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The role of smart cities in sustainable development: empirical evidence from Türkiye

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Abstract

Purpose – This study aims to empirically examine the effects of smart cities on sustainable development for the period 1990–2019 for Türkiye.

Design/methodology/approach – The relationship between smart cities and sustainable development was analyzed with the help of the ARDL Bounds Test. In addition, the consistency of the model was tested with the FMOLS estimator. The indicators of the smart city were selected following the literature to represent smart cities, and the author created the smart city index. The study used other variables thought to impact sustainable development as secondary data.

Findings – The results show that smart cities positively and significantly impact sustainable development in Turkiye in both models during the sampling period. In addition, while real GDP, population density, and financial development variables positively affect sustainable development, population density has a negative effect on sustainable development, according to the results obtained from FMOLS estimators.

Originality/value – The first novelty of this study is the creation of the smart city index. The second novelty is that there are almost no studies on the effects of smart cities on sustainable development, especially for Türkiye.

Keywords Smart cities, Sustainable development, ARDL bound test, FMOLS

Paper type Research paper

1. Introduction

The increase in human population and, therefore, technology, consumption, and production, in short, human activities, has brought the concept of sustainability to the agenda by putting pressure on the environment. Thus, economic growth, the ultimate goal of developed and developing economies, has evolved towards sustainable growth. Discussions regarding the idea that economic growth can only be sustainable when the natural environment's dependency is considered continued until the early 1980s (Zervas, 2012). In the 1980s, the United Nations (UN) became an essential actor in forming the concept of sustainable development and filling the content of the concept. To achieve consensus on the concept, the concept of sustainable development was produced in the Brundtland Report titled "Our Common Future" by the WCED (1987).

According to this report, sustainable development is defined as development that meets today's needs without compromising the ability of future generations to meet their own needs (Yeni, 2014; Özaslan, 2023, p. 101).

Another definition of sustainable development was made by Hart (1999). According to Hart (1999), it is a concept in which the economy exists within society and society exists

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within the environment. In other words, considering these three components is the path to sustainable development.

Figure 1 expresses the dimensions of sustainable development. Although each of these factors is undoubtedly important, scientists consider the Environmental factor the most serious as it carries the possibility of irreversible damage.

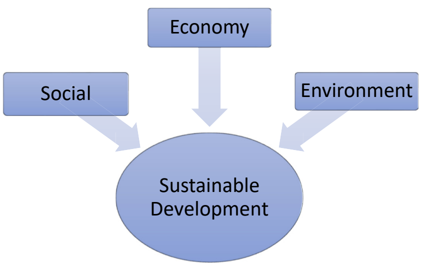
From the Industrial Revolution to the present, the rapid increase in the urban population and the consequent increase in source use unavoidably led to many challenges for cities. In this context, it is of great importance that the structure of cities gradually changes and transform into today's conditions in terms of sustainability. As the world's population increasingly turns to cities, it will significantly expand existing urban environments, bringing the need to create new ones. Today, although cities use about 2% of the earth's surface, they use about 75% of the natural sources accessible globally (Toli & Murtagh, 2020). According to the United Nations Environment Program (UNEP, 2018), it is predicted that there will be approximately 50 billion tons more primary energy consumption, raw materials, fossil fuels, food, and water consumption in cities in 2050 compared to 2010 (UNEP, 2012). Therefore, it is expected that people living in cities will face various difficulties related to the performance, competitiveness and livelihoods of the city population in the coming years. The smart city, which has come to the fore to overcome these difficulties, is defined as a city that aims to make itself more sustainable, efficient, equitable, and livable (NRDC, 2012).

Today, the world is in the midst of a complete transformation. Both producers and consumers accept this transformation. While consumers prefer more environmentally friendly, technological products and resources in all areas of life, manufacturers also implement policies towards these requests. Policymakers and local administrators also accept this transformation. This was reflected in the creation of the 11th UN Sustainable Development Goals (SDGs), which aim to make cities more inclusive, safe and sustainable (UN, 2018).

Our study aims to analyze the empirical impact of smart cities on sustainable development for Turkiye with data from 1990–2019. The study is critical because it is one of Turkiye's first empirical studies. The concept of a smart city was introduced in the study, and the indicators of the smart city were expressed. Then, theoretical and empirical studies on smart cities were examined. Third, model predictions for the relationship between smart urbanization and sustainable development were carried out with the help of the ARDL bound test and FMOLS estimator.

2. Definition and indicators of smart cities

Today, the urbanization of the world population density has become a significant problem that needs to be addressed. While only about 30% of the world's population lived in cities in



Source(s): Seydioğulları (2013)

Figure 1. Economy, environment, and society component that creates sustainability

the 1950s, today, the rate of living in cities has increased to around 55%. It is a guess that this rate will increase to 68% by 2050. With the gradual settlement of human populations from rural to urban regions, coupled with the overall growth of the world population, it is expected that 2.5 billion more people will be increased to urban regions by 2050, and about 90% of this increase will occur in emerging countries such as China and India in Asia and Africa (UN, 2018). Rapid urbanization has come to the fore with the increase in urbanization. Rapid urbanization has significantly developed people's living standards by providing benefits such as water supply, sewerage systems, residential and office buildings, education services, and convenient transportation.

Cities are often local economic centers that help increase economic prosperity and create more business. The density of educated people in urban areas helps to develop the industrial structure and increase productivity in production (Bertinelli & Black, 2004). However, rapid urbanization brings with it some new difficulties and problems. For example, the increasing population in cities increases the need for energy, which is mainly met from traditional sources. This causes the maximum use of natural sources, increases ecological and environmental problems, and increases social disorder problems.

At this point, smart urbanization facilitates overcoming these problems and difficulties, provides new opportunities for urban problems to be solved faster, and creates a better living environment by providing better services to citizens (Yin *et al.*, 2015). Although smart urbanization has been widespread in recent years, it is considered to have a long history based on the previous century's vision of the urban future. However, the development of technology required for the realization of smart urbanization and taking concrete steps in this area took time. As it is known, most strategies, such as smart urbanization with advanced technology, require a long time to mature (Bilici & Babahanoğlu, 2018, p. 126).

The increase in the urban population rate and the effect of globalization has led to a rapid change in urban life, culture, and habits of the city residents. As a result, the usage patterns of the cities and the demands of the people staying in the cities started to change and transform. In addition to being more vibrant, productive, and innovative, cities today face many problems, such as traffic, health, informality, and unplanned urbanization due to the dense population they are exposed to (Akgül, 2013; Örselli & Akbay, 2019).

These city problems have led to new perspectives in presenting services such as design, planning, finance, and urban infrastructure. In this context, both central and local governments have brought forward the development of new strategies such as network connections, sensors, e-governance, e-government, sustainability, and people-orientedness to solve the problems encountered (Şahin & Örselli, 2003; Şahin, 2016, p. 254). Thus, to improve the quality of life for modern cities, "smart city" applications have come to the forefront, offering practical solutions to the intensifying urban life, where technology and life are intertwined.

The literature has no definite consensus on defining the smart city concept. Each definition deals with the subject from different aspects and different perspectives. It should not be forgotten that the definitions of the smart city will constantly change due to technological development and the dynamics of the population structure. In this context, the concept of the smart city, in general, refers to an ecological city where information technologies are used in the presentation of urban services, participation is provided by technology, and some individuals and institutions actively learn in following innovations (Gül and Atak Çobanoğlu, 2017, p. 1544).

The International Business Machines Corporation (IBM) initially recommended understanding the smart city in 2008 as a resolution to the "smart world" strategy. The smart city refers to implementing the IoT system that connects national sources such as electricity grids, highways, and water supply systems through diverse smart sensors (Chu, Cheng, & Yu, 2021, p. 3).

In other words, a smart city is a city that constantly supports innovation, tries to solve problems with highly educated or human capital, prioritizes significantly developed quality of life and economic development, and also as a concept that highlights the improvement of human capital through optimal administration of natural sources and sustainable urban development in general (Ojo, Dzhusupova, & ve Curry, 2016).

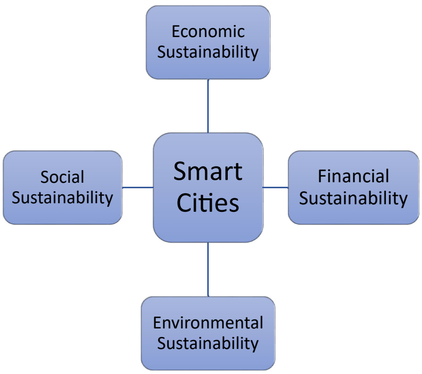
According to Sarma and Sunny (2017), smart urbanization is a concept that improves economic growth and social development through innovations in technology and increased cooperation. Hall *et al.* (2000) define smart urbanization as integrating systems by monitoring the status of infrastructures such as bridges, roads, subways, tunnels, railways, communication, water, and efficient energy to ensure the most optimal use of the city's resources.

Within the framework of the definitions made, it can be seen that smart urbanization concentrates on four basic components: economic sustainability, financial sustainability, social sustainability, and environmental sustainability. In this context, considering the scope of smart cities, to find a way to today's urban problems and to raise the standard of living, the city should be considered as a sizeable multi-faceted system that includes all other phenomena such as infrastructure, superstructure, information and communication technologies, and environmental awareness. In this context, the components of smart cities are expressed in Figure 2.

The concept of smart urbanization is becoming more and more widespread around the world. Over 1,000 smart cities are still being constructed globally, and the number of smart cities is anticipated to increase by 20% in the next few years. In this context, European countries focus on transportation, energy, public services, and infrastructure issues to ensure smart urbanization.

3. Literature review

The purpose of this study is to empirically test the existence of a connection between smart urbanization and sustainable development. Considering the change in living conditions, developing technology and population growth, changing the needs of individuals living in cities, and causing an environmental and economic transformation, smart urbanization has come to the fore more frequently in the economics literature in recent years. On the other hand, although studies on the definition and applications of smart urbanization are included in the literature, the number of studies empirically investigating the effect of the concept on



Source(s): Bilici and Babahanoğlu (2018)

Figure 2. Components of smart cities

sustainable development is quite limited. This study is critical because it is one of the first studies for Turkiye that empirically examines the relationship between smart urbanization and sustainable development. The national and international literature in this field consists of studies that examine smart urbanization from a theoretical perspective. For this reason, it is expected that this study will fill the gap in the literature.

One of the important studies on smart cities the study by Mishra, Kumari, Janaki Krishna and Dubey (2022). In the study, they first discussed the national and international status of smart cities. In this context, although urban development is very strong and systematic in developed countries, smart city development in developing countries like India faces various challenges such as delayed investments, coordination of stakeholders at local, state and central levels, timelines and job displacement. Due to these problems, the authors stated that policy makers should focus more on this issue for the development of smart cities. In their study, Blasi, Ganzaroli, and De Noni (2022) theoretically examined how smart cities affect sustainable development goals using the literature review method. In the study findings, it was observed that concepts such as sustainability, waste management, civic participation and innovation are common even though they are researched in different ways. Similarly, Schuch de Azambuja (2021) conducted a systematic literature review of 169 articles to identify issues affecting the progress of smart sustainable cities. The results provide a comprehensive list of 57 drivers and 63 barriers classified according to five key dimensions of a smart sustainable city; these are the three sustainability pillars (society, environment and economy) combined with governance and urban infrastructure. The findings revealed that "governance" is the most important area for SSC development and multi-stakeholder engagement is one of the main challenges.

Dincă *et al.* (2022) conducted an important study for 28 European states in the period 2011–2019 with the help of Ordinary Least Squares, Fixed Effects and Random Effects regression models using balanced panel data to investigate and determine the factors that can support the development of the smart environment, which is a feature of smart cities. More specifically, the study aims to measure the extent to which air pollution can be reduced by taking various circular economy, financial and environmental factors as determinants. The study findings point out that particular attention should be paid to factors such as carbon dioxide-producing activities that significantly increase air pollution. Accordingly, policies such as evaluating the air quality in the environment and using renewable energy to achieve sustainable cities, investments in the education of the population, and the correct implementation of the circular economy are important.

Çetin and Çiftçi (2019) examined the concept of a smart city with examples from the world and Turkiye. In the study, they provided an overview based on the literature review on sustainable smart cities, expressed in scientific and technological trends, as the future planning application. In this context, they stated that cities should be managed more effectively in both ecological and social areas by taking advantage of smart technologies" advantages in planning. On the other hand, they emphasized that smart urbanization, which uses technology at a high level to cope with both physical and socio-economic problems arising from rapid growth, will overcome these problems.

In Mirghaemi's (2019) study on smart cities in Turkiye, he stated that more emphasis should be placed on comprehensive national and local policies to develop the smart city phenomenon in Turkiye. He also stated in his study that smart city approaches in Turkiye should be continued in many areas, such as public transportation, and extended to other social categories, such as energy and smart buildings. As a result of the study, it has been reached that more organized and widespread studies should be done on the political placement of the concept in question in Turkiye.

Örselli and Akbay (2019) examined exemplary applications in the world and smart city applications in Turkiye comparatively in terms of technology. As a consequence of the study, they stated that smart cities want high costs and a robust infrastructure in information and communication technologies. Therefore, countries with a higher level of development, a more robust economy, and vital capital infrastructure are ahead in the smart city market. They stated that Turkiye was influenced by smart city applications worldwide and included smart city applications, albeit to a lesser extent.

Yigitcanlar and Kamruzzaman (2018) investigated the contributions of smart urbanization in achieving sustainable urban results for 15 UK Countries for the period 2005–2013 with the help of Panel Data Analysis. According to the findings, there is a positive connection between technology adoption and sustainable outcomes in cities studied in the UK context. It shows no strong proof that smart urbanization impacts CO2 emissions. In the study, it is stated that smart city applications in England cannot make a significant contribution to sustainability.

Wang, Lin, Liu, Wang, and Xu (2021), in their study with the help of Panel Data Analysis for the period 2004–2017, analyzed the correlation between smart cities and green space utilization effectiveness in China. Following the study findings, smart city development significantly improves the efficiency of green space use and increases the overall effectiveness by 15%. They also stated that smart city development promotes the effectiveness of green use in urban areas through information industry development and local innovation capabilities.

Jiang, Jiang, Wang, and Wu (2021) examined the relationship between green total factor productivity of smart urbanization for 2005–2016 in the first smart city original group in China with the help of panel data analysis. The study's findings contain evidence that smart urbanization significantly affects green total factor productivity in the sample group and in the specified period.

In their study for China, Xu *et al.* (2022) analyzed whether smart cities make cities more innovative with the help of the PSM and DID model for the 2008–2017 period. As a result of the analysis, they found that Smart City policies do indeed affect urban innovation positively and significantly. In addition, the study investigated whether policy impacts vary by regional location and city scale, and the results revealed that the effect was significantly positive only for megacities and cities in central China.

In the study of Xin and Qu (2019), they investigated the connections between smart city policies and urban green total factor productivity (GTFP) in the context of China, based on the Panel Data Method for the period 2006–2017. The study conclusion shows that smart city policies increase urban GTFP between 16% and 18%, and the larger the city, the more vital and more critical this ratio.

Wang and Zhou (2022) examined the dynamic relationship between smart urbanization and urban sustainability using the PVAR Model with the help of the 2012–2017 dataset and a dataset consisting of 77 smart cities in China. The results showed that smart urbanization has positive effects on urban sustainability.

Ye, Zhao, and Cai (2021) analyzed the effect of smart urbanization on the quality of foreign direct investment (FDI) in China using the 2006–2017 period data and Panel Data Analysis. The research results show that smart urbanization significantly improved the quality of FDI in the period and sample group used.

4. Model and data set

This study aims to empirically analyze the effect of smart urbanization on sustainable development in Turkiye for the period 1990–2019. Due to limited data on smart urbanization, the study's data set covers 1990–2019. For this purpose, a model was created as follows:

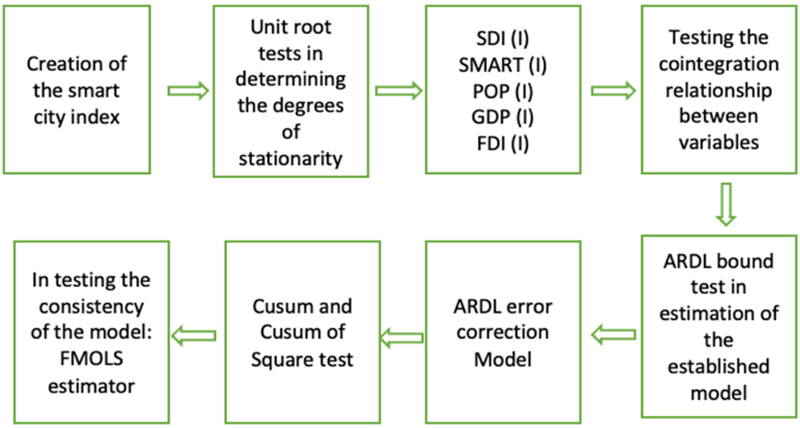
$$\mathrm{SDI_t} = \beta_0 + \beta_1 \mathrm{SMART_t} + \beta_2 \mathrm{lnPOP_t} + \beta_3 \mathrm{lnGDP_t} + \beta_4 \mathrm{FDI_t} + \varepsilon_t \tag{1}$$

The t index in equation (1) indicates that the data used in the model are time series β_0 is the constant term of the model, and β_1, β_2, β_3, and β_4 are the coefficient values of the independent variables.

To empirically reveal the link between smart urbanization and sustainable development, the procedural steps shown in Figure 3 were followed.

Many concepts in the literature define smart urbanization. Therefore, it is thought that representing it by creating an index using various indicators, rather than representing it with a single indicator, will yield more accurate results. In this context, the variables used to create the smart city index in the study are expressed in Table 1.

As in the study of Fistola and La Rocca (2014), many studies examining smart urbanization have tried to understand the city's smartness based on several variables within the urban system. In this context, technology was the indicator based on these studies (Dameri & Rosenthal-Sabroux, 2014; Dickey & Fuller, 1979). In this study, the first of the indicators used in creating the smart urbanization index and representing the technology is the internet usage rate per capita. The prevalence of the internet usage rate in a city is a commercial indicator of how much the public adopts the internet in that city. On the other hand, the everyday use of the internet shows the quality of the online services provided by the city (Yigitcanlar & Kamruzzaman, 2018, p. 51). The second indicator chosen in the creation of the smart city index and representing the technology is the number of patent applications. The smartness of a city is made possible by integrating innovation and technology into urban life. Since the number of patent applications is internalized with technology in many studies, it was also preferred in this study.



Source(s): Created by author

Figure 3. Analysis stages of the relationship between smart cities and sustainable development

Table 1. Indicators used in creating the smart cities index

Indicators	Resource
Internet Usage Rate (per capita)	World Bank
Patent Applications	World Bank
School Enrollment Rate	World Bank
Renewable Energy Usage (% total)	World Bank

Source(s): Compiled by the author

In the study, the schooling rate is the third indicator chosen to create the smart urbanization index. The smart city concept is characterized by high intellectuality or human capital needed to support innovations and solve problems (Örselli & Akbay, 2019, p. 230). In this direction, the schooling rate, frequently preferred in the literature, has been used to represent human capital in the study. The last indicator used in the study's creation of the smart urbanization index is the use of renewable energy. While defining the smart city, it is essential not to ignore the environment and to choose policies for this purpose. Ensuring development in pollution caused by fossil fuels, environmental protection, and sustainable resource management are among the most critical factors of smart urbanization (Giffinger & Gudrun, 2010).

In the index created to represent the smart city, the Principal Components Analysis (PCA) method was applied within the selected indicators" framework to obtain the variables" relative importance and create the Smart City Index. Suppose a data set has significant covariances or correlations between p variables. In that case, using a set consisting of linear components and a smaller number of linear components may be preferable instead of using this data set directly in the analysis (Özdamar, 2004; Oktay & Alkan, 2010). At this point, principal component analysis refers to obtaining the data set consisting of the original p variables and a smaller number of new variables that are linear components of these variables. Principal component analysis is a dimension reduction process by applying simple transformations to the original variables. Kaiser-Meyer-Olkin (KMO) and Bartlett Chi-Square Tests were applied to investigate whether the variables were suitable for principal component analysis, and the results are given in Table 2.

When Table 2 is examined, the Kaiser-Meyer-Olkin value of the study was found to be 0.57. The fact that the KMO value is more significant than 0.50 indicates that our variables are suitable for principal component analysis.

On the other hand, it is seen that the Bartlett Chi-Square Test in the table is statistically significant. This indicates the existence of a high correlation relationship between the variables. In other words, it can be said that the variables are suitable for principal component analysis.

With the 1990–2019 period data set, other variables, except for smart urbanization, used in the study examining the connection between smart urbanization and sustainable development in Turkiye were selected according to economic and social factors: Real GDP and financial development index were used as economic factors, and population density was used as social factors. The variables used in the study are expressed in Equation (1) above, and their explanations are given in Table 3. Among the variables stated in Table 3 and to be

Table 2. Kaiser-Meyer-Olkin (KMO) and Barlett test results

KMO test	0.57
Bartlett Ki-Kare Test	19,35 (0.000)

Source(s): Created by the author using Eviews

Table 3. Variables and definitions

Variables	Definitions	Resource
SDI	Sustainable Development Index	https://www.sustainabledevelopmentindex.org/
SMART	Smart City Index	Created by the author
POP	Population density	World Bank
GDP	Real GDP	World Bank
FDI	Financial Development Index	IMF Database

Source(s): Compiled by the author

used in the model, only the logarithms of SDI, POP, and GDP variables were taken to eliminate small fluctuations and make them linear. Logarithmization was not performed for other variables.

5. Methodology and empirical findings

5.1 ADF and PP unit root tests

While conducting econometric studies, the models used are created under certain assumptions. The most essential point of the analysis, especially with time series data, is to test the stationarity of the series. Performing analysis with non-stationary time series raises the problem of spurious regression and leads to misleading analysis results. Augmented Dickey-Fuller (ADF) and Phillips Perron unit root tests improved by Dickey and Fuller were used in the study.

Dickey and Fuller used the critical values and hypotheses they used in the unit root test (ADF), which they expanded in 1981, and Dickey & Fuller (1979) used the unit root test. On the other hand, while using test statistics, they used criteria such as the Akaike information criterion (AIC) or the Schwarz information criterion (SIC) to decide the appropriate number of lagged terms in the extended test. In this context, while the AIC information criterion gives more robust results in finite samples, the SIC information criterion gives more confident results in large samples (İzolluoğlu, 2019). In the question test, the null hypothesis states that the series contains a unit root; they are not stationary. In contrast, the alternative hypothesis states that the series is stationary; they do not contain a unit root (Pata, Yurtkuran, & Kalça, 2016).

On the other hand, the other unit root test used in the study is the Phillips and Perron (1988) unit root test. The question test is improved to counter the weakness of the DF and ADF tests in testing the stationarity of time series. It gives more robust results than DF and ADF unit root tests in time series stationarity analyses with trends (İzolluoğlu, 2019). The unit root results of both tests are given in Table 4. Accordingly, it is seen that each of the series used in the study has a unit root at the level and becomes stationary at the first difference.

5.2 ARDL bound test

The methods improved by Engle and Granger (1987), Johansen (1988) and Johansen and Juselius (1990) are mainly used to test the cointegration connection between the series.

However, these cointegration tests have some disadvantages. For example, if there are more than two variables in the Engle-Granger method, more than one cointegration

Variables	ADF	PP
lnSDI	−1.9943	−2.1052
Dln(SDI)	−4.9277***	−4.9142***
FDI	−2.0774	−2.2312
D(FDI)	−3.9220***	−8.4564***
SMART	−1.7248	−1.7773
D(SMART)	−3.8195**	−3.8195**
lnPOP	−2.9790	−1.9887
Dln(POP)	−4.2342**	−8.5001***
lnGDP	−2.4930	−2.5343
Dln(GDP)	−5.2947***	−6.4391***

Note(s): *** and ** indicate significance at the 1% and 5% levels, respectively
Source(s): Created by the author using Eviews

Table 4.
ADF and PP unit root tests

relationship comes to the fore. In the tests of Johansen (1988) and Johansen and Juselius (1990), all series must have the same degree of stationarity (Koçak, 2014).

Pesaran, Shin, and Smith (2001) Delay Distributed Autoregressive Models (ARDL) test was developed at this point. The ARDL bound test has some advantages over other tests. For example, in the question test, without regard to whether the series is I(0) or I(1), both long-term and short-term relationships can be detected. In addition, according to Narayan and Narayan (2006) , the test results of the ARDL method are more effective and unbiased than the test results of the classical cointegration methods and give better results in small samples. In our study in which the relationship between smart urbanization and sustainable development is tested, the model of the cointegration relationship is specified in Equation (2):

$$\Delta lnSDI = \beta_0 + \sum_{i=1}^{M} \beta_1 \Delta lnSDI_{t-p} + \sum_{i=1}^{m} \beta_2 \Delta lnPOP_{t-p} + \sum_{i=1}^{m} \beta_3 \Delta SMART_{t-p} + \sum_{i=1}^{m} \beta_4 \Delta lnGDP_{t-p} + \sum_{i=1}^{m} \beta_5 \Delta FDI_{t-p} + \beta_6 \Delta lnSDI_{t-1} + \beta_7 \Delta lnPOP_{t-1} + \beta_8 \Delta SMART_{t-1} + \beta_9 \Delta lnGDP_{t-1} + \beta_{10} \Delta FDI_{t-1} + \varepsilon_T \quad (2)$$

The lag length expressed in equation (2) and indicated by p must be determined to apply the bounds test approach.

After this stage, F statistics is applied to the first period values of the dependent and independent variables to determine the cointegration relationship. The hypotheses required are given below.

$$H_0 = \beta_6 = \beta_7 = \beta_8 = \beta_9 = \beta_{10} = 0$$

$$H_0 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq \beta_9 \neq \beta_{10} \neq 0$$

In determining the cointegration relationship, the F statistical value calculated according to the hypotheses expressed above should be compared with the critical values calculated by Pesaran *et al.* (2001). If the calculated F statistical value is greater than the critical upper value, it can be said that there is a cointegration relationship between the variables. In this context, Table 5 shows that the calculated F statistic value is greater than the critical upper value. After this stage, the ARDL model can be established to obtain the short- and long-term coefficients.

To obtain the short and long-term coefficients of the study, the lag lengths of the dependent and independent variables were determined, and the appropriate ARDL model was created. After this stage, the ARDL long-term coefficients were first obtained, and then the short-term relationship of the variables was determined with the ARDL error correction model.

Equation (3) and Equation (4) below refer to the models created to obtain the long-term and short-term coefficients, respectively.

k	*F* Statistic	Lower bound	Upper bound
4	36.03	2.56	3,49

Note(s): k is the number of independent variables from Equation (2). Critical values are determined by Pesaran *et al.* (2001) Table taken from CI (iv)
Source(s): Created by the author using Eviews

Table 5. Cointegration test results

$$\Delta lnSDI = \beta_0 + \sum_{i=1}^{M} \beta_1 \Delta lnSDI_{t-p} + \sum_{i=1}^{m} \beta_2 \Delta lnPOP_{t-p} + \sum_{i=1}^{m} \beta_3 \Delta SMART_{t-p} + \sum_{i=1}^{m} \beta_4 \Delta lnGDP_{t-p} + \sum_{i=1}^{m} \beta_5 \Delta FDI_{t-p} + \varepsilon_t \quad (3)$$

$$\Delta lnSDI = \beta_0 + \sum_{i=1}^{M} \beta_1 \Delta lnSDI_{t-p} + \sum_{i=1}^{m} \beta_2 \Delta lnPOP_{t-p} + \sum_{i=1}^{m} \beta_3 \Delta SMART_{t-p} + \sum_{i=1}^{m} \beta_4 \Delta lnGDP_{t-p} + \sum_{i=1}^{m} \beta_5 \Delta FDI_{t-p} + ECT_{t-1} + \varepsilon_t \quad (4)$$

The long-run coefficients of the ARDL model are expressed in Table 6 below.

According to Table 6, the increase in smart urbanization positively impacts sustainable development and the coefficient is statistically significant. Smart cities are sustainable, with a high quality of life and efficient resource use. Smart urbanization, which is based on technology on the one hand and supports environmental sustainability on the other, is a critical factor in realizing sustainable development today. The spread of smart urbanization helps to prevent disasters that threaten the world, especially global warming and produces more rational solutions to meet the needs of today's people. It also leads to a more livable world for future generations because the main aim of smart cities is to leave livable city life to future generations.

Population density is another variable whose effect on sustainable development is examined in the study. The increase in population density reduces sustainable development. This result is also statistically significant. There is no agreement in the economics literature in studies on the effect of population on sustainable development. In most of these studies, it is stated that the effect of population growth on sustainable development by causing environmental deformation is negative. On the other hand, in studies where the population positively affects sustainable development, the population is accepted as the most crucial source of human capital. As human capital increases, the social and economic dimensions of sustainable development develop (Akyol, 2020, p. 20). The role of human capital in economic growth and development, especially in theories based on endogenous growth models, has made significant contributions in this field (Telatar & ve Terzi, 2010).

On the other hand, the study found that the increase in GDP increased sustainable development, and the coefficient was statistically significant. The country's income level is very important in realizing sustainable development. While the increase in the income level in the country causes investments to be transferred to more productive areas, it also supports sustainable development by increasing human capital.

Table 6. The long-run coefficients of the ARDL model (3, 2, 2, 0, 0)

Variable	Coefficient	*p* value
DSMART	0.433096	0.0000***
DlnPOP	−7.474455	0.0013***
DlnGDP	1.575502	0.0026***
DFDI	1.593711	0.0445**
C	7.163330	0.0742*

Note(s): ***, **, and * indicate 1%, 5%, and 10% significance, respectively
Source(s): Created by the author using Eviews

The last variable examined in the study is the financial development index. Table 6 shows that the increase in financial development positively affects sustainable development, and this coefficient is statistically significant. In the process of sustainable development, both the state and the private sector have essential duties. In this context, the financial sector can be effective in direct and indirect sustainable development. To achieve sustainable development, an increase in investments must occur, and this investment increase is only possible with the efficiency and depth provided by an advanced financial system. The way for future generations to have at least as much capital and natural resources as today's generations is through the development of the financial sector (Kanberoğlu & Oğuz, 2016).

After obtaining the coefficients for the long-term relationship of the variables, the appropriate lag length was determined as (3,2,2,0,0), and the ARDL Error Correction Model results expressing the short-term relationship are presented in Table 7. The error correction term (ECM) must be negative and statistically significant between 0 and -1 for the error correction model to work. According to Table 7, the error correction term coefficient was −0.97. That is, the sign of the ECM coefficient is statistically significant and negative, coinciding with the expectation. In other words, 97% of the deviations occurring in the short term disappear in the next period and quickly reach the long-term equilibrium.

In the study, tests related to varying variance, autocorrelation, and stability of the model were performed, and the test results are given in Table 8 and Figure 4.

According to the results in Table 8, the explanatory power of the model with *R2* is 0.97. There

is no autocorrelation problem in the model as a result of the Breusch-Godfrey LM test, and there is no problem of varying variance in the model as a result of the Breusch-Pagan test. In addition, as a result of the Jarque-Bera normality test, it was concluded that the error terms passed the normality test. In other words, the test result reveals that the errors have a normal distribution.

As the ARDL model's final stage, the parameters" stability is tested with Cusum and CUSUM of Square graphs. The error terms and test parameters remain within critical limits according to the CUSUM and CUSUM of Square tests. In other words, this result indicates that the model is stable.

Variable	Coefficient	*T* Statistic	*p* value
lnSDI(-1)	−0.151995	−3.172892	0.0099
lnSDI(-2)	−0.207775	−4.248226	0.0017
FDI	0.312006	0.150212	0.0645
FDI(-1)	−0.807978	−4.436803	0.0013
SMART	0.311993	8.499670	0.0000
SMART(-1)	−0.097458	−2.311972	0.0434
ECM	−0.975202	−18.00791	0.0000***

Source(s): Created by the author using Eviews

Table 7. ARDL error correction model result (3,2,2,0,0)

R^2	0.97	AIC	−4.88
Log-likelihood	60.73	SIC	−4.53
Breusch- Godfrey LM Test	2.34 (0.21)	Breusch-Pagan-Godfrey	0.38 (0.93)
F Statistic	370.78 (0.000)	Jargue-Bera	0.61(0.73)

Source(s): Created by the author using Eviews

Table 8. Diagnostic test statistics

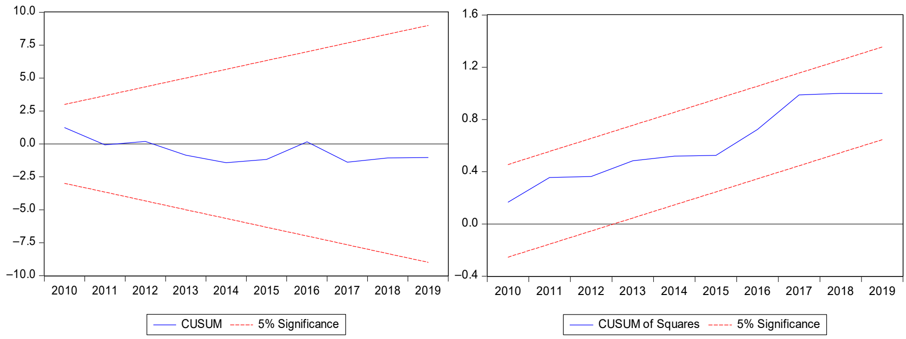


Figure 4.
Cusum and cusum of squares

Source(s): Created by the author using Eviews

5.3 FMOLS cointegration estimator for testing the consistency of the model

After performing the cointegration test, it is necessary to analyze the data with cointegration estimators to know the direction of the long-term relationship between the variables. From time to time, the problem of endogeneity arises between economic variables, and the interpretation of estimators that do not consider this problem causes inaccurate results (Pazarcı, Kar, & Altuntaş, 2023, p. 571). The internality problem in cointegrated series is eliminated by the FMOLS cointegration estimator developed by Phillips and Hansen (1990). Thus, it becomes possible to interpret the long-term coefficients. The FMOLS method allows for significant heterogeneity between individual sections. It is also designed to include correlations that may cur between the constant term, error term, and the differences of the independent variables (Kök & ve Şimşek, 2006). Table 9 contains FMOLS estimation results.

According to the FMOLS estimator results given in Tables 9, it has been concluded that similar to the ARDL Bound test used as the primary model, smart urbanization, increase in GDP and FDI increase sustainable development, but unlike the primary model, the increase in population density reduces sustainable development. In addition, all coefficients are statistically significant.

6. Conclusion

Today, urbanization is accepted as a complex system gradually developing and changing. The fact that information and communication technologies take place in every aspect of our lives comes to the fore due to today's locality. In this context, in the coming years, all cities will have to use smart systems to increase the quality of life and for sustainable development. At this point, smart urbanization has come to the fore as a solution to the sustainability problems arising from environmental and social reasons in recent years, and today, sustainable development depends on accessing smarter solutions. To be defined as a smart city, it must

Table 9.
FMOLS estimation results

Dependent variable: Sustainable development index

Variable	Coefficient	*p* value
LnPOP	−4.847993	0.0000***
SMART	0.346579	0.0000***
LnGDP	1.091387	0.0003***
FDI	1.402991	0.0022**
C	−5.884719	0.1839

Source(s): Created by the author using Eviews ensure sustainable growth and development. For this, it is necessary to encourage an economic model that includes more efficient use of resources and technology, competitiveness, knowledge, and innovation.

This study aims to examine the impact of smart urbanization on sustainable development empirically. For this purpose, the empirical relationship between 1990 and 2019 for Turkiye was analyzed with the help of the ARDL bound test, and the coefficients" consistency was examined through FMOLS estimators. The analysis findings show that smart urbanization positively and significantly impacts sustainable development in the ARDL bound test and FMOLS estimators. New ideas or development policies, such as smart urbanization, have come to the fore due to the increase in disasters such as global warming, the concern for the future of society, and the idea that the world will be more livable and sustainable. In this context, smart cities are expressed as sustainable cities with a high quality of life and efficient resource use. Today, smart urbanization is of great importance in the realization of the economic, environmental, and social goals of the United Nations (UN) to be reached by 2030.

In the study, the effects of other variables, which are thought to have an impact on sustainable development and determined within the framework of the model, were also controlled. Accordingly, firstly, it was found that while the increase in population density affected sustainable development negatively in the ARDL bound test and FMOLS estimator, the coefficients were statistically significant in both models. Secondly, it was found that the increase in GDP positively affects sustainable development in both models, and the coefficients are significant in both models. The last variable examined in the study is FDI. FDI has a positive and significant effect on sustainable development in both models.

The study shows that smart urbanization is essential in ensuring sustainable development. In this context, based on the findings obtained from the article, the following policy recommendations can guide policymakers:

(1) Technological infrastructures must be provided to develop smart city systems to ensure sustainable development. In this regard, both the private and public sectors need to increase their R&D expenditures.

(2) Another critical point for realizing sustainable development and smart urbanization is ensuring social acceptance and the human capital factor. Because human capital is of great importance in better understanding and using the technological structure in realizing smart urbanization. In this context, training for human resources needs to be increased.

(3) One of the important policies in realizing smart urbanization is the success of waste management and the widespread use of renewable energy resources. Because one of the most critical components of smart cities is the environmental component, in this context, all public and private organizations that are pioneers in this field should be encouraged to use renewable energy, and inefficient energy use should be reduced to minimum limits.

When all these are evaluated together, the findings obtained from the study are similar to the studies of Örselli and Akbay (2019) and Xu *et al.* (2022). Accordingly, in the studies in question, it was stated that smart cities require high costs and a solid infrastructure in information and communication technologies. Therefore, countries with a higher level of development, a more robust economy and a stronger capital infrastructure stand out in the smart city market. Turkey is influenced by smart city applications around the world and includes smart city applications to a small extent.

Although this study is thought to make specific contributions to the existing literature, it has some limitations. The most important limitation of the study is the lack of accessible secondary data on smart urbanization. For this reason, data access is difficult, especially in calculating smart urbanization for Turkiye. In future studies, different macroeconomic impacts of smart urbanization can be examined using different methods, and comparative analysis of regions with different development levels can be made. In addition, in new studies on this subject, more diverse models can be created by including additional control variables.

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