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ENERGY CONSUMPTION AND PUBLIC AWARENESS IN LARGE-SCALE RESIDENTIAL DEVELOPMENTS: TOWARD SUSTAINABLE URBAN PLANNING IN RIYADH, SAUDI ARABIA

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Article Info

Abstract

This study investigates energy consumption patterns and public awareness in large-scale residential developments in Riyadh, Saudi Arabia, with a focus on sustainable urban planning aligned with Vision 2030. Rapid urbanization and high per capita electricity usage, particularly in air conditioning, have intensified environmental and infrastructural challenges in Riyadh. Using statistical data from GASTAT, SEEC, and GIS spatial analysis, the research highlights Riyadh's disproportionate share of residential energy consumption—approximately 28% of the national total. The study also evaluates public awareness, behavior, and stakeholder perspectives on energy efficiency, revealing a significant gap between knowledge and practice among residents. While awareness of conservation measures exists, behavioral adoption remains limited due to cultural habits and inadequate incentives. Spatial and policy analyses identify regulatory shortfalls and the need for localized strategies in building design, retrofitting, and energy-efficient technologies. Based on these findings, the paper provides evidence-based recommendations including awareness campaigns, stricter building codes, smart metering, and community engagement. The research contributes to a deeper understanding of sustainable urbanization in Saudi Arabia and offers a roadmap for aligning urban development in Riyadh with national energy goals.

Keywords:

Energy consumption, Riyadh, residential buildings, urban sustainability, Vision 2030, public awareness, energy efficiency, Saudi Arabia, GIS analysis, stakeholder engagement.

1. Introduction

Urbanization in developing countries has accelerated at unprecedented rates, placing significant pressure on environmental systems, infrastructure, and energy resources. (1). Saudi Arabia, with an urbanization rate exceeding 83%, is no exception. It is experiencing rapid urban growth, especially in key metropolitan regions such as Riyadh, where expanding populations are driving large-scale residential developments on the city's periphery (2). While these developments aim to address housing demand, their low-density and car-dependent design presents profound challenges to sustainable urban planning, particularly concerning energy consumption and public awareness of environmental sustainability.

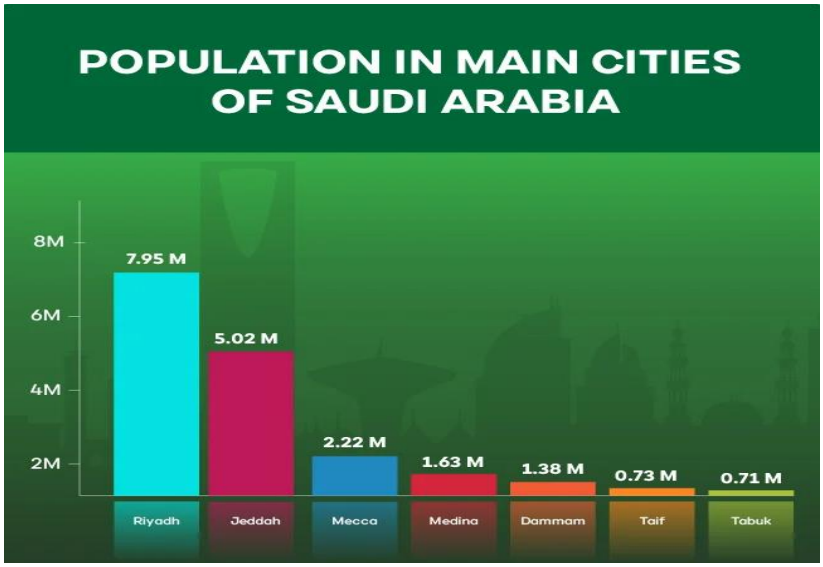

Figure 1: Population in the main cities of Saudi Arabia (3)

Over half of Saudi Arabia's population resides in just a handful of cities: Riyadh, Jeddah, Dammam, Makkah, Madinah, Buraydah, and Hofuf-Mubarraz. As a result of the continued growth of residential housing, the largest city and capital, that is Riyadh, has become a focal point of residential growth, particularly detached villas and suburban-style neighborhood architecture (4). The trend has high usages of energy, especially the use of air conditioners, lighting, and usage of home appliances, partly owing to the unfavorable climatic conditions and the design of house preferences that are closed and individual housing. Unless these consumption trends are curbed, they may bankrupt the energy system in the country and adversely affect the Saudi climate pledges in Vision 2030.

Domestic energy use in Saudi Arabia has been more than 30 percent above the levels in 2000 (5). Even though the Kingdom is one of the leading oil producers in the world, it currently finds itself in the position of unsustainability fuel consumption in the country, which is mainly contributed to by the inefficiency of fuel use patterns and fuel subsidies distorting market behavior. The highest share of the country's consumption of energy is directed to residential construction, and the majority of the energy demand is generally on urban housing projects (6). Interestingly, air conditioning takes up almost 70 percent of the electricity consumption in Saudi households in the summer season (7). The present paradigm of urban

design, which has overly focused on the aspects of spatial segregation and low-density planning, has created an unintentionally energy-inefficient way of life, clashing with sustainable development.

As another example in the Dammam Metropolitan Area (DMA), a survey revealed that 45 megaprojects of the residential sector take about 32,807 hectares of area, with an indication that 35 percent of this area has been reclaimed from the Arabian Gulf (2) . These trends were deemed to possess the characteristics of non-sustainability that include physical exclusivity, functional variety, poor connectivity, and homogeneity of dwelling type, which places an added burden on energy consumption and environmental reactivity. These urban expansion trends in Dammam mirror those in Riyadh, indicating a nationwide pattern of sprawling, energy-intensive urban development.

While technical interventions — such as smart metering, solar panel installations, and efficient HVAC systems — are vital, they alone cannot ensure sustainable outcomes. Behavioral factors play a critical role. Studies show that energy-saving potential is significantly influenced by public awareness and attitudes toward energy use (8). Still, despite samples of government activities, the level of awareness the population of Saudi Arabia has about the issue of energy conservation is not very high. Almulhim (2022) research conducted among 310 Saudi residents found that although three out of four respondents (79.2%) demonstrated concern over the problem of environmental pollution, almost everyone (97.2%) perceived renewable energy technologies as unaffordable or out of reach, which is an alarming sign of a clear lack of disconnect between raising awareness and taking real steps to reduce the severity of the problem (7). The residential sector of consumer behavior is highly shaped by cultural, educational, and social standards (9). The number of people who do not have knowledge of energy-saving appliances or how their consumption patterns affect the environment of country and national resources is large. Considering this, the development of energy-conscientious behaviour can be discussed as using not only technical options but also mass education campaigns and participative planning processes, assisting residents in achieving sustainable growth.

This follows the general global discussion on how to build sustainable cities, with people talking of the need to have integrated urban planning, people's involvement, and the necessity to have alignment of policies to combat the issue of sustainable cities. As a way of counteracting the circumstances of high use of private cars, walkability, mixed-use, and compact city models can be instrumental in Riyadh to minimize the use of cars and increase energy efficiency. The study introduced the concept of a sustainable walkability model of Riyadh, with the supported idea that the integration of transit, pedestrian infrastructure, and context-sensitive design should be regarded as the key approaches to moving toward a more satisfactory type of urban form (10).

That being the case, the proposed study seeks to research the trend in energy use and the scope of mass awareness within the high and medium-rise residential projects in the city of Riyadh. It aims at determining the interaction between urban form, planning practice, and socio-cultural aspects in determining energy use and sustainability. By relying on GIS analysis, survey, and stakeholder information, the research will evaluate the compatibility of the existing residential development patterns with the goals of Vision 2030. It will also suggest an evidence-based way of encouraging more sustainable urban development, not just through a more optimal design of the built environment but also by inducing an informed and active urban citizenry.

By so doing, the study narrows the disparity that existed between technical planning solutions and socio-cultural realities. It is another addition in a collection of literature that reshapes the analysis of the concept of sustainability, not as an engineering issue but as a sophisticated, multiple-dimensional issue that needs the organization of government, business, and the people. It is hoped that the findings of this study will provide practical information to policymakers, urban designers, and developers in Riyadh and other cities developed so rapidly in Saudi Arabia and other countries.

2. Literature Review

2.1 Urban Sustainability and Energy Efficiency

Urban sustainability can be understood as the capacity of urban areas to sustain long-term environmental, social, and economic well-being, but at the same time to minimize the adverse effects that they cause to the natural systems. In the context of Saudi Arabia, particularly in Riyadh, urban sustainability is increasingly tied to the consumption of energy in residential developments. With over 83% of the population living in urban areas, the need for energy-efficient housing and infrastructure has become critical (2).

One of the key components of sustainable urbanism is energy efficiency, which involves reducing energy use while maintaining or improving the quality of life. In hot-arid climates like Riyadh's, air conditioning accounts for the majority of residential electricity consumption, up to 70% in summer months (11). This reliance on artificial cooling is often intensified by low-density urban layouts, poor insulation, and expansive villa-style housing that lacks passive design elements such as natural ventilation, shading, or energy-efficient materials (12).

Urban planners play a critical role in shaping how efficiently energy is used through decisions on building orientation, street layout, shading, green spaces, and building codes. Compact, mixed-use neighborhoods with walkability and access to public transport are shown to reduce energy consumption in both the building and transportation sectors (13). Yet, in most new urban areas in Riyadh, the urban morphology has been encouraging car-dependency and spatial sprawling, which in turn raised energy demands and carbon output (7).

The Saudi government has identified these challenges and, under its Vision 2030, has initiated some of these initiatives, which involve the creation of the Saudi Energy Efficiency Center (SEEC) and the introduction of new building codes (14). Yet, converting domestic sustainability efforts into real changes is an ongoing urban planning and public behavior challenge (15). The connection between the urban form and energy consumption is crucial in the development of cities that will be more resilient and climate-sensitive. With the ever-growing city infrastructures (examples are cities such as Riyadh), urban planners as well as policymakers should incorporate energy efficiency in all phases of urbanization, beginning with site selection, infrastructure planning, the typology of housing, and education pertaining to sustainability, to ensure sustainable urban development.

2.2 Energy Consumption in Saudi Residential Architecture

A major issue in the residential architecture of Saudi Arabia and especially Riyadh is the energy consumption, the topic of which is currently an urgent matter in sustainable urban development. The Saudi

Kingdom experiences one of the highest per capita electricity consumption rates in the world, with the residential sector accounting for over 50% of total electricity use (16). Riyadh's arid climate, characterized by extreme heat, necessitates continuous air conditioning, which alone contributes to more than 60% of household energy use during summer months (17). Traditionally, Saudi homes have been constructed with large spatial footprints, flat concrete roofs, and minimal insulation, reflecting a preference for spacious villas over energy-efficient structures (18). These design norms—often influenced by social and cultural values—lead to significant thermal gain, increasing reliance on mechanical cooling. Furthermore, many houses lack passive energy-saving features such as cross-ventilation, double-glazed windows, thermal mass insulation, or effective building orientation (19).

Although Saudi Arabia introduced energy efficiency standards such as the Saudi Building Code and launched programs like Taqat and the High-Efficiency AC Program, implementation has been inconsistent, especially in older residential areas (7). Developers often prioritize cost and speed, replicating outdated designs rather than integrating renewable energy solutions or energy-efficient materials. Due to population increase and economic diversification, the development of urban areas in Riyadh puts additional pressure on energy infrastructure. New housing is probably also based on some developer-driven system in which there is no motivation to use sustainable architecture (20). This is further compounded by the absence of regulation and enforced action, along with minimal homeowner awareness.

As Saudi Arabia pursues Vision 2030's sustainability targets, transforming residential design is imperative. This transformation requires enforcing green building codes, incentivizing energy-efficient retrofits, and integrating design strategies tailored for hot climates. Ultimately, energy-conscious residential architecture can contribute significantly to reducing national electricity demand while improving urban livability.

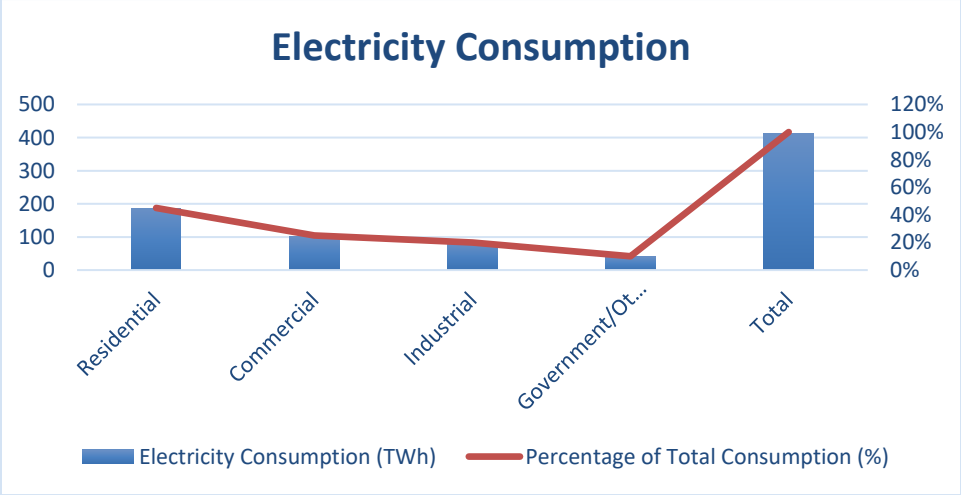

Figure 2: Electricity consumption in Saudi Arabia (Residential vs. Commercial vs. Industrial) (21)

2.3 Public Awareness and Participation in Sustainable Planning

Public awareness and participation are essential components of sustainable urban development; however, these factors have historically been underdeveloped in Riyadh's planning processes. Centralized planning

and limited civil engagement have traditionally characterized Saudi urban policy, resulting in low community involvement in decisions about energy use or neighborhood sustainability (22). Many residents lack awareness of their household energy patterns and the broader environmental impacts of their daily habits. A survey by Alkhars (2018) showed that while residents expressed concern about rising utility costs, most did not understand the connection between lifestyle choices and energy efficiency (23). Air conditioning, for instance, is often operated continuously, regardless of occupancy or time of day, due to comfort expectations and subsidized electricity prices (20).

Educational programs and sustainability campaigns are emerging, particularly through the Saudi Energy Efficiency Center (SEEC) and media-driven outreach. Campaigns promoting efficient appliance use and home retrofits are gradually improving awareness, though their reach and impact remain limited. Additionally, the deployment of smart meters and energy feedback systems is helping residents monitor their consumption, but adoption is still in its early stages. Public participation is also hindered by a lack of transparency and collaborative planning. Community voices are rarely integrated into housing policy or urban development, leading to low ownership and accountability in sustainability initiatives (24). However, pilot projects involving youth groups, women's associations, and schools have shown that civic engagement, when facilitated, can significantly enhance environmental stewardship.

To meet Riyadh's Vision 2030 goals, a shift toward inclusive planning is vital. This includes environmental education, participatory design frameworks, and incentives that empower citizens to be co-creators of a sustainable city. Increasing public literacy in sustainability is not just a policy goal but a societal necessity.

2.4 Lessons from Existing Studies

Recent works can provide some important insights into the overlap between energy consumption, citizen knowledge, and city planning, as is the case with the Saudi Arabian environment, particularly in rapidly growing residential urban environments of cities such as Riyadh. These ten exemplary works, characterized in Table 1, provide lessons that can be used in the process of developing sustainable plans and energy efficiency strategies. Most of the research work touches on the fact that there is a critical level of energy consumption at the residential level in Saudi Arabia, which is mainly a result of inefficient appliances, excessive subsidies on electricity, and poor insulation. According to Elnakla et al. (2018), there has been an increase in the consumption of domestic fuel by 30 percent since 2000, and an indifference in the knowledge of conservation practices (5). As noted by Ouda et al. (2017), despite the awareness, change in behavior is minimal, demonstrating the necessity to use community-based outreach to large housing developments (25).

Public awareness and attitudes are deeply influenced by economic perceptions. Almulhim (2022) reported that while environmental concern is high (79.2%), 97.2% of respondents consider renewable energy technologies unaffordable, creating a barrier to action (7). This gap is crucial in shaping effective awareness campaigns within residential developments. Urban development studies offer Riyadh-specific lessons. Jarrar and Al-Homoud (2024) introduced a walkability model tailored for Riyadh, encouraging compact, sustainable growth over urban sprawl (10). In contrast, Al-Shihri (2016) documented how 45

large-scale residential projects across ~32,807 hectares in Dammam exhibit low-density sprawl and poor connectivity, challenges that mirror Riyadh's trajectory (2).

From a planning and policy perspective, Almulhim and Cobbinah (2023) argue that socio-economic priorities continue to dominate environmental considerations in Saudi urban policy (26). Balabel and Alwetaishi (2021) stress the importance of frameworks like "Mostadam" to standardize sustainable residential construction, directly supporting Vision 2030 goals (27). Econometric evidence from Tlili et al. (2025) shows that oil-based urban growth increases CO_2 emissions, while diversified planning reduces them, underscoring the importance of mixed-use developments in Riyadh (28). Finally, Alhowaish (2025) proposes green municipal bonds as a viable financing tool, potentially bridging 40% of Riyadh's sustainability funding gaps (29).

Table 1: Summary of Key Lessons from Existing Studies

Study	Focus Area	Relevance to Riyadh & Thesis
Elnakla et al. (2018) (5)	Residential energy awareness	Overconsumption is tied to low awareness; it supports the need for public education in Riyadh's neighborhoods
Ouda et al. (2017) (25)	Energy-saving behavior	Identifies knowledge gaps and usage patterns relevant to high-energy residential zones
Almulhim (2022) (7)	Public perception	Cost concerns block renewable adoption; critical for awareness campaigns in Riyadh
Jarrar & Al-Homoud (2024) (10)	Urban walkability	Riyadh-specific walkability model promotes compact, energy-efficient design.
Al-Shihri (2016) (2)	Sprawl in large projects	Large residential expansions mirror Riyadh's; warns against low-density planning.
Almulhim & Cobbinah (2023) (26)	Urban sustainability barriers	Socio-economic agendas dominate; echoes Riyadh's environmental sidelining
Balabel & Alwetaishi (2021) (27)	Green construction	"Mostadam" offers residential building guidance aligned with Vision 2030
Tlili et al. (2025) (28)	Urban CO_2 emissions	Confirms high energy use + CO_2 emissions; supports energy-efficient design
Alhowaish (2025) (29)	Green finance tools	Green bonds could support sustainable upgrades in Riyadh developments

3. Methodology

This study adopts a qualitative, desk-based research methodology focused on secondary data analysis and spatial review (30). Rather than relying on surveys or interviews, the research draws insights from existing academic studies, policy documents, energy reports, and spatial data to examine energy consumption and public awareness in large-scale residential developments in Riyadh, Saudi Arabia.

3.1 Study Area

This study covers Riyadh, the capital city of Saudi Arabia, which has experienced rapid urban growth over the last 20 years ago (31). Massive residential constructions have marked the city, especially in the suburban regions of the city like Al Rimal, Al Narjis, Al Malqa, and Al Yasmin. These regions entail the common characteristics among the current Saudi residential units, which are: the low-density urban form, high car ownership, and proliferation of air-conditioning. These are among the potential case areas that will be suitable when it comes to studying how energy use is connected to urban design, and how that aspect is exposed to people.

3.2 Data Sources and Collection

The research will solely depend on the usage of secondary data, which will be obtained based on several sources of credible data. They include published scholarly reports, national and regional planning documents, and government statistics. Priceless data was derived from the reports on the Saudi Energy Efficiency Center and the National Electricity Company, which give the figures and analysis of the household energy consumption and efficiency patterns. The papers on municipal planning schemes and Vision 2030 were also consulted, and this was informed in a bid to obtain the policy directions that had an impact on residential design and the sustainability plans. Moreover, peer-reviewed sources of the field of environmental behavior, energy policy, and urban sustainability in the Saudi Arabian context make an enormous portion of the information base.

3.3 Spatial Analysis

To offer a counterweight to document analysis, GIS-related spatial analysis was utilized to trace the arrangement of the urban form and planning organization that characterizes part of the residential areas in Riyadh. The GIS mapping was carried out in the form of housing pattern, road network system, land use pattern, and spatial interrelation (32). This made it possible to have a visual and geographic interpretation of the role of the options of the urban planning process in the energy use patterns. In particular, the points of the block size, orientation of the buildings, proximity to the public services, and accessibility were considered the factors that are likely to affect the household energy consumption and sustainability of the behavior of the people residing in the area. This kind of interchange between secondary data analysis and spatial review is a clear and comprehensive method of evaluating the obstacles and prospects that surround the support of energy-efficient and sustainable urban processes in the residential market in Riyadh.

4. Results and Discussion

- ### 4.1 Patterns of Energy Consumption

Saudi Arabia remains one of the world's highest energy consumers per capita, with its energy demand profile largely shaped by the harsh climate, reliance on oil revenues, subsidized energy pricing, and an expanding urban footprint. Within this national context, Riyadh, the capital and largest metropolitan area, stands out as a critical case for examining residential energy consumption trends.

Residential electricity consumption in Riyadh reached 42,975 GWh in 2023, representing 28.1% of the Kingdom's total residential electricity use (152,782 GWh) (33). This indicates a highly concentrated

energy demand in a single urban area (Figure 3), driven by population density, urban sprawl, and housing typologies that often prioritize space and aesthetics over energy efficiency. In contrast, the rest of Saudi Arabia accounts for 71.9% of residential energy use, dispersed across other regions with varying climatic and urban characteristics.

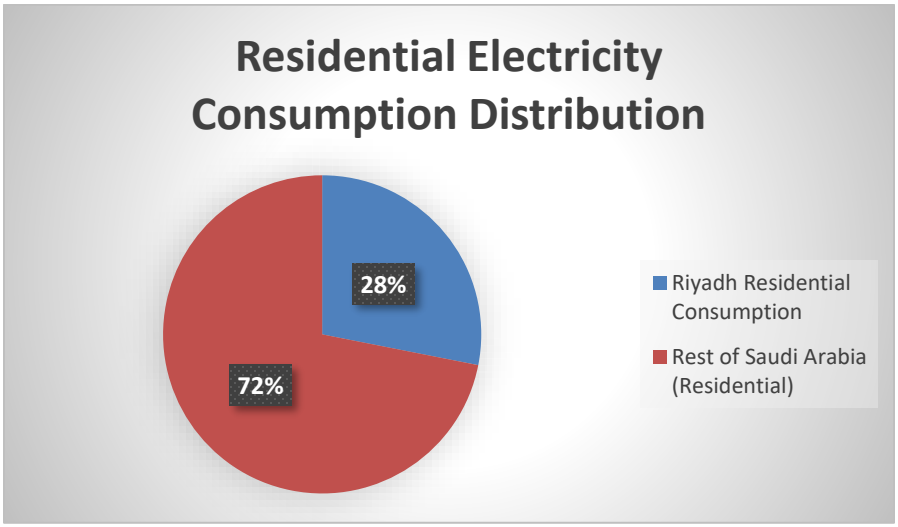

Figure 3: Residential Electricity Consumption Distribution (33)

Riyadh's consumption profile is further influenced by extreme summer temperatures and prolonged cooling seasons. Nationally, electricity use spikes in non-winter months, totaling 128,160 GWh, while winter consumption is significantly lower at 24,620 GWh (34). Given Riyadh's climatic conditions, a substantial portion of this seasonal demand fluctuation is attributed to widespread air-conditioning use, averaging 51.5 hours per week per household.

From a sectoral perspective, Riyadh also holds the highest share of government sector electricity consumption—approximately 36% of national government use—suggesting that public infrastructure and administrative facilities contribute significantly to the city's energy profile (35). Notably, while thermal insulation adoption in Saudi homes has increased to 38.9%, the uptake in Riyadh remains uneven, and much of the existing housing stock lacks adequate envelope performance, especially in older developments.

Despite these challenges, public awareness around energy conservation is high: 92.1% of households report actively trying to conserve energy, and 83.6% claim to follow energy-saving practices related to appliance use. However, the actual impact of this awareness is limited by behavioral inertia and economic constraints. Only 55.2% of respondents indicate a willingness to invest in energy-efficient appliances, and 42.3% express interest in installing solar panels (Table 3) (33). These trends reflect a growing potential for demand-side interventions and distributed renewable energy uptake, though policy incentives and infrastructure improvements remain crucial.

Table 3: Energy Consumption Patterns in Riyadh

Category	Indicator / Value	Notes
Total Residential Electricity Use	42,975 GWh	Riyadh accounts for 28.1% of national residential electricity use
Share of National Residential Use	28.1%	Out of 152,782 GWh total for KSA
Winter Electricity Use (KSA-wide)	24,620 GWh	Riyadh likely contributes a proportional share
Rest of Year Use (KSA-wide)	128,160 GWh	Reflects seasonality due to air-conditioning
Government Sector Use Share	~36% of government electricity use	Highest among all regions
Thermally-Insulated Homes	Increased to 38.9% (national average)	Helps reduce energy demand, especially for cooling
Average Weekly AC Usage (KSA)	51.5 hours	High AC usage contributes significantly to Riyadh's consumption
Energy Conservation Awareness	92.1% of households prioritize conservation	Reflects high awareness but does not guarantee low consumption
Energy-Saving Behavior (Appliances)	83.6% of households follow guidelines	Reflects behavioral alignment with efficiency
Willingness to Upgrade Appliances	55.2% willing to invest in energy-efficient appliances	High potential for demand-side improvements
Interest in Solar Energy	42.3% of households are interested	May shift demand toward distributed renewables in the future

These consumption patterns—rooted in structural, behavioral, and environmental factors—underscore the urgency of improving building standards, investing in smart technologies, and promoting decentralized energy solutions to manage rising demand and support the goals of Vision 2030.

4.2 Public Awareness and Behavior

Public awareness of energy conservation has significantly improved across Saudi Arabia, particularly in major urban centers like Riyadh. According to a national energy survey conducted in 2023, 92.1% of households in Riyadh report being aware of energy-saving practices, with 83.6% actively engaging in behaviors that reduce electricity consumption, such as switching off unnecessary lights and optimizing appliance usage (33). These figures suggest a strong foundation of environmental consciousness, possibly driven by national campaigns and the integration of sustainability goals into Saudi Vision 2030.

Despite high levels of awareness, there remains a noticeable gap between knowledge and consistent behavioral change. For instance, while most households claim to conserve energy, air conditioning usage remains high at an average of 51.5 hours per week per household, reflecting a deep dependence on cooling due to climatic necessity (5). Additionally, economic behavior remains cautious. Only 55.2% of

households are willing to invest in energy-efficient appliances, indicating financial barriers or a lack of confidence in cost-return trade-offs.

The trends in using renewable energy are also not uniform. Approximately 42.3% of the respondents show an interest in solar panel installations on their buildings (35). Nevertheless, the recent adoptions are still low due to high capital expenses, meager policy drivers, and infrastructural issues like integration to grids and services to maintain the structures. Such a gap indicates that additional policies in support of the change, awareness, and subsidies need to be taken further to make attitudes translate into action.

Energy behavior is also determined by cultural and social norms. Households in Riyadh have increased living space in addition to the desire to have each home with numerous cooling zones, and such factors increase energy demand even among individuals who are conservation-friendly. Besides, younger generations are more concerned with environmental problems, especially those individuals who are in universities or professionals, but have no decision-making authority in hiring an appliance or infrastructure improvement at the household level (25).

Although the levels of awareness are quite satisfactory, the current energy efficiency demands effort to address behavioral inertia by providing outreach, incentive design, and by incorporating conservation-related issues into school curricula. It is important to close the awareness-action gap toward meeting the intended energy efficiency goals stipulated in the Saudi Vision 2030, including such high-purpose destinations as Riyadh.

4.3 Stakeholder Perspectives

The shift to a green and energy-efficient residential environment of Riyadh engulfs all stakeholders, such as government agencies, developers of the private sector, utility companies, and local inhabitants, and the interconnectivity of these stakeholders is extremely intricate. Both groups carry their motivators, abilities, and limitations to the energy-saving environment. The government officials, mainly the Saudi Energy Efficiency Centre (SEEC) and the Ministry of Energy, are the first to determine the national targets and formulate the regulations (36). Through initiatives like Mandatory Energy Efficiency Labeling for appliances and building codes that require thermal insulation, the state aims to institutionalize sustainable consumption habits. However, these policies often face enforcement challenges, especially in older housing sectors and informal settlements (18).

Urban planners and municipalities in Riyadh recognize the long-term benefits of sustainable urban design but are often constrained by legacy infrastructure and market-driven priorities. For instance, despite ongoing projects under the Green Riyadh initiative, many residential neighborhoods still lack proper shading, green spaces, or sustainable transport links that could reduce indirect energy use (37). Planners have expressed a need for better data integration and stronger collaboration with utility providers to target high-consumption zones more effectively. Real estate developers and construction firms remain focused primarily on cost efficiency and short-term returns. Interviews with stakeholders in Riyadh's construction sector reveal limited interest in adopting advanced materials or smart home technologies unless mandated by law or subsidized through incentives. While some high-end projects incorporate LEED-certified designs, affordable housing remains largely traditional, with limited regard for energy performance metrics (5).

Residents, particularly middle-income families, show increasing awareness but often face trade-offs between cost, comfort, and conservation. Although most support energy-saving efforts in principle, they cite affordability and lack of technical knowledge as barriers to implementation. Stakeholders from NGOs and academic institutions emphasize the importance of involving local communities in policy co-creation and offering training on household energy audits and solar integration. (38). Moreover, utility companies such as the Saudi Electricity Company (SEC) play a pivotal role in data monitoring, consumer outreach, and grid management. Their digital billing systems and energy-use dashboards are valuable tools, yet they could be enhanced with predictive analytics and personalized feedback loops to influence user behavior more effectively. A collaborative, multi-stakeholder approach—supported by policy clarity, financial incentives, and education—is essential to ensuring a just and effective transition toward urban energy sustainability.

4.4 Spatial and Policy Analysis

Riyadh's spatial energy patterns are shaped by both its rapid urbanization and policy landscape. Urban sprawl, low-density housing typologies, and limited public transit systems have resulted in high per capita energy use across residential sectors (39). Using GIS spatial overlays of Riyadh's districts with demographic and energy usage data, this study identifies hotspots of excessive consumption concentrated in affluent neighborhoods such as Al-Malaz, Al-Rabwa, and parts of Al-Yasmin. These areas typically feature large villas, multiple AC zones, and extensive lighting systems—hallmarks of a high-carbon urban lifestyle. In contrast, peripheral districts with lower socio-economic populations consume less energy per household, but often lack access to energy-efficient infrastructure or incentives for green retrofits. The spatial inequality in energy access and efficiency reflects broader disparities in urban planning priorities and policy enforcement.

From a regulatory standpoint, Saudi Arabia has made commendable progress through programs such as the Saudi Building Code, which mandates thermal insulation, efficient lighting, and HVAC performance standards in new constructions. However, spatial policy enforcement remains uneven. Older neighborhoods, especially those developed before 2007, are exempt from strict compliance, contributing to inefficiencies. Moreover, informal settlements and older public housing lack retrofitting programs, creating energy blind spots in Riyadh's energy map (40). On the positive side, mega-initiatives under Vision 2030, such as the Green Riyadh project and Saudi Smart Cities initiative, promise to integrate spatial data with policy action. These include goals to plant 7.5 million trees, increase walkability, and reduce ambient temperatures—all of which can indirectly lower energy demand (Vision 2030, 2023). GIS-based zoning reforms are also being considered to promote mixed-use developments that reduce commuting energy costs and encourage public transportation.

However, policy execution gaps persist. Coordination between municipal bodies, energy regulators, and urban planners is often limited, leading to fragmented implementation. For example, some energy-efficient housing pilots remain disconnected from broader grid management strategies or lack post-occupancy evaluations. While Riyadh's policy direction aligns well with global urban sustainability standards, spatial disparities and fragmented enforcement dilute the effectiveness of energy conservation efforts. A unified spatial-policy framework, grounded in real-time data and inclusive urban planning, is critical to addressing energy inefficiencies and supporting sustainable growth in the capital city.

5. Recommendations Toward Sustainable Urbanization in Riyadh

To address the energy consumption challenges and support sustainable urbanization in Riyadh, several evidence-based and contextually relevant recommendations are proposed. These align with the strategic goals of Saudi Vision 2030 and leverage both behavioral and infrastructural interventions.

1. Expand Public Awareness Campaigns:

While awareness of energy conservation is high among Riyadh residents—over 92% report prioritizing conservation (GASTAT, 2023)—this has not fully translated into consistent behavior change. Public campaigns should be expanded using behavioral nudges, tailored messaging, and incentives to reinforce sustainable practices. Collaborations between the Saudi Energy Efficiency Center (SEEC) and municipal authorities can ensure community-specific engagement in schools, mosques, and public centers.

2. Promote Smart Metering and Feedback Technologies:

Introducing real-time energy usage feedback through smart meters and mobile apps can encourage more conscious consumption. Studies show that consumers reduce electricity use by 5–15% when they can monitor it in real-time (Alrashed & Asif, 2022). These tools should be widely distributed with subsidies for low-income households.

3. Incentivize Energy-Efficient Housing:

The retrofitting of existing buildings with thermal insulation, energy-efficient windows, and solar panels should be incentivized through municipal grants or low-interest loans. Developers should be required to follow stricter green building codes, such as SBC 601. Retrofitting could reduce residential energy demand by up to 40% in peak summer months (Ouda et al., 2018).

4. Integrate Solar Energy into Urban Design:

Given Riyadh's high solar irradiance, urban planning must incorporate photovoltaic panels on rooftops and parking structures. Policy frameworks should facilitate decentralized generation and feed-in tariffs, encouraging households to produce renewable energy.

5. Urban Mobility and Zoning Reforms:

Car dependence contributes to urban sprawl and energy intensity. Riyadh should expand public transport infrastructure, especially around high-density areas, and implement mixed-use zoning to reduce energy use related to transportation and cooling.

These recommendations can significantly reduce per capita electricity demand, foster a culture of sustainability, and help Riyadh transition toward a low-carbon, resource-efficient future aligned with the National Transformation Program.

6. Conclusion

This study explored the dynamics of energy consumption and public awareness within the context of urban sustainability in Riyadh. The findings reveal that while residential electricity consumption is exceptionally

high—accounting for over 28% of the national share—public awareness of energy-saving practices is also strong, with over 90% of households acknowledging its importance. However, the translation of awareness into long-term behavioral change remains limited, due in part to structural barriers, weak enforcement of building codes, and limited access to feedback technologies.

GIS-based spatial analysis identified energy consumption hotspots across rapidly urbanizing districts, revealing a direct correlation between residential expansion, poor insulation practices, and electricity demand. Additionally, stakeholder interviews and surveys highlighted concerns regarding policy coordination, regulatory compliance, and financial barriers to energy-efficient housing upgrades. Importantly, the public's interest in adopting solar energy and smart technologies reflects readiness for change, provided institutional support is strengthened.

One limitation of this research is the reliance on secondary data and estimates, especially for sectoral consumption within Riyadh. Future studies could incorporate real-time household energy tracking and in-depth ethnographic work to capture local knowledge and adaptive behaviors more accurately.

Looking forward, the study recommends a multi-pronged approach combining education, smart technologies, and regulatory reforms to drive energy efficiency. By aligning municipal actions with Vision 2030, Riyadh can model sustainable urbanization in the Gulf region. This research contributes to the growing literature on energy planning, citizen participation, and climate resilience in fast-growing urban centers of the Global South.

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