhang, 2001; Huang and Tang, 2012; Nevado-Pena et al., 2015).

From the operational point of view, a comparative research effort investigating joint dynamics over a number of metropolitan areas should distinguish the impact of economic downturns on land-use change in different settlement structures (e.g. mono-centric, polycentric, mixed, dispersed). Evidence that bare lands – basically soils with no vegetation due to natural causes (e.g. climate aridity, degraded soils) or to human action (e.g. wildfires, overgrazing, soil erosion, pollution or compaction due to excessive crop mechanization) – have represented an important stock of land available to development, is a consequence of such processes (Allen, 2003; Aguilar, 2008; Colantoni et al., 2015; Perrin et al., 2018).

The dimension of diversification in land-use flows also enriched the interpretation of complex landscape transformations in metropolitan regions (Duvernoy et al., 2018). Depending on growth or stagnation, the indicators of diversity and evenness showed cyclical trends as a function of economic downturns (Di Feliciantonio et al., 2018). Following the classification in 'generalist' and 'specialist' land-use changes provided in Colantoni et al. (2016), economic expansions led to 'specialist' trajectories of change, with urbanization as the dominant process of change (Chelleri et al., 2015). Economic stagnations instead led to more 'generalist' trajectories of change – with urbanization mixed with an evident pressure on non-urban landscapes (e.g. Smiraglia et al., 2015) leading to heterogeneous dynamics such as agricultural intensification, rural extensivation, land abandonment, or the progressive recovery of forest areas (Cuadrado-Ciuraneta et al., 2017). These dynamics occurred at progressively greater distances from downtown Athens, exerting a higher pressure on natural landscapes (Gounaridis et al., 2019). In line with the trade-off delineated below, the outcomes of the present study document how direct (i.e. urbanization-driven) and indirect human pressures on landscapes diverged along the economic cycle (Grekousis et al., 2013). While direct human pressure was higher with economic expansions (Chorianopoulos et al., 2014), the indirect, negative impact of landscape transformations (mostly involving non-urban uses of land) was more intense during stagnations.

5. Conclusions

Improvements in geo-spatial data sources for land-use science provide a basic information ground for research and policy. Benefiting from high semantic resolution (while having intermediate spatial resolution), the diachronic maps adopted in this study allow a coherent, pixel-based analysis of landscape transformations *vis à vis* metropolitan cycles and economic downturns. These maps were continuously updated thanks to automatic interpretation of satellite images with a fairly broad (and comparable) land-use nomenclature, both in terms of information and spatial coverage. Linking regional expansions and stagnations with the metropolitan cycle (e.g. urbanization, suburbanization, counter-urbanization, and re-urbanization), and clarifying the impact these socioeconomic dynamics exert on landscape changes, is the novel contribution of our study to regional science.

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Figure 1. Spatial distribution of urban settlements and bare land in metropolitan Athens by year.

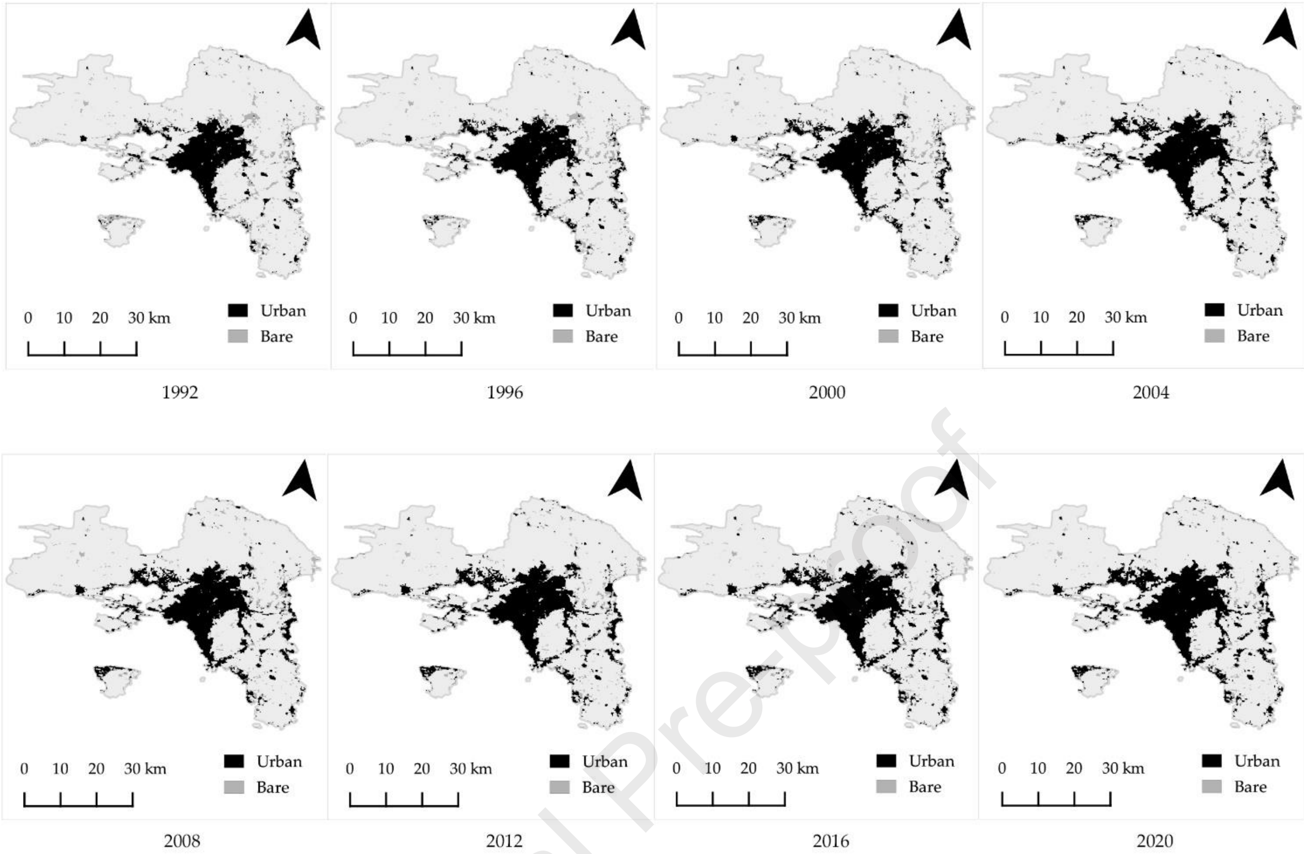

Table 1. Per cent class area in total landscape by land-use and year in metropolitan Athens.

Class		1992	1996	2000	2004	2008	2012	2016	2020
	Cropland	18.3	17.8	17.9	16.8	16.6	16.5	16.4	15.8
	Tree Crop	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.7
	Agricultural Mosaic	7.8	7.2	5.9	5.6	5.2	4.9	4.8	4.8
Agriculture		*33.8*	*32.9*	*31.6*	*30.2*	*29.6*	*29.2*	*28.9*	*28.3*
	Forests	10.1	9.7	10.2	10.2	9.4	8.9	9.0	8.8
	Natural mosaics	5.8	5.9	6.7	7.0	8.2	8.8	9.0	9.2
	Shrubland	23.9	24.3	24.2	24.2	24.2	24.3	24.1	23.8
	Grassland	2.8	2.7	2.4	2.4	2.3	2.2	2.2	2.3
	Wetland and water	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Natural (forest and non-forest)		*43.6*	*43.8*	*44.6*	*44.8*	*45.1*	*45.3*	*45.3*	*45.1*
Urban areas		*13.0*	*14.5*	*15.7*	*17.9*	*18.7*	*19.3*	*19.9*	*21.0*
Bare land		*9.5*	*8.8*	*8.0*	*7.1*	*6.5*	*6.2*	*5.9*	*5.6*

Table 2. Results of a summary analysis of land-use change in metropolitan Athens by class (1: agricultural land; 2: natural land; 3: urban areas; 4: bare land; see Table 1) and indicator (per cent share in total landscape, per cent share in total landscape change, average distance from downtown Athens, km).

		Share (%) in total landscape					Share (%) in total landscape change					Average distance from Athens (km)				
		1	2	3	4	Tot	1	2	3	4	Tot	1	2	3	4	Tot
								1996								
1992	1		0.75	0.61		1.36		22.2	17.8		40.0		46.4	18.3		33.9
	2	0.43	0.57	0.05	0.13	1.19	12.6	16.8	1.6	3.9	35.0	23.5	24.4	19.1	20.9	23.4
	3															
	4		0.00	0.85		0.85		0.1	24.9		25.0		54.4	20.5		20.6
	Total	0.43	1.33	1.51	0.13	3.39	12.6	39.1	44.3	3.9	100.0	23.5	36.9	19.6	20.9	26.9
								2000								
1996	1		1.47	0.29		1.76		39.8	7.9		47.7		31.2	22.8		29.8
	2	0.39	0.52	0.15	0.03	1.08	10.5	14.1	3.9	0.9	29.3	28.5	27.2	22.0	24.3	26.9
	3															
	4	0.02	0.00	0.82		0.85	0.7	0.1	22.3		23.0	16.7	16.8	24.7		24.4
	Total	0.41	1.99	1.26	0.03	3.70	11.1	53.9	34.1	0.9	100.0	27.8	30.2	23.9	24.3	27.7
								2004								
2000	1		0.30	1.09		1.38		10.5	38.6		49.1		31.9	21.6		23.8
	2	0.05	0.30	0.06	0.04	0.44	1.7	10.5	2.0	1.4	15.6	27.8	27.0	20.7	29.3	26.5
	3															
	4	0.02	0.00	0.97		0.99	0.8	0.1	34.4		35.3	15.3	15.4	21.6		21.4
	Total	0.07	0.60	2.11	0.04	2.82	2.5	21.1	75.0	1.4	100.0	23.9	29.4	21.6	29.3	23.4
								2008								
2004	1		0.39	0.31		0.69		15.7	12.5		28.2		26.2	25.0		25.7
	2	0.05	1.15	0.06		1.25	1.9	46.8	2.3		51.0	13.0	20.3	28.8		20.4
	3															
	4		0.00	0.51		0.51		0.1	20.7		20.8		26.7	26.2		26.2
	Total	0.05	1.54	0.87		2.46	1.9	62.7	35.4		100.0	13.0	21.8	25.9		23.1
								2012								
2008	1		0.32	0.16		0.48		15.8	7.8		23.7		30.6	24.5		28.5
	2	0.07	1.06	0.06	0.00	1.19	3.2	52.1	2.9	0.2	58.4	26.7	33.5	31.7	46.8	33.1
	3															
	4	0.01	0.00	0.35		0.37	0.5	0.1	17.4		18.0	17.5	20.1	26.7		26.4
	Total	0.08	1.39	0.57	0.00	2.04	3.7	68.0	28.1	0.2	100.0	25.5	32.8	26.6	46.8	30.8
								2016								
2012	1		0.06	0.19		0.25		5.9	19.4		25.3		19.4	27.6		25.7
	2	0.01	0.37	0.08		0.46	1.2	37.1	8.1		46.4	20.5	35.4	27.5		35.4
	3															
	4		0.01	0.27		0.28		1.5	26.8		28.3		18.0	26.6		26.2
	Total	0.01	0.44	0.54		0.99	1.2	44.5	54.3		100.0	20.5	35.3	27.1		34.8
								2020								
2016	1		0.02	0.62		0.64		1.1	28.8		29.9		37.9	22.4		32.8
	2	0.02	0.96	0.20		1.18	0.9	44.7	9.5		55.2	19.7	28.0	17.1	41.7	27.1
	3														24.1	24.1
	4		0.00	0.32		0.32		0.1	14.8		14.9	10.6	61.2	29.0		28.7
	Total	0.02	0.99	1.14		2.15	0.9	46.0	53.1		100.0	18.5	30.4	25.9	24.9	28.5
								2020								
1992	1	0.01	3.30	3.26		6.56	0.03	19.3	19.1		38.5	54.1	33.9	21.4		27.7
	2	0.99	4.49	0.67	0.19	6.34	5.8	26.3	3.9	1.1	37.2	25.6	29.0	20.9	23.5	27.4
	3															
	4	0.05	0.03	4.08		4.16	0.3	0.2	23.9		24.4	16.3	21.3	23.0		22.9
	Total	1.05	7.81	8.00	0.19	17.06	6.2	45.8	46.9	1.1	100	25.3	31.0	22.2	23.5	26.4

Table 3. Selected indicators of land-use change in metropolitan Athens by time interval (* except forests).

Time interval	Land-use change in total landscape (%)					Distance from downtown Athens (km)					Diversification index	
	Total	Urban	Agriculture	Forest	Natural*	Total	Urban	Agriculture	Forest	Natural*	Shannon H	Pielou J
1992-1996	3.39	44.3	12.6	19.8	19.3	26.9	19.6	22.5	47.3	26.3	2.25	0.71
1996-2000	3.70	34.1	11.1	23.7	30.2	27.7	23.9	23.8	31.3	29.2	2.41	0.76
2000-2004	2.82	75.0	2.6	4.2	16.9	23.4	21.6	22.9	32.3	28.6	1.85	0.55
2004-2008	2.46	35.4	1.9	5.8	56.9	23.1	25.9	14.3	27.4	21.2	2.26	0.70
2008-2012	2.04	28.1	3.7	8.8	59.2	27.0	26.6	25.8	34.0	32.6	2.47	0.75
2012-2016	0.99	54.3	1.2	14.5	30.0	34.8	27.1	16.2	35.5	29.2	2.54	0.80
2016-2020	2.15	53.1	0.9	11.7	34.3	28.5	25.9	18.5	37.7	29.3	2.51	0.77

Figure 2. Biplot of a Principal Component Analysis illustrating the relationship between land-use change and time intervals (four-years long) reflecting economic downturns in metropolitan Athens.

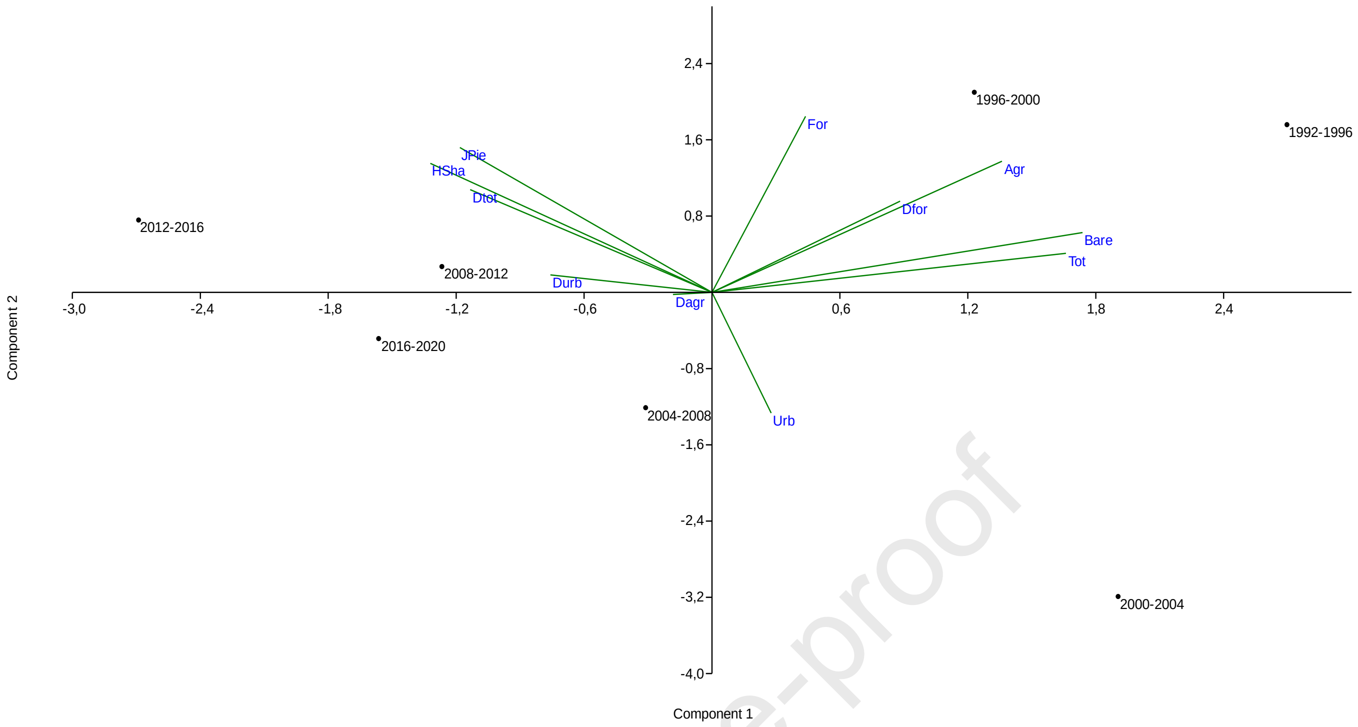

Table 4. Results of a Partial Least Square regression investigating the latent relationships ('dimensions') between land-use and socioeconomic indicators in metropolitan Athens by time interval (bold indicates significant regression coefficients at $p < 0.05$, grey outlines the time interval with the highest and the lowest score in each dimension, based on sign).

Variable	Dimension 1	Dimension 2	Dimension 3	Variable	Dimension 1	Dimension 2	Dimension 3
Income growth	**-0.31**	-0.07	**0.34**	Chg(total)	-0.21	0.01	**0.53**
Population growth	**-0.34**	**0.33**	**-0.34**	Chg(urban)	**-0.42**	-0.18	-0.25
Elderly index	-0.20	0.19	**-0.40**	Chg(cropl)	-0.02	0.07	**0.49**
Greek native	-0.11	0.18	0.10	Chg(forests)	0.09	**-0.33**	**0.52**
Tertiary education	**-0.35**	**0.46**	-0.05	Chg(bare)	**0.39**	0.28	-0.14
Activity rate	-0.14	0.28	**0.75**	Dist(total)	0.22	-0.29	-0.05
Employment rate	-0.20	-0.25	0.14	Dist(urban)	**0.34**	-0.13	-0.15
Unemployment rate	0.21	**0.36**	0.03	Dist(cropl)	0.15	**0.61**	0.23
Industrial workers	-0.29	-0.15	-0.06	Dist(forests)	0.00	0.03	-0.18
Services' workers	**-0.35**	-0.03	0.05	Dist(bare)	0.30	**0.35**	0.00
High-skill employees	**-0.35**	-0.01	-0.07	Diversity H index	**0.43**	-0.26	0.04
Total employees	**-0.33**	-0.08	0.01	Evenness J index	**0.39**	**-0.32**	0.10
Long-term unemployment	0.21	**0.35**	0.03				
Unemployment in services	0.16	**0.43**	0.03	1992-1996	-1.35	0.09	1.97
				1996-2000	0.55	-0.05	2.72
1992-1996	-0.99	0.49	-0.20	2000-2004	-3.44	1.72	-0.82
1996-2000	0.20	-1.22	3.07	2004-2008	-0.34	-0.46	-1.02
2000-2004	-3.94	1.11	-0.43	2008-2012	2.32	1.60	-0.33
2004-2008	-0.92	-0.64	-0.26	2012-2016	1.52	-2.08	-1.57
2008-2012	5.07	3.50	-0.81	2016-2020	0.73	-0.82	-0.96
2012-2016	0.92	-1.02	-0.78				
2016-2020	-0.33	-2.22	-0.59	Explained Variance (%)	74.7	13.2	10.6

Research highlights

Distinctive land-use dynamics were observed along the economic cycle.

Diachronic land-use maps (1992-2020) from ESA-CCI were used in this study.

Metropolitan growth followed a land-saving model during economic expansions.

A more dispersed settlement model was associated with economic stagnations.

Landscape diversification was higher under stagnations and lower during expansions.

DECLARATIONS

The authors declare that:

The study illustrated in our article does not contain any experimentation with human subjects.

All authors declare to do not have any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

The authors did not use any generative artificial intelligence (AI) and AI-assisted technologies in the writing process.

The authors finally declare that the work described in the present submission has not been published previously and it was not submitted to any other journal for evaluation.

Easy Come, Easy Go: Short-term Land-use Dynamics *vis à vis* Regional Economic Downturns

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