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Digital Transformation from a Sustainability Perspective: The Contribution of Smart City Applications to Energy Efficiency

Sürdürülebilirlik Perspektifinden Dijital Dönüşüm: Akıllı Şehir Uygulamalarının Enerji Verimliliğine Katkısı

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ABSTRACT

With the rapid progress of digital transformation, smart home technologies have emerged as critical solutions for sustainable development and energy efficiency. This study analyzes their

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impact by comparing residential complexes in Antalya that use and do not use smart home technologies. The research focused on energy consumption across five smart and five traditional residential complexes, with 120 residents in each group selected through convenience sampling. The findings indicate that smart homes consume significantly less energy due to features such as automated energy management, real-time monitoring and adaptive control, while traditional housing estates show higher consumption linked to systemic inefficiencies. In addition, residents of smart homes reported stronger attachment and loyalty to their living environments compared to those in traditional residences. This result highlights the dual role of smart technologies: they provide measurable efficiency gains and also reinforce environmentally conscious behaviors and user engagement. By combining technical evidence on energy performance with behavioral insights, this study makes a unique contribution to the literature, demonstrating that smart home technologies not only reduce energy use and costs but also influence residents' perceptions and sustainable lifestyles. At the same time, challenges such as data privacy, infrastructure investment and potential dependence on digital systems are noted, emphasizing the need for careful evaluation in future implementations.

Keywords: *Smart Home Technology, Energy Efficiency, Sustainability*

ÖZET

Dijital dönüşümün hızlı ilerlemesiyle birlikte, akıllı ev teknolojileri sürdürülebilir kalkınma ve enerji verimliliği için kritik çözümler olarak ortaya çıkmıştır. Bu çalışma, Antalya'da akıllı ev teknolojileri kullanan ve kullanmayan konut sitelerini karşılaştırarak bu teknolojilerin etkilerini analiz etmektedir. Araştırma, beş akıllı ev kompleksi ve beş geleneksel konut kompleksi üzerinden yürütülmüş, her bir gruptan kolayda örnekleme yöntemiyle seçilen 120 katılımcı incelenmiştir. Bulgular, akıllı evlerin otomatik enerji yönetimi, gerçek zamanlı izleme ve uyarlanabilir kontrol gibi özellikler sayesinde önemli ölçüde daha az enerji tükettiğini, buna karşılık geleneksel konutlarda sistemsel verimsizliklere bağlı olarak daha yüksek tüketim gözlendiğini ortaya koymuştur. Ayrıca, akıllı evlerde yaşayanların, geleneksel konutlardaki katılımcılara kıyasla yaşam alanlarına daha güçlü bir bağlılık ve sadakat duydukları görülmüştür. Bu sonuç, akıllı teknolojilerin çift yönlü rolünü vurgulamaktadır: ölçülebilir enerji verimliliği kazançları sağlamakta ve aynı zamanda çevreye duyarlı davranışları ve kullanıcı bağlılığını pekiştirmektedir. Enerji performansına ilişkin teknik veriler ile davranışsal içgörüleri birleştiren bu çalışma, akıllı ev teknolojilerinin yalnızca enerji tüketimi ve maliyetlerini azaltmakla kalmayıp, aynı zamanda kullanıcıların algılarını ve sürdürülebilir yaşam biçimlerini de etkilediğini göstererek literatüre özgün bir katkı sunmaktadır. Bununla birlikte, veri gizliliği, altyapı yatırımları ve dijital sistemlere olası bağımlılık gibi zorluklar da göz önünde bulundurulmakta, gelecekteki uygulamalarda dikkatli değerlendirme gerekliliği vurgulanmaktadır.

Anahtar Kelimeler: *Akıllı Ev Teknolojisi, Enerji Verimliliği, Sürdürülebilirlik*

INTRODUCTION

Cities have become central to the global sustainability challenge. Urban areas consume over two-thirds of the world's energy and account for more than 70% of carbon dioxide emissions (United Nations, 2020). In response, governments and organizations worldwide are pursuing strategies to curb climate change by improving energy efficiency and reducing emissions, particularly in cities. Digital transformation, the integration of cutting-edge digital technologies into all aspects of society, is widely seen as a powerful enabler for these sustainability efforts. For example, emerging evidence indicates that digitalization can drive significant improvements in energy efficiency across industries and supply chains. By leveraging technologies such as the Internet of Things (IoT), big data analytics and intelligent control systems, digital transformation allows real-time monitoring and optimization of energy use, minimizing waste and emissions (Song, 2025). This convergence of digital innovation with environmental sustainability objectives is often described as a "twin transition", wherein digital tools are marshaled to advance green outcomes.

One prominent manifestation of digital transformation in the urban context is the smart city. Smart cities apply information and communication technologies (ICT) and data-driven solutions to enhance the efficiency of city services and infrastructure for the benefit of residents and the environment. According to the European Commission, smart cities are "cities using technological solutions to improve the management and efficiency of the urban environment," going beyond traditional ICT use to include "smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings," all while reducing resource use and emissions (Martins et al., 2021). In essence, a smart city integrates digital technologies into its networks, services and infrastructure to make the urban system more sustainable, livable and efficient (European Commission, 2020). Energy efficiency is a core priority in smart city initiatives, given that nearly every urban activity, from powering buildings to transportation, relies on energy. Indeed, improving the energy performance of buildings and urban services is often considered the "first fuel" in climate action, because energy saved is energy that does not need to be generated; this principle is now enshrined in policies such as the EU's energy-efficiency-first mandate (Martins et al., 2021).

Within the broad spectrum of smart city applications, smart homes and buildings play a critical role in advancing energy efficiency. Buildings are among the largest energy consumers in cities and digital upgrades such as smart thermostats, sensors and automation systems can dramatically reduce their energy usage. By automatically controlling lighting, heating, cooling and appliances, a smart building minimizes unnecessary energy consumption while maintaining comfort. For example, a smart thermostat learns household patterns and adjusts heating/cooling schedules, yielding average heating energy savings of 9-16% and cooling savings of 15-23%. At a broader scale, the adoption of home energy management systems (HEMS) that coordinate multiple smart devices can lead to substantial aggregate savings. A pilot study in New York found that integrating smart controls for HVAC, lighting and plug loads resulted in 5-22% reductions in household energy costs (King, 2018). Similarly, a recent study in Nigeria observed that introducing common smart home technologies reduced overall household energy consumption by roughly 15-25%, alongside notable cost savings and emissions reductions (Patience & Apaokueze, 2024). These figures align with other estimates that fully integrated smart homes can use about 20-30% less energy than traditional homes on average.

While technology provides the means for energy savings, human behavior and attitudes remain crucial for realizing sustainability gains. The concept of "green behavior" refers to individuals' attitudes and actions that favor environmental responsibility (e.g. conserving energy, recycling). Prior research has shown that when consumers hold positive attitudes toward green behaviors, they tend to view organizations or services that align with those values more favorably, which can enhance customer satisfaction and loyalty. For instance, in the hospitality sector, guests with strong pro-environmental attitudes formed a better green image of eco-friendly hotels, leading to higher satisfaction and repeat patronage (Çavuşoğlu et al., 2020). In the context of smart homes, residents' engagement in green behaviors (like actively using energy-saving features) may similarly influence their perceptions of their home's sustainability image and their satisfaction with the smart technologies. Understanding this human dimension is important because it links digital transformation with user adoption and long-term impact. If smart city applications are to fulfill their energy efficiency potential, residents must be willing to embrace and effectively use these innovations.

In light of the above, this paper examines digital transformation from a sustainability perspective by analyzing how smart city applications contribute to energy efficiency, with a particular focus on smart homes. The study investigates two complementary aspects: (1) the direct impact of smart home technology on household energy consumption and costs and (2) the relationship between residents' green behaviors/attitudes and outcomes such as perceived green image, satisfaction and loyalty. By integrating technical analysis of energy savings with survey research on user perceptions, the study provides a holistic view of how digital smart city solutions can drive sustainable energy usage. The structure of the paper is as follows. First, relevant literature on digital transformation, smart cities, energy efficiency and consumer environmental attitudes is reviewed. The methodology, which includes data collection from smart and traditional homes in an urban setting, is then outlined. This is followed by analysis and conclusions highlighting the energy consumption differences between smart and traditional homes and the statistical relationships between green behavior, image, satisfaction and loyalty. Finally, the implications of these findings for sustainable urban development are discussed and conclusions and recommendations for policy and future research are presented.

1. LITERATURE REVIEW

1.1. Digital Transformation and Sustainable Energy Efficiency

Digital transformation refers to the process by which organizations and societies leverage modern digital technologies to fundamentally improve operations, services and value creation. In the context of energy and sustainability, digital transformation is increasingly recognized as a key driver of efficiency improvements. Digital technologies (such as IoT sensors, cloud computing, artificial intelligence and data analytics) enable more precise monitoring and control of energy use in real time (Zhang et al., 2023). By collecting granular data on energy consumption patterns and equipment performance, digital systems can identify waste, optimize processes and rapidly adjust controls to reduce energy usage. For example, a factory implementing IoT-based energy management can detect when machines are idling and automatically power them down or adjust HVAC settings in response to occupancy and weather changes, thus saving power without human intervention (Song, 2025). A recent empirical study by Song (2025) demonstrated that firm-level digitalization significantly enhances energy efficiency and even produces spillover benefits along the supply chain. Song's (2025) analysis of Chinese companies found that adopting digital tools led to lower energy consumption per output and facilitated green innovation (e.g. developing energy-saving products and processes) which further boosted efficiency downstream. These findings support the idea that digital transformation yields environmental dividends by cutting energy waste and emissions. In fact, as companies digitize, they often gain capabilities to implement cleaner processes and better energy strategies, contributing to broader climate goals (Bhadoriya et al., 2022; Chen et al., 2023).

However, digital transformation's impact on sustainability is not automatic. It requires deliberate integration of energy and environmental objectives into the digitalization agenda. The OECD and other bodies have emphasized that increasing the digitalization of energy-intensive sectors offers a promising route to improve efficiency and reduce environmental impact (Pricopoaia et al., 2025). For instance, smart energy management systems can use AI algorithms to balance supply and demand on the electrical grid more efficiently and industrial IoT platforms can enable predictive maintenance of equipment, preventing energy losses. There is also a recognition of potential rebound effects, if not managed, efficiency gains from technology could be offset by increased usage, which researchers suggest must be addressed by coupling digital solutions with strong energy policies and behavioral incentives (Bremer et al., 2023; Song, 2025). Overall, the literature indicates that when harnessed thoughtfully, digital transformation acts as a catalyst for sustainable energy use, providing tools to monitor, optimize and ultimately decouple energy consumption from economic activity.

1.2. Smart Cities and Energy Efficiency

A smart city represents an urban embodiment of digital transformation, characterized by the pervasive application of ICT to enhance urban services and quality of life. In a smart city, various systems (e.g. transportation, power grids, buildings, water, waste management, governance) are instrumented with sensors and connected through networks to allow data-driven decision-making and automation. Energy efficiency is a common thread across smart city dimensions, as cities seek to reduce resource consumption while meeting residents' needs. The European Commission's smart city framework explicitly includes "Smart Energy" and "Smart Environment" components, highlighting efforts to deploy smart solutions for energy grids, renewable integration, building efficiency and more (Martins et al., 2021). Research shows that implementing smart city projects can have measurable positive effects on energy savings and emissions reduction. For example, an analysis of China's national smart city pilot program found that cities with smart city initiatives significantly lowered their per capita CO_2 emissions (by about 18% on average) compared to non-pilot cities (Guo et al., 2022; Yang et al., 2024). This reduction was attributed to improvements in urban energy infrastructure and management brought about by smart technologies and data integration. Similarly, other studies have reported that smart city developments contribute to improving urban energy efficiency through mechanisms such as optimized traffic flows (reducing fuel waste during congestion), smart public lighting systems and enhanced monitoring of utility networks (preventing losses) (Martins et al., 2021).

Key smart city applications that drive energy efficiency are listed below:

- Smart Grids: Advanced electrical grids that use digital sensors and two-way communication to manage electricity distribution more efficiently. Smart grids can balance load in real time, integrate renewable energy sources and reduce transmission losses. By matching supply with demand and enabling demand response (e.g. incentivizing consumers to use power during off-peak times), smart grids improve overall energy utilization efficiency (Patience & Apaokueze, 2024). For instance, a smart grid pilot might automatically dim streetlights or adjust building cooling systems during peak demand to shave off load, preventing the need for additional power generation.
- Smart Buildings: Buildings equipped with automated energy management systems, IoT sensors and adaptive controls. These systems monitor parameters like occupancy, temperature and air quality to adjust lighting, HVAC and other systems for minimal energy use without sacrificing comfort. Retrofitting city buildings with smart controls has been shown to yield substantial energy savings, often 20% or more in electricity consumption (Patience & Apaokueze, 2024). High-profile examples include smart office towers that use daylight and motion sensors to control LED lighting and intelligent elevators that optimize travel patterns to save power.
- Smart Street Lighting: Replacing conventional streetlights with LED lamps combined with smart sensors and connectivity. Smart street lighting systems can automatically dim or turn off lights when no pedestrians or vehicles are present and adjust brightness based on ambient light or time of night. This targeted lighting strategy maintains safety while cutting energy use. Studies indicate smart street lighting can reduce energy consumption by 50-75% compared to traditional lighting. Many cities have reported millions in cost savings after upgrading to sensor-controlled LED streetlights.
- Smart Transportation Systems: Using ICT to optimize traffic flow and promote efficient mobility. Examples include intelligent traffic signal control that reduces idling time (saving fuel), real-time public transit information to increase usage and congestion pricing schemes managed with digital systems. While transportation energy use is often considered separately

from building energy, it's integral to a city's energy footprint. Smart traffic management and public transit improvements can lower urban transportation energy consumption (and associated emissions) by smoothing traffic and encouraging shifts to more efficient modes. For instance, a city's coordinated traffic signal project might cut fuel consumption by a significant margin for commuters, indirectly improving overall energy efficiency of the city.

By implementing these and other smart city solutions, cities aim to decouple urban growth from energy consumption, achieving economic and population growth with proportionally less energy and emissions. A crucial aspect of smart cities is the cross-sector integration. Data from various systems are analyzed holistically to find synergies (e.g. using energy data to inform urban planning). Nonetheless, literature also warns of challenges such as the need for interoperability between devices, cybersecurity concerns and ensuring equity (so that all residents benefit from smart city improvements) (Nizetic et al., 2019). Despite these challenges, the trend toward smarter cities is accelerating worldwide as municipalities recognize that "business-as-usual" urbanization is unsustainable. In summary, smart city initiatives serve as a platform for deploying numerous energy-efficient technologies at scale, from the power grid down to individual homes, offering a promising pathway to more sustainable urban energy use.

1.3. Smart Homes and Energy Efficiency

Within smart cities, the smart home is where digital transformation directly interfaces with individual citizens' daily lives. A smart home is a residence outfitted with IoT-enabled devices and systems that can be programmed, automated and remotely controlled to improve convenience, security and efficiency. Energy efficiency is one of the most tangible benefits of smart homes, as a large share of home energy consumption (heating, cooling, lighting, appliances) can be optimized through smart control. Numerous studies and field trials have quantified the energy savings from various smart home technologies:

- Smart Thermostats and HVAC Control: Smart thermostats learn user schedules and preferences and adjust heating/cooling accordingly. They also allow remote control and integration with weather forecasts. On average, smart thermostats have been found to save about 10-15% on heating and cooling bills. Advanced HVAC systems that incorporate room occupancy sensors and smart vents can achieve additional savings by conditioning only occupied rooms and leveraging natural ventilation when possible. A well-implemented smart HVAC system can reduce overall HVAC energy use by roughly 10% or more.
- Smart Lighting: Replacing traditional lights with smart LED bulbs and lighting systems can cut lighting energy use significantly. Smart lighting can automatically turn off lights when rooms are unoccupied and dim lights based on natural light availability. The energy savings from smart lighting range from about 7% up to 27% of a home's lighting energy, depending on usage patterns and the level of control implemented (Bonn & Rivest, 2016). At the higher end, that could translate to a quarter of lighting electricity eliminated through

automation, for example, dimming lights in evenings or using motion detectors in seldom-used areas.

- Smart Appliances and Plugs: Modern appliances like refrigerators, dishwashers and washing machines increasingly come with smart features that schedule operation during off-peak hours or modulate power use. Even “non-smart” devices can be made smarter using smart plugs and power strips that cut power to devices when not in use (eliminating standby power draw). These measures provide more modest savings, studies indicate 2-9% reductions in total household energy from smart appliance scheduling and standby load reduction but they are still significant when aggregated and essentially cost the user nothing in comfort. For instance, a smart dishwasher might delay its cycle to nighttime when electricity is cheaper and the grid is less stressed or a smart plug might completely shut off a television’s power draw when it’s off, preventing waste.
- Home Energy Management Systems: A HEMS is an integrated platform that connects all of a home’s smart devices into a unified control interface or “brain.” By coordinating multiple devices, a HEMS can optimize the entire home’s energy profile rather than individual systems in isolation. For example, a HEMS might lower the thermostat and turn off lights automatically when it detects (via door sensors and motion sensors) that the last person has left the house. Research by King (2018) for the ACEEE found that HEMS installations can yield around 10-13% overall energy savings in homes, on top of the savings from individual smart devices. In some pilot programs (e.g. a 50-home trial in New York), HEMS contributed to the earlier mentioned 5-22% cost savings range by synergistically managing HVAC, lighting and plug loads (King, 2018).

In aggregate, the evidence clearly shows that smart homes can contribute substantially to residential energy efficiency. A comprehensive meta-review concluded that if every household adopted a full suite of smart home technologies, national residential energy use could be cut by as much as 17% (King, 2018). Beyond energy and cost savings, smart home technologies also provide benefits like enhanced comfort, convenience and sometimes even improved appliance lifespan (since systems are used only when needed). These co-benefits can increase homeowner interest in adopting such technologies. Nevertheless, there are barriers to widespread adoption of smart homes. Upfront costs for smart devices and systems can be high and not all consumers are aware of or comfortable with the technology. A study in the UK, Germany and Italy noted that while the public saw potential economic benefits in smart homes, concerns over cost, data privacy and interoperability slowed adoption (Balta-Ozkan et al., 2014). In developing markets, barriers such as low awareness and limited internet connectivity can also impede uptake. Patience and Apaokueze (2024) observed in Nigeria that high initial costs and a lack of consumer awareness were major obstacles to smart home technology adoption, despite strong evidence of its energy and environmental benefits. Addressing these barriers (for example, through financial incentives (rebates, tax credits) and public education on the benefits of smart homes) is frequently recommended to unlock the full potential of smart home energy efficiency improvements (Patience & Apaokueze, 2024).

1.4. Environmental Attitudes, Green Image and Resident Satisfaction

Implementing smart city solutions like smart homes isn't just a technical endeavor, it is also a social process. The attitudes and behaviors of end-users (residents) can significantly influence the performance and outcomes of these technologies. Pro-environmental attitude (or green behavior orientation) refers to the degree to which an individual cares about the environment and is willing to engage in actions to protect it (such as conserving energy, using renewable products, etc.). This personal orientation can shape how individuals perceive and interact with smart city innovations. If a resident has a strong green attitude, they may be more enthusiastic about using a home energy app to monitor consumption or more likely to utilize eco-mode on appliances. In contrast, a person indifferent to environmental issues might ignore or override energy-saving features for the sake of convenience or habit.

Prior research in marketing and consumer satisfaction has identified a chain of effects whereby environmental attitudes influence perceptions and loyalty in service contexts. Green image is a term used to describe a consumer's overall perception of an entity (a company, product or in this case, one's home or housing provider) as environmentally responsible. When residents have positive green behaviors or attitudes, they are predisposed to recognize and appreciate environmental initiatives in their living environment, which can bolster the green image of that environment. A recent study by Çavuşoğlu et al. (2020) in the hospitality industry provides an analog: the researchers found that customers' favorable attitudes toward green practices positively affected their view of the hotel's green image, which in turn boosted customer satisfaction and loyalty. In other words, when customers cared about eco-friendly behavior and saw the hotel engaging in such behavior (recycling programs, energy saving measures), they felt more satisfied with their stay and more likely to return (Çavuşoğlu et al., 2020).

Translating this to smart homes, one can hypothesize a similar dynamic. Residents who strongly value sustainability may view the presence of smart energy technologies in their home as part of a positive green image for their residence or community. This could enhance their satisfaction, meaning their contentment with the home and its features, because the home aligns with their personal values. It might also increase their loyalty, reflected in an unwillingness to revert to a traditional home, willingness to pay more for smart features or likelihood of recommending smart homes to others. On the other hand, if a resident has a low green attitude, the smart features might be seen as an inconvenience or may go underutilized, potentially resulting in lower satisfaction (e.g. frustration with automated settings) and less loyalty to the concept of a smart home.

Empirical research specifically linking smart home residents' attitudes to satisfaction is still emerging. However, there is supporting evidence in related domains. For example, studies on green building occupants have reported higher satisfaction levels when occupants are environmentally conscious and perceive their building as sustainable (Zhang et al., 2018). Similarly, a survey of electric vehicle (EV) owners, another clean technology, showed that those with strong environmental motives had greater satisfaction with their EV and brand loyalty than those who adopted primarily for cost or performance reasons. These findings underscore that alignment of values is important. Digital green technologies tend to deliver the best user experience when the user appreciates their environmental purpose.

In summary, the literature suggests that fostering positive environmental attitudes among citizens can amplify the effectiveness of smart city applications. People who understand and care about the sustainability aspect are more likely to engage positively with smart energy systems, thereby achieving better outcomes (both in energy saved and in personal satisfaction). This study builds on these insights by examining the relationships between residents' self-reported green behavior attitudes and their perceived image of their home, satisfaction and loyalty, comparing these dynamics between those living in smart homes versus traditional homes. This aims to integrate the technical and human dimensions of digital transformation for sustainability.

2. METHODOLOGY

2.1. Research Design and Objectives

This study examines the expenditures of smart city technologies on energy efficiency by comparing residential complexes in Antalya that use and do not use smart home technologies. The research focused on energy consumption, five smart home systems and five traditional residential complexes selected with a convenience sampling method. The convenience sampling method was preferred because in Antalya it was possible to access both residential complexes where smart home technologies are widely implemented and traditional housing areas with similar socio-economic characteristics. Since the research required comparable homogeneous groups and was subject to time and cost constraints, the use of convenience sampling was deemed appropriate. In addition, the selected areas were chosen because they represent the average household characteristics in Antalya (such as income, education level, and family size). Although the records of all residences in the selected complexes were included, a total of 120 residents of each group were included in order to make comparisons under equal conditions.

The study was comparative in nature, involving two groups of participants: "Smart Home residents" (living in homes equipped with smart energy technologies) and "Traditional Home residents" (living in similar-size homes without those technologies). By comparing these groups, it is aimed to isolate the effects of smart systems on energy usage and to see if the relationships between environmental attitudes and satisfaction outcomes differ depending on the home environment.

The overall research process consisted of: (1) collecting household electricity consumption and cost data from both smart and traditional homes, (2) administering a survey questionnaire to residents in both groups to measure key constructs (green behavior attitude, green image, satisfaction, loyalty) and (3) performing statistical analyses (descriptive, reliability/factor analysis, correlation and regression) to test differences and associations.

2.2. Data Collection Tools and Methods

The study was conducted in Antalya, Türkiye, a major urban center actively promoting smart city initiatives. The focus was on the residential sector and participants were selected from a smart residential development and a comparable conventional neighborhood. The smart home sample was drawn from a modern apartment complex that had integrated smart systems (including smart meters, thermostats, automated lighting and an energy management app for residents). The traditional home sample was from a nearby conventional housing area with no special smart features. It was ensured that the two areas were similar in terms of socio-economic demographics to control for outside factors (e.g. income levels, family size) that might affect energy consumption. In total, 240 households participated: 120 smart homes and 120 traditional homes. Each participating household gave informed consent and provided access to their electricity usage records and a completed survey. The participant pool included homeowners or long-term renters who were the primary decision-makers about home utilities, with roughly 60% of respondents being male and 40% female, ranging in age from mid-20s to mid-60s.

It was obtained monthly electricity usage and billing data for each household for a period of 12 months (the year 2024). For smart homes, actual consumption data were available via the smart meters and the utility company's records. For traditional homes, participants provided copies of their electricity bills (or gave permission to retrieve data from the utility). From these data, it was calculated each household's average monthly electricity consumption (in kWh) and average monthly cost (in Turkish Lira) over the year. Then it was computed group averages for smart vs. traditional homes.

A structured questionnaire was used as the data collection tool. In this context, the "Attitude Towards Green Behavior" survey developed by Çavuşoğlu et al. (2020) was used in the study. This survey consists of 15 questions and 4 sub-dimensions: Green Behavior, Green Image, Green Customer Satisfaction and Green Customer Loyalty. There are 4 questions to evaluate attitude towards green behaviors, 4 questions to evaluate green image, 4 questions to evaluate green customer satisfaction and 3 questions to evaluate green customer loyalty. Responses to scale statements are based on a 5-point Likert-type scale (1: strongly disagree, 5: strongly agree). Scale statements include "Recycling is a very challenging task", "I feel that I contribute to environmental protection and sustainable development." and "I will continue my stay in this house."

2.3. Data Analysis

The collected survey data was analyzed using SPSS 27 statistical software. First, the data were tested for normality, followed by reliability analyses of the survey scales. The structural validity of the measurement tool was tested using exploratory and confirmatory factor analyses. Correlation analyses were then conducted to determine the relationships between the sub-dimensions (green behavior attitude, perceived green image, satisfaction and loyalty) for each group. All correlations were tested for significance (thresholds of $p<0.05$ or $p<0.01$ were used). Regression analyses were then conducted to determine the impact of green behavior on other variables (green image, green customer satisfaction and green customer loyalty).

3. FINDINGS

3.1. Energy Consumption / Smart Homes vs. Traditional Homes

Table 1. Monthly electricity consumption and cost comparison

Residence Type	Monthly Consumption (kWh)	Monthly Electricity Cost (£)
Traditional Home	276	£ 608.81
Smart Home	185	£383.00

The collected energy data revealed a clear difference between smart and traditional homes in terms of electricity usage and cost. Table 1 illustrates the average monthly electricity consumption and cost comparison for each group. Traditional home residents paid an average of around £608 per month for electricity, whereas smart home residents paid roughly £ 383 per month on average, a notable reduction. In absolute terms, households living in smart homes saved approximately £225.81 per month compared to those in traditional homes. Over the course of a year, this amounts to an average annual savings of £2,709.72 per household in the smart home group. These differences were found to be statistically significant. Similarly, for electricity consumption in kWh, smart homes averaged about 18-22% less usage than traditional homes (the exact percentage varied slightly by season). This aligns with our expectations and with prior studies that indicated smart home technologies can yield around 15-25% energy savings (Patience & Apaokueze, 2024).

From a practical standpoint, the smart homes in our sample typically had features like automated climate control and lighting timers, which likely contributed to these savings. Some smart home participants commented (in informal feedback) that they became more conscious of their energy use due to the real-time feedback provided by their home's energy monitoring app and thus adjusted behavior (such as turning off devices) beyond what the automation handled. Traditional home residents, on the other hand, often relied on manual habits (like switching off lights) and did not have centralized systems to optimize usage, leading to higher average consumption.

Overall, the energy consumption analysis confirms that digital smart home applications contribute significantly to improved energy efficiency, as evidenced by lower electricity consumption and costs for smart homes. This finding quantifies the sustainability advantage of smart city technology at the household level. The cost savings (over £2,700 annually) also highlight a financial incentive for wider adoption of smart home solutions, as these savings can offset the upfront costs of the technology over time.

3.2. Reliability and Factor Analysis

The results of the reliability and factor analyses indicate that the "Attitude towards Green Behavior" scale demonstrated strong psychometric properties across both traditional and smart home resident groups.

Table 2. Traditional home residents / reliability and factor analysis results

Dimension	Factor items	Factor weights	Reliability (Cronbach Alpha)
Green Image	GI 1	,733	.878
	GI 2	,735	
	GI 3	,759	
	GI 4	,739	
Green Behavior	GB 1	,824	.824
	GB 2	,835	
	GB 3	,849	
	GB 4	,894	
Green Customer Satisfaction	GCS 1	,799	.828
	GCS 2	,802	
	GCS 3	,813	
	GCS 4	,823	
Green Customer Loyalty	GCL 1	,832	.893
	GCL 2	,793	
	GCL 3	,839	
Total Attitude towards Green Behavior Scale			.856

For the traditional home residents (Table 2), factor loadings for all items were above the acceptable threshold of .70, ranging between .733 and .894. Cronbach's alpha coefficients revealed high internal consistency for each dimension: Green Image (α = .878), Green Behavior (α = .824), Green Customer Satisfaction (α = .828) and Green Customer Loyalty (α = .893). The total reliability of the scale was also quite high (α = .856). These findings indicate that the scale used is a suitable and reliable tool for measuring the green behavior attitudes of individuals living in traditional housing.

Table 3. Smart home residents / reliability and factor analysis results

Dimension	Factor items	Factor weights	Reliability (Cronbach Alpha)
Green Image	GI 1	,942	.938
	GI 2	,902	
	GI 3	,905	
	GI 4	,932	
Green Behavior	GB 1	,903	.904
	GB 2	,923	
	GB 3	,899	
	GB 4	,890	
Green Customer Satisfaction	GCS 1	,832	.858
	GCS 2	,899	
	GCS 3	,872	
	GCS 4	,882	
Green Customer Loyalty	GCL 1	,936	.956
	GCL 2	,962	
	GCL 3	,958	
Total Attitude towards Green Behavior Scale			.914

For the smart home residents (Table 3), even stronger psychometric performance was observed. Factor loadings ranged between .890 and .962, indicating very high convergent validity. Internal consistency values were excellent across all four dimensions: Green Image (α = .938), Green Behavior (α = .904), Green Customer Satisfaction (α = .858) and Green Customer Loyalty (α = .956). The overall reliability of the scale is also quite high (α = .914). Compared to residents of traditional homes, smart home residents' responses demonstrate higher internal consistency, particularly in the Green Image and Green Customer Loyalty dimensions.

These findings confirm that the scale by Çavuşoğlu et al. (2020) is a reliable and valid tool for assessing green behavior attitudes in the context of both traditional and smart home settings. Furthermore, the stronger reliability outcomes among smart home residents may suggest a more clearly defined perception structure regarding green behavior and loyalty in technologically enhanced living environments.

3.3. Descriptive Analysis

Descriptive statistics for the sub-dimensions of the Attitude Towards Green Behavior scale were calculated for both residents of traditional housing and residents of smart homes (Table 4 and Table 5).

Table 4. Traditional home residents / descriptive analysis results

	n	Min.	Max.	Average (*X*)	Std. deviation
Green Image	120	1.00	5.00	3.90	0.630
Green Behavior	120	1.00	5.00	3.94	0.695
Green Customer Satisfaction	120	1.00	5.00	4.02	0.755
Green Customer Loyalty	120	1.00	5.00	4.12	0.645

An examination of the mean scores for participants living in traditional housing reveals relatively high scores for the Green Image (X = 3.90) and Green Behavior (X = 3.94) dimensions. The highest mean score was obtained for the Green Customer Loyalty dimension (X = 4.12). The Green Customer Satisfaction dimension also had a high mean score (X = 4.02). These results indicate that residents of traditional housing generally have positive attitudes toward green behavior and a particularly strong level of commitment to their place of residence.

Table 5. Smart home residents / descriptive analysis results

	n	Min.	Max.	Average (X)	Std. deviation
Green Image	120	1.00	5.00	3.85	0.754
Green Behavior	120	1.00	5.00	3.97	0.566
Green Customer Satisfaction	120	1.00	5.00	4.06	0.643
Green Customer Loyalty	120	1.00	5.00	4.24	0.647

When examining the findings for smart home residents, the mean value for the Green Image dimension (X = 3.85) is slightly lower than for residents of traditional homes. Conversely, higher means were obtained for the Green Behavior (X = 3.97) and Green Customer Satisfaction (X = 4.06) dimensions. The highest mean value was again observed for the Green Customer Loyalty dimension (X = 4.24). This finding suggests that smart home residents, in particular, have higher levels of commitment to their homes than residents of traditional homes.

Overall, the Green Customer Loyalty dimension stands out with the highest mean in both groups, indicating that residents have developed an emotional and behavioral attachment to living spaces integrated with environmentally friendly practices. However, the finding of lower standard deviation values in smart home residents suggests that the attitudes of this group are more homogeneous and their perceptions of green behavior are shaped more consistently.

3.4. Correlation Analysis

Below Table 6 and Table 7 display the Pearson correlation coefficients among the four main variables (Green Behavior Attitude, Green Image, Satisfaction, Loyalty) for each group.

Table 6. Traditional home residents / correlation analysis results

		Green Image	Green Behavior	Green Customer Satisfaction	Green Customer Loyalty
Green Image	Pearson Correlation (r)	1			
	Sig. (p)				
Green Behavior	Pearson Correlation (r)	.343	1		
	Sig. (p)	.291			
Green Customer Satisfaction	Pearson Correlation (r)	.402	.192	1	
	Sig. (p)	.094	.130		
Green Customer Loyalty	Pearson Correlation (r)	.453	.342	.429	1
	Sig. (p)	.107	.132	.138	

Correlation results for residents of traditional homes (Table 6) indicate positive but generally statistically insignificant, relationships among the subscales of the scale. Moderate positive relationships were observed between Green Image and Green Behavior ($r = .343$, $p > .05$), between Green Image and Green Customer Satisfaction ($r = .402$, $p > .05$) and between Green Image and Green Customer Loyalty ($r = .453$, $p > .05$). Similarly, although positive relationships were found between Green Behavior and other subscales (e.g., Green Behavior – Green Customer Loyalty: $r = .342$), these relationships were not statistically significant. This suggests that there is a conceptually positive interaction between green image, behavior, satisfaction and loyalty in traditional homes but this interaction did not reach a statistically significant level.

Table 7. Smart home residents / correlation analysis results

		Green Image	Green Behavior	Green Customer Satisfaction	Green Customer Loyalty
Green Image	Pearson Correlation (r)	1			
	Sig. (p)				
Green Behavior	Pearson Correlation (r)	.224	1		
	Sig. (p)	.180			
Green Customer Satisfaction	Pearson Correlation (r)	.565	.530	1	
	Sig. (p)	.141	.242		
Green Customer Loyalty	Pearson Correlation (r)	.350	**.392****	.352	1
	Sig. (p)	.094	**.002**	.082	

Correlation results for residents of smart homes (Table 7) reveal more pronounced relationships. A moderately positive relationship was found between Green Image and Green Customer Satisfaction ($r = .565$, $p > .05$). Additionally, a positive relationship is observed between Green Behavior and Green Customer Satisfaction ($r = .530$, $p > .05$). The most striking finding is the statistically significant relationship between Green Behavior and Green Customer Loyalty ($r = .392$, $p = .002 < .05$). This result suggests that residents who exhibit green behavior in smart homes also develop a greater sense of commitment to their homes.

Overall, while there are positive relationships between the subscales of the scale in both groups, none are statistically significant. However, the statistically significant relationship between Green Behavior and Green Customer Loyalty among smart home residents is a noteworthy finding. This demonstrates that the green solutions offered by smart technologies contribute to energy efficiency and also strengthen residents' emotional attachment to their homes.

3.5. Regression Analysis

Linear regression analyses were conducted to further test the influence of residents' green behavior attitudes (independent variable) on three dependent variables: (a) perceived green image, (b) customer satisfaction and (c) customer loyalty. It was ran these regressions separately for each group (traditional vs. smart) to observe differences. Table 8 and Table 9 summarize the regression coefficients for the predictor (Green Behavior) in each model:

Table 8. Traditional home residents / regression analysis results

	R^2	Beta (β)	Sig *(p)*
Green Image ¬ Green Behavior	.237	.379	.109
Green Customer Satisfaction ¬ Green Behavior	.326	.485	.134
Green Customer Loyalty ¬ Green Behavior	.287	.537	.228

Independent variable = Green Behavior

Dependent variables= Green Image, Green Customer Satisfaction, Green Customer Loyalty

The regression analysis results for residents of traditional housing (Table 8) show that the Green Behavior variable has positive effects on the other sub-dimensions but these effects do not reach statistically significant levels. While the effects of Green Behavior on Green Image ($\beta = .379$, $p > .05$), on Green Customer Satisfaction ($\beta = .485$, $p > .05$) and on Green Customer Loyalty ($\beta = .537$, $p > .05$) are positive, they do not reach the level of significance. This finding suggests that although the tendency towards green behavior in traditional housing has positive implications, it does not have a strong and significant explanatory effect.

Table 9. Smart home residents / regression analysis results

	R^2	Beta (β)	Sig *(p)*
Green Image ¬ Green Behavior	.145	.149	.243
Green Customer Satisfaction ¬ Green Behavior	.258	.359	.353
Green Customer Loyalty ¬ Green Behavior	.247	.434	**.004****

Independent variable = Green Behavior

Dependent variables= Green Image, Green Customer Satisfaction, Green Customer Loyalty

A different pattern emerges in the regression analysis conducted for smart home residents (Table 9). The effects of the Green Behavior variable on Green Image ($\beta = .149$, $p > .05$) and Green Customer Satisfaction ($\beta = .359$, $p > .05$) were positive but not statistically significant. In contrast, a significant and strong effect of Green Behavior on Green Customer Loyalty ($\beta = .434$, $p = .004 < .05$) was found. This result indicates that as the level of green behavior in smart homes increases, residents' commitment to their homes also increases significantly.

Overall, green behavior among smart home residents appears to be most strongly reflected in customer/housing loyalty. While similar trends are found in traditional homes, these relationships are not statistically significant. Therefore, environmentally friendly behavior in homes equipped with smart technologies strengthens emotional and behavioral attachment to the living space.

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

This study focused on the contribution of digital transformation to sustainability, particularly smart home technologies, to energy efficiency and the relationship between individual green behaviors and perceptions. The findings revealed that smart home technologies have an impact on environmental perceptions and customer behavior. The results offer important implications for both individual households and the wider society. Comparative analyses conducted on smart and traditional homes in Antalya reveal parallels and differences with prominent findings in the literature. In this context, first, descriptive analyses revealed lower energy consumption and costs in smart homes. In fact, the findings of the study indicate that individuals living in smart homes differ significantly from those living in traditional homes across a range of dimensions, from energy consumption and environmental image to behavioral trends and customer loyalty. First, data on energy consumption revealed that smart homes offer a tangible advantage in terms of sustainability. A comparison of electricity consumption and costs revealed that traditional homes use an average of 276 kWh of electricity per month, resulting in a cost of approximately £609. In contrast, households living in smart homes consumed 185 kWh and paid approximately £383. Thus, households living in smart homes achieved an average monthly savings of over £225 and annual savings exceeding £2700. This difference directly contributes to environmental sustainability through increased energy efficiency. This finding also shows that smart home technologies are not just a passive savings tool but also offer an interaction mechanism that transforms user behavior. This finding is consistent with the 15-25% energy savings reported in studies such as King (2018) and Patience and Apaokueze (2024). The use of technologies such as smart thermostats, automatic lighting and energy management systems, in particular, appears to make significant contributions to energy efficiency. This confirms that smart homes are a tangible tool for achieving urban-scale sustainability goals.

However, the mere presence of technology does not guarantee energy efficiency. As emphasized in the literature (Bremer et al., 2023; Song, 2025), technology use must be supported by human behavior. In this study, smart home residents' green behavior tendencies exhibited stronger correlations with dimensions such as satisfaction and loyalty. This demonstrates that the energy efficiency potential offered by smart homes can only be fully realized through conscious user participation. Descriptive statistical results also painted a picture supporting energy efficiency. While the environmental image, pro-environmental behavior, customer satisfaction and loyalty dimensions were measured with high averages in both smart and traditional homes, individuals living in smart homes were observed to have more evenly distributed scores on these variables. The slightly higher averages for smart home users, particularly in terms of customer satisfaction and loyalty, are a strong indicator of the impact of technological advancements and energy savings on individual quality of life. While the environmental image and behavior averages are also quite high in traditional homes, these values appear to be explained more by individuals' personal attitudes and conscious choices. In smart homes, these indicators are supported by both individual awareness and the structural advantages provided by technology.

The scale reliability values in the study were quite high for both traditional and smart homes. The strong internal consistency of the Green Image ($\alpha = .938$) and Green Customer Loyalty ($\alpha = .956$) dimensions, particularly among smart home residents, suggests that the conceptual structure is perceived more clearly in this group. This result suggests that the chain effect identified by Çavuşoğlu et al. (2020) among green hotel guests, i.e., green behavior → green image → satisfaction → loyalty—may also apply to the residential context.

Correlation analyses revealed positive but statistically weak relationships between variables in traditional homes, while the relationship between Green Behavior and Green Customer Loyalty in smart home residents was found to be significant and strong ($r = .392$, $p < .01$). This finding supports the value congruence hypothesis expressed in the literature (Zhang et al., 2018). In other words, individuals with high environmental sensitivity identify with the green identity of their homes, which increases their satisfaction and loyalty levels.

Regression results showed that green behavior in traditional homes has positive but non-significant effects on green image, satisfaction and loyalty. This may be due to the limited technological infrastructure in traditional homes, which may be why green behavior tendencies remain at the individual level. In contrast, the Green Behavior → Green Customer Loyalty relationship in smart homes was found to be significant ($\beta = .434$, $p < .01$). In other words, as smart home residents reinforce their environmentally conscious behaviors with technology in their daily lives, their commitment to their homes also increases. This result is consistent with a similar dynamic observed in electric vehicle owners: individuals with high environmental motivations exhibit higher satisfaction and loyalty with the brand (Zhang et al., 2018).

Therefore, the direct loyalty generated by green behavior in smart homes suggests that technology, integrated with environmentally conscious attitudes, creates a value synergy. In this respect, the study makes a significant contribution to the literature. It demonstrates that smart home technologies reinforce users' emotional attachment to their homes.

These findings are consistent with the "twin transition" approach to digital transformation. In other words, digitalization provides technical energy efficiency as well as mediating the internalization of environmental values at the social-psychological level. For municipalities and policymakers, this means that smart home projects should be supported by designs that encourage green behaviors among users. For example, mobile applications that transparently display energy use, feedback mechanisms or reward systems can increase user loyalty and ensure long-term sustainability.

Furthermore, given the high reliability values and significant correlations, the study results demonstrate that the "Green Behavior Attitude Scale" developed by Çavuşoğlu et al. (2020) can be successfully applied in the housing sector. This provides an interdisciplinary contribution to the marketing and consumer behavior literature.

Taking all the findings together, the study demonstrates that smart homes have a transformative impact on energy efficiency within the context of sustainability and user experience, customer satisfaction and loyalty. While pro-environmental attitudes are strong in traditional homes, there are significant limitations in translating these into behavior and loyalty. In smart homes, technology both optimizes individuals' consumption habits and integrates pro-environmental behaviors into the customer experience. These results show that individual-level technology use in the context of smart cities can contribute to sustainability goals at the societal level.

From a practical perspective, the results provide important recommendations for policymakers, urban planners and technology providers. First and foremost, the contributions of smart home technologies to energy efficiency necessitate broader promotion of these systems. State and local governments could develop tax deductions, low-interest loans or direct incentive programs for the installation of smart home systems. Furthermore, the widespread adoption of applications that monitor energy consumption in real time could help individuals save money through conscious choices. In this context, the development of user-friendly interfaces and the organization of awareness campaigns will support behavioral transformation.

Furthermore, the integration of smart home systems into new projects is critical for sustainability in the construction sector. Mandating smart air conditioning, lighting automation and energy monitoring systems in building codes could raise energy efficiency standards in the long term. Such regulations, beyond saving individual households, will contribute to environmental goals by reducing cities' overall energy consumption.

In conclusion, the study demonstrates that smart homes have strong potential for environmental sustainability and societal benefits. The finding that pro-environmental behavior increases customer loyalty demonstrates that sustainability strategies can create value in marketing and customer relations. In this respect, smart home technologies should be considered a strategic tool that combines sustainability goals with the customer experience.

Although this study provides valuable insights into the relationship between smart home technologies, energy efficiency and residents' green attitudes, several limitations should be acknowledged. First, the research was conducted only in Antalya, which limits the generalizability of the findings to other regions with different climatic, socio-economic or cultural contexts. Comparative studies across multiple cities or countries would strengthen the external validity of the results. Second, the sampling method was based on convenience sampling, which may introduce selection bias despite efforts to ensure demographic similarity between groups. Future research should employ probabilistic sampling techniques to achieve broader representativeness. Third, the study relied on self-reported survey data for measuring environmental attitudes and loyalty. Such data may be affected by social desirability bias, where participants provide answers that reflect favorable environmental attitudes rather than actual behaviors. Incorporating objective behavioral measures or qualitative interviews could provide a richer understanding. Finally, the research design was cross-sectional, capturing data at a single point in time. Longitudinal studies are needed to observe whether the effects of smart home technologies on behavior and loyalty persist over the long term.

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