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King Abdullah Petroleum Studies and Research Center

Discussion Paper

Achieving Net-Zero GHG Emissions of Saudi Arabia by 2060

The Transformation of the Building Sector

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Abstract

In this paper, an economy-wide, net-zero pathway that enables Saudi Arabia to achieve net-zero greenhouse gas emissions by 2060 is investigated, with a specific focus on the critical role played by the building sector. An exploration is undertaken of the significance of energy efficiency measures, the circular carbon economy framework and the Saudi Energy Efficiency Center's instrumental contributions in reducing energy demand and GHG emissions within the building sector. An integrated assessment modeling approach is used in this study to provide a comprehensive view of the long-term impacts of these measures. The findings underscore that by 2060, economic growth and population increase will necessitate the doubling of floor space in Saudi Arabia. Continuing the air conditioning labeling program could yield annual savings of up to 80 TWh. Ultimately, lowering fluorinated gas emissions is crucial for the Kingdom's building sector to achieve net-zero emissions. The findings elucidate the necessity for continued policy support and investment in energy efficiency in both the building sector and across various domains to effectively meet net-zero goals and foster a more sustainable and resilient built environment in Saudi Arabia.

Keywords: Integrated assessment modeling; Climate objectives; Energy efficiency; Saudi Arabia.

Introduction

The vast and extreme climatic conditions in Saudi Arabia have led to high energy consumption in building operations. The building sector, which includes residential, commercial and governmental buildings, accounts for a considerable part of the Kingdom's electricity demand. Over the last decade, buildings have consistently been responsible for most of the total electricity consumed in the Kingdom of Saudi Arabia, of which 46% is attributable solely to the residential sector (WERA 2022). The demand for cooling and air conditioning during scorching summers is particularly noteworthy, as it reaches up to 65% of the total household electricity consumption (Aldubyan, Krarti, and Williams 2020; Krarti, Aldubyan, and Williams 2020; Krarti, Dubey, and Howarth 2017; Matar 2015). According to the Water and Electricity Regulatory Authority, buildings are responsible for approximately 75% of the country's electricity consumption (WERA 2022), making them a key focus in efforts to reduce energy consumption and greenhouse gas emissions.

The KSA has made a notable commitment to addressing climate change implications by setting a target to achieve net-zero greenhouse gas emissions by 2060 (Saudi Vision 2030 2016). This is in conjunction with its nationally determined contribution; the KSA aspires to curtail annual emissions by 278 MtCO2e by 2030 (Saudi Arabia 2022). The country's important stature as a leading energy exporter in the global energy domain accentuates the gravitas of this net-zero pledge.

Central to Saudi Arabia's strategic measures are the Saudi Vision 2030 blueprint, an initiative conceived to structurally recalibrate and diversify the nation's economic portfolio away from a predominant oil-based focus, thereby steering the country toward a more resilient economic paradigm (IMF 2023). To adhere to this vision, the nation enacted pivotal energy price reforms in 2016 and 2018 (Aldubyan and Gasim 2021; Durand-Lasserve et al. 2020; Gasim and Matar 2023; Gonand et al. 2019). These reforms sought to incentivize judicious energy consumption by aligning the price points of electricity, gasoline and diesel with their intrinsic costs. Historically entrenched implicit incentives often distorted energy pricing, culminating in profligate consumption patterns (Gasim and Matar 2023). To counter this situation, the Saudi government has embarked on revising energy price structures across multiple sectors, notably residential and commercial consumers, thereby fostering judicious consumption. In 2018, residential electricity usage fell by 13 terawatt hours compared to 2017, of which higher residential electricity prices contributed 9 TWh to the decline (Aldubyan and Gasim 2021).

The Kingdom has also adopted the circular carbon economy (CCE) model as a strategic measure to curtail GHG emissions and catalyze the energy transition imperative for climate change mitigation (Al Shehri et al. 2023). An intrinsic component of the CCE paradigm focuses on curtailing energy demand via enhanced efficiency. Within this framework, the Saudi Energy Efficiency Center has emerged as an instrumental entity in strengthening Saudi Arabia's adherence to CCE objectives. The SEEC has demonstrated commendable progress in advocating efficiency measures across diverse sectors that encompass buildings, transport and industries (Belaïd and Massié 2023). The Center is pivotal in formulating and implementing standards that accentuate sustainable operational practices, particularly in building design and functionality. These standards address diverse building facets, from insulation parameters to advanced lighting, energy-efficient air conditioners and other appliances. Implementation of the CCE model not only minimizes energy demand but also accrues financial advantages for households. Complementing these measures, the SEEC has rolled out energy efficiency labeling mechanisms and stringent regulatory protocols (Al-Tamimi 2017) and pioneered retrofitting initiatives for government buildings to decrease energy demand and its consequent emissions (SEEC 2021). From 2014 to 2018, energy efficiency improvements in residential buildings reduced electricity consumption by at least 7.7 TWh and significantly slowed the growing electricity demand from buildings (Aldubyan and Gasim 2021).

The building sector in Saudi Arabia holds immense potential in steering the nation toward a more sustainable and decarbonized future. Understanding the role of the building sector in decarbonization is crucial for several reasons. First, buildings account for 28% of the total primary energy consumption in the Kingdom (Ministry of Energy, 2023) and more than one-third of the domestic GHG emissions (Worldmeter 2016). As Saudi Arabia has experienced rapid urbanization, there has been a commensurate increase in construction activities and associated carbon emissions (UN-Habitat 2018). Additionally, Saudi Arabia's Vision 2030 targets clean energy and sustainability, and the sustainable building sector presents vast economic opportunities. Meeting international climate agreements and targets also necessitates an in-depth focus on this sector. In addition to carbon reduction, sustainable building practices enhance residents' health, well-being and productivity, which have obvious societal benefits (Edwards and Naboni 2013). Therefore, to adopt a holistic approach to a sustainable future and hit net-zero targets, contributing to and transforming the building sector is indispensable.

In this research, we utilize an integrated assessment modeling approach to examine the long-term effects of Saudi Arabia's goal of achieving net-zero GHG emissions by 2060, specifically focusing on the building sector. Integrated assessment models (IAMs) offer a wide-ranging view and cover various sectors, including electricity, buildings, transport, industry and the environment. These models typically have less detailed spatial and time-based data, as they prioritize long-term trends and patterns. The subsequent sections of the paper provide an overview of the modeling structure, methods used for the building sector, scenario setup, assumptions and results, followed by a discussion and main findings.

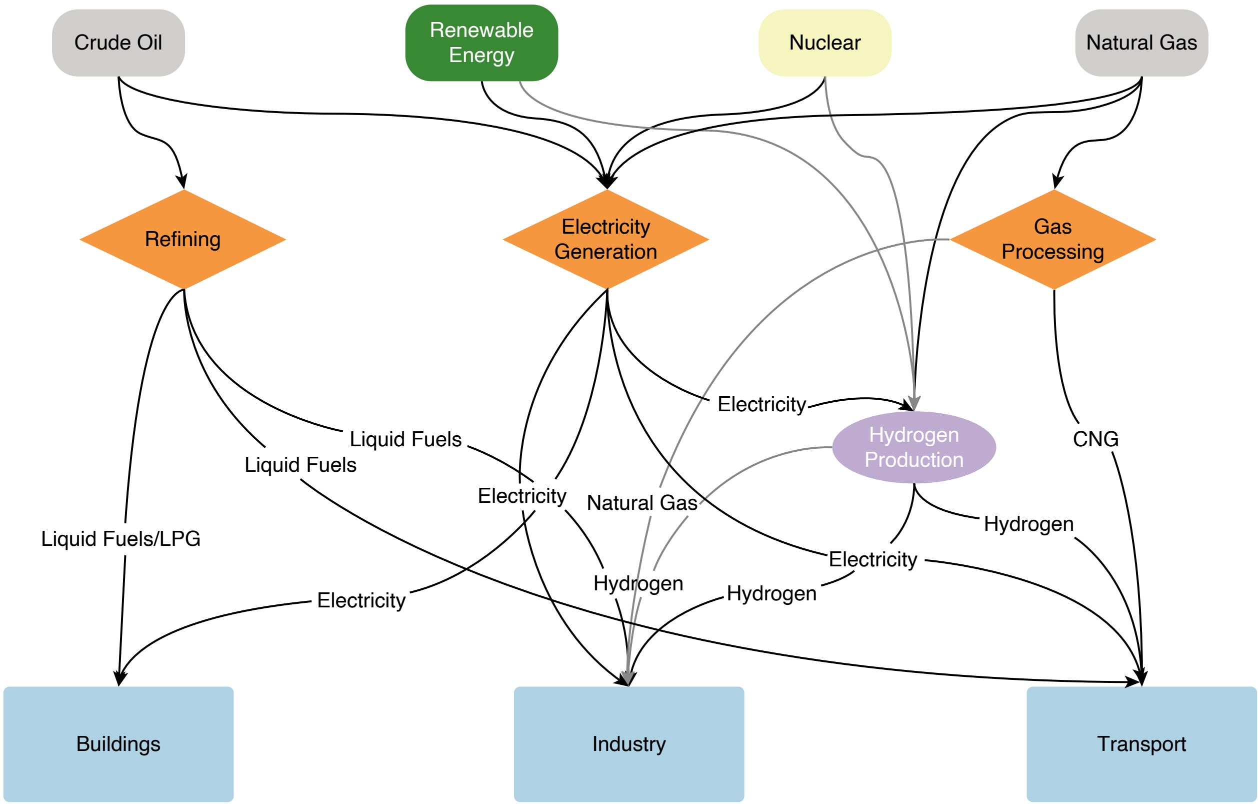
Methodology and Scenario Framework: GKAM-KSA

We used a modified version of the Global Change Analysis Model (v6.0), which is an integrated assessment model representing the behavior and interactions between the energy system, water, agriculture and land use, economy and climate (Calvin et al. 2019). The GCAM is an open-source community tool that has been analytically utilized to support policymakers for more than 30 years and has been documented in hundreds of peer-reviewed publications (Calvin et al. 2019; Edmonds and Reilly 1983; Kim, Edmonds, et al. 2006). For example, the GCAM was the primary model used to develop scenarios for the U.S. Mid-Century Strategy and support the State Department during the Paris Negotiations (U.S. Mid-Century Strategy 2021). The GCAM was also one of the core models utilized in China's recent carbon neutrality report (Energy Foundation China 2020).

For this study, we separated the KSA into energy economy regions. The GCAM-KSA includes 33 energy-economy regions (32 original regions plus the KSA) and runs in five-year intervals from 2015 (calibration year) to 2100 by solving for the equilibrium prices and quantities of various markets in each period. Because the GCAM-KSA is a dynamic recursive mode, the solutions for each modeling period depend largely on the conditions of the current modeling period. GCAM-KSA tracks the emissions of 24 gases, including GHGs (i.e., CO2, N2O, CH4, F-gases), short-lived species and ozone precursors, which are endogenously based on the resulting energy, agriculture, land use and water systems.

Although the GCAM has a detailed representation of water, agriculture and land use systems, in the GCAM-KSA v1.0, we primarily focus our analysis on the energy systems and associated emissions (GCAM Documentation v6.0 2022). The model's energy system for Saudi Arabia (Figure 1) contains representations of fossil resources (oil and gas), uranium and renewable sources (wind, solar and geothermal), along with the processes that transform these resources into final energy carriers (electricity generation, refining, hydrogen production and gas processing), which are ultimately needed to deliver the goods and services demanded by end-use sectors (buildings, transportation and industry).

Figure 1. Schematic of the energy system for Saudi Arabia in the GCAM-KSA.



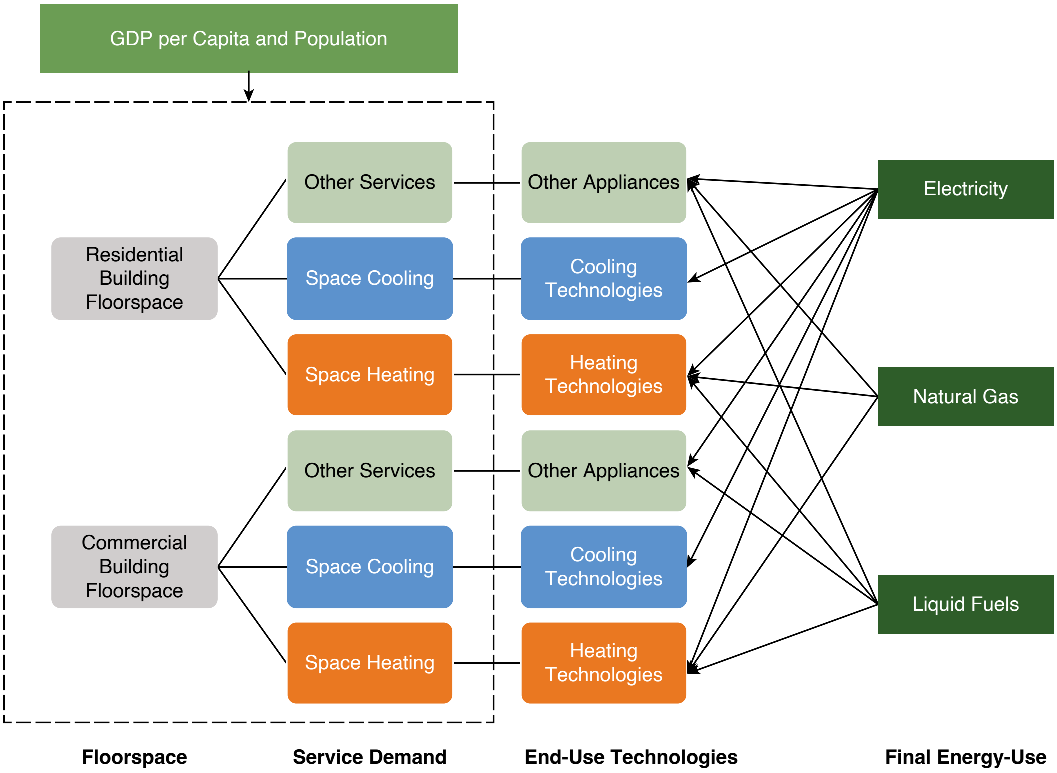
Note: CNG represents compressed natural gas, and LPG represents liquefied petroleum gas. For more detailed structure and methodology of the end-use sectors, please refer to the series of GCAM-KSA v1.0 sectoral papers (Kamboj, Hejazi, Qiu, Kyle, & Iyer, 2023).
Source: KAPSARC.

Within the GCAM-KSA framework, the Saudi Arabian building sector is bifurcated into two primary categories: residential and commercial buildings (including government buildings), as illustrated in Figure 2. Each category is characterized by a cumulative floorspace area and accompanied by physical parameters that encompass the thermal conductance of the building envelope and the floor-to-surface area ratio. Correspondingly, each building classification necessitates three distinct energy services related to its floorspace: space heating, space cooling and a tertiary category encapsulating services such as appliances, lighting and water heating. The provision of these energy services emanates from competition among various end-use technologies, with each technology consuming one or multiple marketed fuels, including electricity, natural gas and liquid fuels (Clarke et al. 2018; Eom et al. 2012).

Notably, the existence of this model within a comprehensive, long-term global assessment framework mandates that it have a symbiotic relationship with the broader economy and energy system. This interrelation is facilitated primarily through two mechanisms. Initially, demographic dynamics and gross domestic product directly modulate the requisition for floorspace and the associated services. Subsequently, fluctuations in fuel prices sway both the relative and actual costs of delivering services via disparate end-use technologies. Markedly, fuel prices are not externally determined in the GCAM-KSA framework. Rather, they are inherently calibrated within the model, contingent on variables such as resource availability, climatic and other policy considerations, technological advancements and other determinants (Eom et al. 2012).

The expansion of the building sector is quantified through increases in per capita building floor space, a metric subjected to a confluence of factors. This metric exhibits a pronounced relationship with per capita GDP and demographic trends. Moreover, the availability of floor space is determined not only by market demand but also by the supply side, which is contingent on geographical and institutional limitations. Furthermore, while income significantly affects the demand for floor space, it is not the sole determinant. Fluctuations in the regional real estate market, which encompass the costs of acquisition and leasing as well as the operational expenses associated with energy services, also play a crucial role. Notably, the integration of energy service costs into the assessment of floor space is vital, particularly under a policy regime that imposes a carbon price, which could potentially escalate operational costs and affect the affordability of new building floor space. However, variations in energy prices do not dramatically influence the demand for floor space, given that other costs associated with building construction and maintenance predominate (Chaturvedi et al. 2014; Eom et al. 2012).

Figure 2. Structure of the building sector for Saudi Arabia in the GCAM-KSA.



Note: Adapted from Clarke et al. (2018).
Source: KAPSARC.

The demand and supply per capita building space (m²/capita) for period *t* are represented as follows:

$$q_{B,t} = k_D \, . \, P_{B,t}^{a} \, . \, i_t^{b}$$
$$q_{s,t} = k_s \, . \, P_{B,t}^{j} \, . \, P_{B,t-1}^{d} \qquad \text{..... (1)}$$

where $q_{B,t}$ and $q_{s,t}$ are floorspace demand and supply, $P_{B,t}$ and $P_{B,t-1}$ are the building prices in periods *t* and , $t-1$, i_t is per capita income in period *t*, and *a* and *j* are the price elasticities and *b* and *d* are the income elasticities, respectively. k_D and k_s are the calibration parameters that capture the unobserved effects and regional preferences.

Within the GCAM-KSA framework, the modeling of energy service demand for building services aligns with the methodologies employed for China as delineated by Eom et al. (2012) and for India as described by Chaturvedi et al. (2014). This representation diverges from the conventional elasticity-based approach prevalent in economic modeling. It incorporates the concept that demand for a service escalates as the service becomes more economically accessible, culminating in a saturation point that parallels the notion of a "bliss point." Such a model is adept at encapsulating a quintessential pattern in consumer behavior — namely, the presence of a threshold in energy service consumption where the marginal utility is positive until a certain level of comfort is achieved, beyond which the marginal utility begins to diminish. The demand for any service *j* per unit of floorspace area is a function of three variables:

$$d_j = k_j.\bar{q}_j.\phi_j(P_j, i) = k_j.\bar{q}_j.\left[1 - exp\left(-\frac{ln2}{\mu_j}\frac{i}{P_j}\right)\right] \quad \text{..... (2)}$$

where k_j functions as a calibration parameter, $\bar{q}_j$ specifies the level of demand at saturation for the service and ϕ_j quantifies the influence of economic decision-making, reflecting the portion of the realized satiated demand. This realization is contingent on the cost of the service, P_j, and per capita income *i*. The behavioral parameter μ_j, known as the saturation impedance, modulates the extent to which demand approaches saturation at a particular service affordability, expressed as $^i/_{P_j}$. Therefore, for a fixed affordability ratio, a higher saturation impedance associated with an energy service correlates with a reduced level of service consumption.

As GCAM-KSA models cooling and heating service demand specifically for the building type, the saturation level $\bar{q}_j$ is represented as:

$$\begin{aligned} \bar{q}_{j_{cooling}} &= CDD\eta r - \lambda_C IG \\ \bar{q}_{j_{heating}} &= HDD\eta r - \lambda_H IG \end{aligned} \quad \text{..... (3)}$$

In the above expression, heating degree days (represented as HDD) and cooling degree days (represented as CDD) represent the cumulative temperature deviations for heating and cooling purposes, respectively, measured in hours per degree Celsius, which vary temporally. Thermal conductance, denoted by η, is measured in gigajoules per square meter per hour per degree Celsius ($GJ/m^2\,h^{-1}°C^{-1}$), or by the building's U value, which quantifies the rate of heat transfer through building structures. The variable *r* signifies the building's floor-to-surface area ratio, which represents the proportion of the building envelope exposed to external temperatures. *IG* indicates the internal gains within a building and is measured in gigajoules per square meter (GJ/m^2), while λ_C and λ_H are scalars for internal gains. These scalars adjust for the temporal discrepancy between when space conditioning is necessary and when internal gains occur.

Scenario Framework and Critical Assumptions

In this study, four scenarios up to 2060 are considered using the GCAM-KSA. These scenarios were chosen to evaluate the long-term impact of various policies and mitigation efforts on Saudi Arabia's energy system. For all scenarios, we assume a growing economy and an increasing population, with per capita income reaching USD 37,000 (2020 prices) in 2060 and a total population of 60 million. We include the impact of COVID-19 on the GDP growth rate in 2020 and the recovery thereafter in 2025 as per the International Monetary Fund projections (IMF, 2023). The population and GDP growth rates thereafter align with the shared socioeconomic pathways' "middle of the road" assumptions for the growth rate from the shared socioeconomic pathways database (Oliver Fricko, 2017). The Saudi Arabia-specific critical policies and mitigation targets used to characterize the scenarios in this study are as follows:

- The **No Policy** scenario is a counterfactual scenario where we assume no specific climate mitigation targets, i.e., no NDC targets. This scenario does not account for the recent policy-driven mitigation efforts of energy efficiency gains and price reforms in the end-use sector, nor does it consider support for low-carbon technologies; rather, traditional hydrocarbons drive future development.

- The **Current Policy**[1] scenario considers the gains of various energy efficiency measures taken by the SEEC and the two rounds of energy price reforms conducted in 2016 and 2018 in the country. This scenario also considers fulfilling the target of equal power capacity of renewable and gas-based electricity generation by 2030. No new additional policies are assumed for the remaining decades after 2030.

[1] *The Current Policy scenario does not include the impact of two key initiatives in the Kingdom due to insufficient information to assess their long-term impacts on emissions. The first is the goal of planting 650 million trees in the Kingdom by 2030. The second is the impact of the King Abdulaziz Project on Riyadh's public transport, which aims to equip Riyadh with an extensive public transport network, including metro lines and bus routes.*

- The **NDC Continued** scenario applies emissions constraints to the Current Policy scenario to achieve an emissions reduction of 278 MtCO2eq by 2030 relative to the No Policy scenario. The emissions constraints beyond 2030 reflect the same rate of declining GHG intensity of GDP (i.e., 4%) achieved from 2020 to 2030 to meet the NDC target.
- The **NZ 2060** scenario is assumed to meet the NDC target by 2030, as reflected in the NDC Continued scenario, and a linear decline to net-zero GHG emissions occurs from 2030 to 2060.

Table 1. Scenario design and key assumptions.

Policies and mitigation target
No Policy
No energy efficiency gains in the building and transport sectors.
No energy price reforms, i.e., subsidized fuel prices continue.
No climate mitigation policy, i.e., no NDC target.
No market/support for low-carbon technologies.
Current Policy
Energy efficiency gains are reflected based on various initiatives by the SEEC in end-use sectors.
Reflects energy price reforms by calibrating 2020 fuel prices in the model to the actual fuel prices in Saudi Arabia after two rounds of price reforms in 2016 and 2018.
Equal electricity generation capacity of renewable and gas-based plants.
NDCs Continued
Includes policies from the current policy scenario and meets the NDC emissions reduction target of 278 MTCO2eq by 2030 compared to the no policy scenario.*
Beyond 2030, continues the same declining rate of the economy's GHG intensity as achieved from 2020 to 2030 to meet the NDC target.
NZ 2060
In addition to the NDCs continued scenario, the net GHG emissions beyond 2030 linearly decline to zero by 2060.

Notes:
** As Saudi Arabia has not officially defined its baseline emissions in the updated NDCs, we have assumed the No Policy scenario as the baseline emissions in this study.*

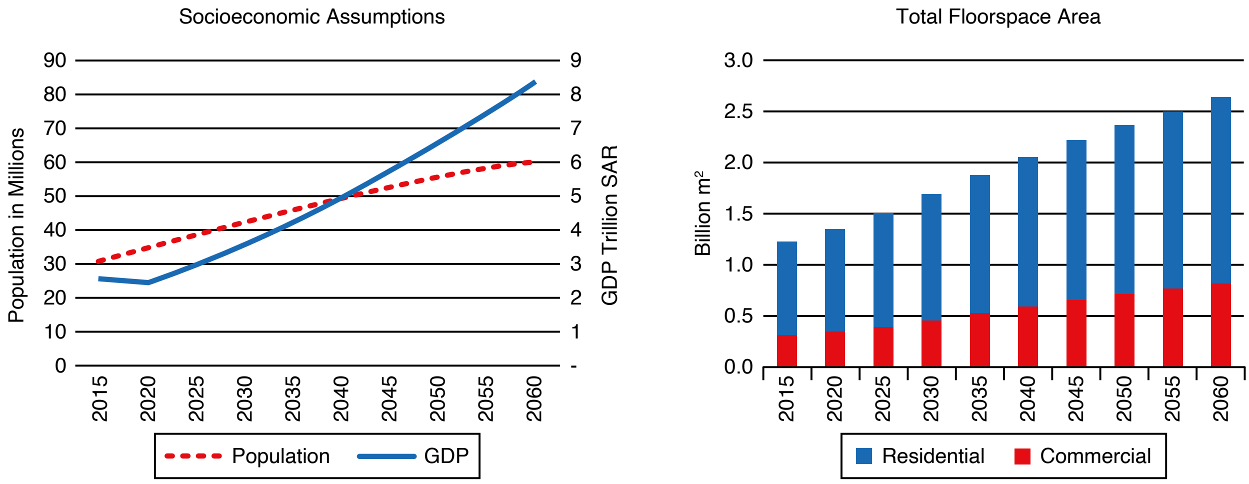
For model regions other than Saudi Arabia, in the emissions-constrained NDC Continued and NZ 2060 scenarios, we assume the fulfillment of other regions' NDC and net-zero targets, as reflected in the NDC scenario from (Gokul Iyer, 2022). This assumption includes various countries' commitments during COP 26 and the continued ambition scenario presented by (Yang Ou, 2021).

Results and Discussion

Economic Growth and a Rising Population Will Result in Doubling the Required Floor Space Area by 2060

The growing population is one of the most critical factors driving the demand for new housing. The Saudi population has increased consistently over the past three decades, growing by approximately 128% during the period of 1990 to 2020. As a reference, the global population grew by 46% over the same period. This high rate is due to high fertility rates and the increasing number of expatriates who come to the Kingdom for work. Despite the slight decrease in the fertility rate in recent years, economic diversification and potential economic expansion are likely to attract more expatriates to work and live in the Kingdom (World Bank 2023). This population growth not only exerts pressure on residential units but also stimulates commercial activities, hence increasing commercial floor space.

Figure 3. Socioeconomic assumptions and total floor space area expansion across scenarios in Saudi Arabia.



Source: KAPSARC.

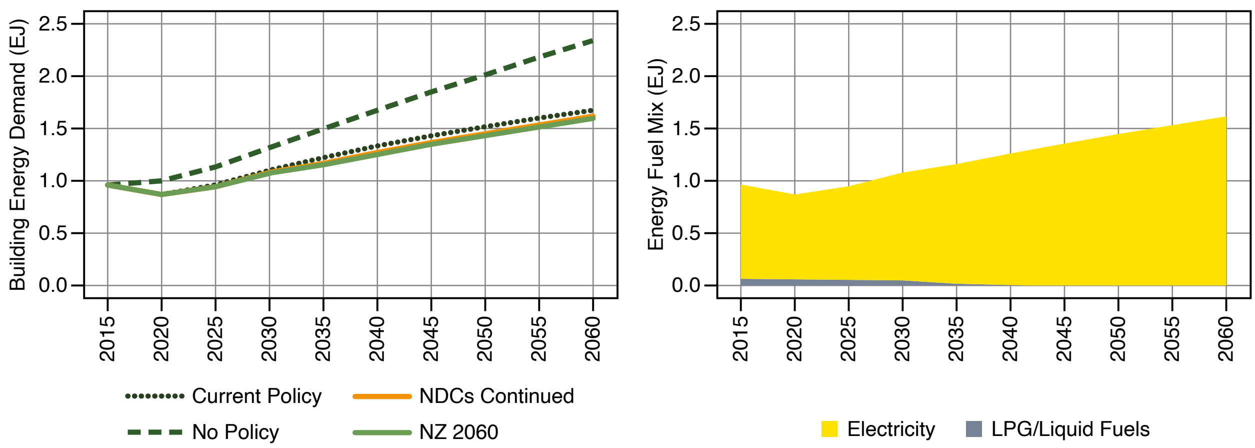
As highlighted in the previous section, Figure 3 indicates that, based on our assumptions, the population of the KSA will increase to 60 million, including expatriates, by 2060, with its GDP anticipated to reach 8.5 trillion SAR at 2020 prices. This demographic growth, coupled with rising incomes, is set to significantly increase the need for living spaces and associated services. In particular, the demand for residential and commercial floorspace is expected to surge in response to these socioeconomic changes. Our analysis suggests that the residential floorspace requirement will experience a twofold increase from 0.91 billion square meters in 2015 to 1.81 billion square meters by 2060. Commercial floorspace is projected to expand at an even more rapid pace, growing by approximately 2.5 times from 0.32 billion square meters in 2015 to 0.82 billion square meters in 2060.

This increase in floorspace demand will have wide-reaching implications for the building sector in Saudi Arabia, necessitating advancements in construction capacity, urban planning and sustainability measures. The sector will need to adapt to these demands by increasing construction projects, in both scale and number, while also considering the environmental impact of such growth. The challenge will be to meet this increasing floorspace requirement efficiently in a way that supports economic growth, satisfies the population's living standards and aligns with the KSA Vision 2030 sustainability goals.

Continuation of Current Energy Efficiency Measures in the Building Sector Will Provide the Required Momentum to Decarbonize the Building Sector

In light of the ambitious goal of the KSA to reach net zero by 2060, the energy efficiency of the building sector will become a game changer. Looking at the CCE framework and its four Rs (reduce, reuse, recycle and remove), we can see that the reduce element comes first. Energy efficiency is a critical element in the reduce element, as it ensures delivery of necessary services while decreases natural resource consumption, hence mitigating GHG emissions. Regular updates of residential constructions, minimum energy performance standards

Figure 4. Final energy demand for the building sector across scenarios (left) and the fuel mix for the building sector under the NZ 2060 scenario (right).



Source: KAPSARC.

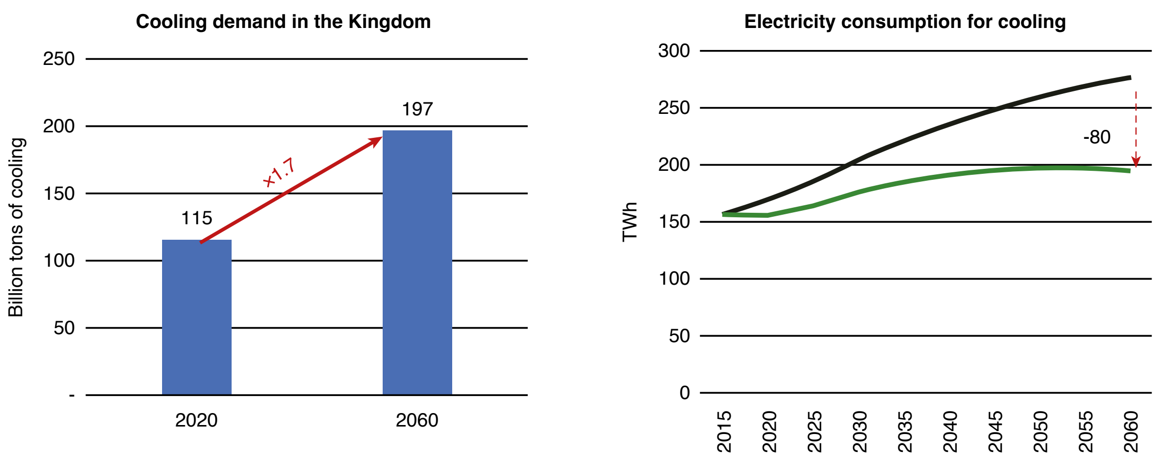
of new residential buildings and moderate renovations of existing buildings can reduce electricity consumption by up to 30% by 2060 (Aldubyan n.d.). Deep MEPS updates and retrofits can also achieve further savings. Commercial buildings hold substantial potential, especially in terms of cooling, which represents a primary source of energy consumption.

The continuation of current energy efficiency initiatives within the building sector is imperative for the KSA's aspiration to attain net-zero emissions by the year 2060. As highlighted in Figure 4, our analysis for the Current Policy scenario indicates a decrease of 28% in the building sector's energy consumption by 2060 under the aegis of the continuation of current energy efficiency policies compared to the No Policy scenario. This trajectory underscores the considerable influence that consistent energy conservation measures may exert upon the sector's carbon footprint. Additional energy savings are estimated based on alterations in consumer behavior due to price changes observed in the NZ 2060 scenario. These changes are expected to eventually eliminate kerosene and liquefied petroleum gas used for cooking purposes within the Kingdom. The commitment to and augmentation of extant policy measures for enhancing energy efficiency in the building sector are posited to shape a remarkable path toward the decarbonization objective, thus positioning the reduction in energy usage as a pivotal element in this strategic endeavor.

Continuation of the Labeling Program for Air Conditioning Can Save up to 80 TWh Annually

Given the hot climate conditions in most Saudi regions, both residential and commercial buildings rely heavily on cooling. Approximately 65% of the total Saudi residential electricity consumption is used for cooling (SEEC 2020). Thus, cooling has the most savings potential, especially for old air conditioning units with low energy efficiency ratings. Enhancing the average installed AC energy efficiency ratings would most likely unleash a significant amount of savings and alleviate future electricity growth in the building sector. For example, replacing all existing residential AC units with efficient ones may result in up to a 30 TWh reduction in electricity consumption (Krarti, Aldubyan, and Williams 2020). Tackling commercial and government buildings should achieve further savings.

Figure 5. Increase in cooling demand in Saudi Arabia (left) and the annual electricity savings for cooling as a result of energy efficiency measures (right).



Source: KAPSARC.

Our analysis highlights that the demand for cooling in 2060 within the Kingdom will increase by 1.7 times from its current state. In this context, the strategic perpetuation of the AC labeling program, which promotes the adoption of units with low energy efficiency ratings, holds significant potential for energy conservation. The empirical evidence underscores that such measures may culminate in an appreciable reduction in energy consumption, specifically facilitating an annual conservation of 80 TWh by 2060 in the NZ 2060 scenario (Figure 5), when compared against a hypothetical No Policy scenario.

The labeling program not only aligns with the Kingdom's broader environmental targets but also represents a cost-effective strategy to mitigate the increased electricity demand for cooling purposes. By fostering energy-efficient practices among consumers and manufacturers alike, the program is not only a facilitator of energy savings but also an instrument for the Kingdom to move toward its net-zero emission goals in a sustainable and economically viable manner.

Reducing F-Gas Emissions Will Be Critical for the Kingdom for Net-Zero Emissions From the Building Sector

The GHG emission results for the building sector (Figure 4) emphasize the critical importance of reducing F-gas emissions within the Kingdom, particularly in the context of Saudi Arabia's ambitious aim to reach net-zero emissions by 2060. This objective carries significant weight. F-gases, or fluorinated gases, are synthetic compounds primarily employed in refrigeration, air conditioning and various industrial applications.

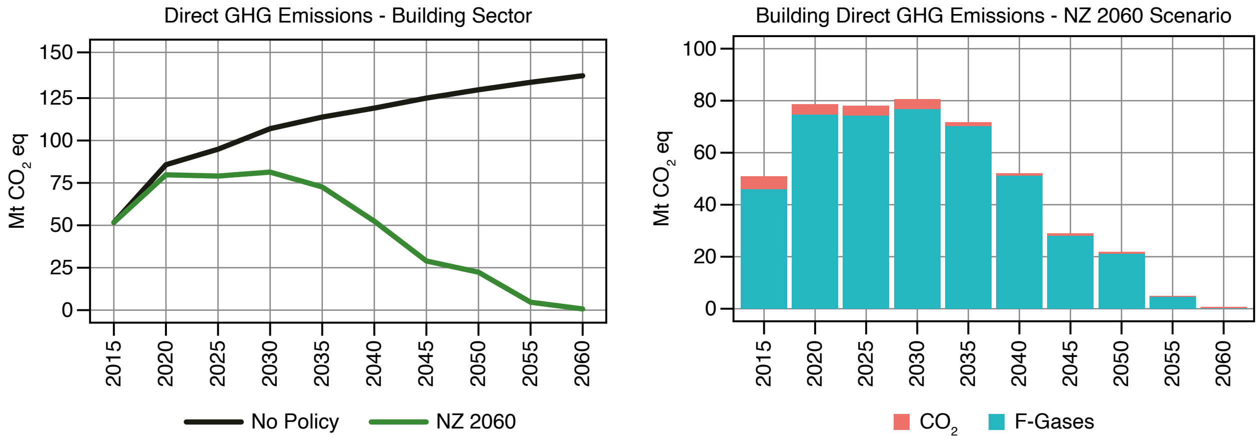
The high global warming potential of GHGs makes them particularly concerning in the context of climate change, especially when considering the integral role played by the building sector in the Kingdom's emissions profile.

F-gases have also been termed "super pollutants"; they include hydrofluorocarbons, perfluorocarbons, nitrogen trifluoride and sulfur hexafluoride. The global warming capacities of these gases are much greater than those of carbon dioxide; some of these gases are potentially almost 24,000 times more impactful (Sovacool et al. 2021). This stark difference in global warming potential means that even minor emissions of these gases can have a disproportionately significant impact on global warming. As such, reducing F-gas emissions is imperative for effectively mitigating climate change and aligning with international climate goals.

Strategies to reduce F-gas emissions, such as transitioning to more energy-efficient cooling and refrigeration technologies, can also lead to improvements in energy savings, cost, reliability and lifetime (Metz 2005). This situation presents a dual benefit, as it not only reduces GHG emissions but also lowers operating costs for businesses and households. In this regard, reducing F-gas emissions represents a win–win situation where economic savings align with environmental benefits.

In addition to their role in climate change, F-gases can pose health risks to individuals. For instance, exposure to high concentrations of F-gases can lead to respiratory and cardiovascular issues. High-quality, durable refrigerators enhance indoor air quality and health, while well-designed ACs can improve ventilation; decrease mold-related ailments, including allergies and asthma; and reduce infections linked with weak airflow or cooling systems, such as tuberculosis, chickenpox and legionella (World Health Organization 2015). Therefore, reducing F-gas emissions not only contributes to mitigating climate change but also improves air quality and safeguards public health.

Figure 6. Direct GHG emissions for the No Policy and NZ 2060 scenarios (left) and GHG emissions in the NZ 2060 scenario (right) for the building sector.



Source: KAPSARC.

Strategies to minimize F-gas emissions include shifting to potential low-global warming refrigerants, amplifying the energy efficiency of refrigeration and cooling systems, executing effective recovery and recycling, instituting robust regulation and reporting, and fostering technological innovation. For instance, the adoption of natural refrigerants, such as ammonia, carbon dioxide and hydrocarbons, can significantly decrease emissions while simultaneously decreasing the impact of global warming. Furthermore, enhancing the energy efficiency of cooling and refrigeration systems curtails cooling demand and dependence on F-gases. This situation can be realized through superior system design, consistent maintenance and more efficient equipment upgrades. Importantly, instituting recovery and recycling systems for F-gases from retired equipment is key to curtailing emissions. Additionally, proper disposal of equipment and refrigerants is crucial to avert leaks and adhere to responsible environmental protocols. Ultimately, formulating regulations that limit the use of high-GWP refrigerants and enforcing F-gas emissions reporting can effectively diminish their associated emissions. These rules can also encourage the transition to eco-friendly alternatives.

The Way Forward

Saudi Arabia is on the brink of a significant transformation driven by its growing population and economic diversification. The country's demographic changes, characterized by an increase in both native and expatriate populations, are creating a massive demand for residential and commercial floor space. This trend is expected to substantially increase the current floor space requirements, reflecting the growing need for housing and commercial facilities.

The residential sector is set to experience a notable increase in floor space demand. This growth stems from the need to accommodate the expanding population and improve living standards. The commercial sector, fueled by Saudi Arabia's economic diversification plan, is also expected to experience a significant increase in floor space demand. These changes call for advancements in construction techniques, urban planning and sustainability measures. The building sector is now faced with scaling up construction projects while integrating sustainable practices that align with Saudi Arabia's Vision 2030 for sustainable growth and improved living standards.

Energy efficiency is a critical area of focus for Saudi Arabia, especially given its commitment to achieving economy-wide net-zero GHG emissions. The energy efficiency of the building sector, which is a significant energy consumer, must continue to increase. This process involves updating construction practices and adhering to minimum energy performance standards in both residential and commercial buildings. Energy-efficient practices, particularly in air conditioning and cooling services, can lead to substantial reductions in electricity consumption.

The AC labeling program in Saudi Arabia exemplifies a strategic approach to energy efficiency. With cooling representing a significant part of residential electricity use, enhancing AC unit efficiency is paramount. The program encourages the use of high-efficiency AC units and is expected to contribute significantly to the country's energy savings goals.

Reducing F-gas emissions is another crucial aspect of Saudi Arabia's environmental strategy. F-gases, known for their high global warming potential, pose a significant challenge in the fight against climate change. Minimizing these emissions involves transitioning to refrigerants with a lower global warming potential and improving the energy efficiency of refrigeration and cooling systems. These efforts are not only environmentally beneficial but also economically advantageous.

Looking forward, further research is needed to explore other services within the building sector, such as lighting, appliances and cooking. These areas also consume significant amounts of energy and have a substantial impact on overall energy efficiency and sustainability. Future studies will delve into the patterns of energy use in other services, identify opportunities for efficiency improvements and assess the potential impact of various interventions. Further research is vital for developing comprehensive strategies that address all aspects of energy use in buildings, thereby contributing to Saudi Arabia's broader environmental and economic goals.

In conclusion, Saudi Arabia's building sector is at a pivotal point because it needs to accommodate rapid growth while embracing sustainable and energy-efficient practices. The path forward involves a strategic balance between development and environmental stewardship, making it a key area of interest in the global context of managing growth and climate challenges.

Appendix I

Table A1.1. Socioeconomic assumptions.

Variables	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	Units
GDP	2.58	2.46	2.99	3.57	4.23	4.95	5.72	6.55	7.43	8.37	Trillion 2020 SAR
Population	31	35	39	43	46	50	53	56	58	60	Million

Table A1.2. Assumption for energy efficiency improvements for cooling for all scenarios except the no policy scenario for Saudi Arabia.

Sector	Consumer	Technology	CAGR (%)	
			2015–2030	2030–2060
Buildings	Residential	Cooling	0.8	0.7
	Commercial	Cooling	0.8	0.7

Appendix 2

Table A2.1. Floorspace area modeled across all scenarios.

Building type	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	Units
Commercial	0.317	0.345	0.392	0.464	0.530	0.595	0.656	0.713	0.767	0.819	Billion square meters
Residential	0.911	1.002	1.106	1.228	1.343	1.454	1.557	1.651	1.738	1.817	Billion square meters

Table A2.2. Modeled final energy use by the building sector across scenarios.

Scenario	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	Units
No policy	0.962	1.004	1.134	1.320	1.495	1.675	1.850	2.013	2.181	2.341	EJ
Current policies	0.962	0.870	0.964	1.101	1.221	1.335	1.434	1.519	1.600	1.676	EJ
NDCs continued	0.962	0.871	0.951	1.082	1.167	1.273	1.369	1.458	1.541	1.620	EJ
NZ 2060	0.962	0.871	0.951	1.082	1.162	1.262	1.361	1.452	1.536	1.615	EJ

Table A2.3. Modeled direct emissions from the building sector in the KSA.

Scenario	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	Units
NDCs continued	51	79	78	80	76	68	56	46	34	33	MtCO2eq
NZ 2060	51	79	78	80	72	52	29	22	5	1	MtCO2eq
Current policy	51	79	88	101	109	115	121	126	131	135	MtCO2eq
No policy	51	85	94	106	112	118	123	128	133	136	MtCO2eq

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References

Al Shehri, T., Braun, J. F., Howarth, N., Lanza, A., and Luomi, M. 2023. "Saudi Arabia's Climate Change Policy and the Circular Carbon Economy Approach." *Climate Policy* 23, no. 2: 151–167. DOI: 10.1080/14693062.2022.2070118

Aldubyan, M. n.d. *Future Residential Electricity Demand in Saudi Arabia and Its Contribution to the Net Zero Target.* Riyadh: King Abdullah Petroleum Studies and Research Center.

Aldubyan, M., and Gasim, A. 2021. "Energy Price Reform in Saudi Arabia: Modeling the Economic and Environmental Impacts and Understanding the Demand Response." *Energy Policy* 148 Part B (January). DOI: 10.1016/j.enpol.2020.111941

Aldubyan, M., Krarti, M., and Williams, E. 2020. *Residential Energy Model for Evaluating Energy Demand and Energy Efficiency Programs in Saudi Residential Buildings.* Riyadh: King Abdullah Petroleum Studies and Research Center.

Al-Tamimi, N. 2017. "A State-of-the-Art Review of the Sustainability and Energy Efficiency of Buildings in Saudi Arabia." *Energy Efficiency* 10: 1129–1141. DOI: 10.1007/s12053-017-9507-6

Belaïd, F., and Massié, C. 2023. "The Viability of Energy Efficiency in Facilitating Saudi Arabia's Journey toward Net-Zero Emissions." *Energy Economics* 124 (August). DOI: 10.1016/j.eneco.2023.106765

Chaturvedi, V., Eom, J., Clarke, L. E., and Shukla, P. R. 2014. "Long Term Building Energy Demand for India: Disaggregating End Use Energy Services in an Integrated Assessment Modeling Framework." *Energy Policy* 64 (December 23): 226–242. DOI: 10.1016/j.enpol.2012.11.021

Clarke, L., Eom, J., Marten, E. H., Horowitz, R., Kyle, P., Link, R., . . . Zhou, Y. 2018. "Effects of Long-Term Climate Change on Global Building Energy Expenditures." *Energy Economics* 72: 667–677. DOI: 10.1016/j.eneco.2018.01.003

Durand-Lasserve, O., Almutairi, H., Aljarboua, A., Murphy, F., Pradhan, S., and Pierru, A. 2020. *Sectoral and Economy-Wide Effects of Domestic Energy Price Reforms in Saudi Arabia.* Riyadh: King Abdullah Petroleum Studies and Research Center.

Edwards, B. W., and Naboni, E. 2013. *Green Buildings Pay: Design, Productivity and Ecology.* Abingdon: Routledge. DOI: 10.4324/9780203082386

Eom, J., Clarke, L., Kim, S. H., Kyle, P., and Patel, P. 2012. "China's Building Energy Demand: Long-Term Implications from a Detailed Assessment." *Energy*: 405–419. DOI: 10.1016/j.energy.2012.08.009

Gasim, A. A., and Matar, W. 2023. "Revisiting Energy Subsidy Calculations: A Focus on Saudi Arabia." *The Energy Journal* 44. DOI: 10.5547/01956574.44.1.agas

Gokul Iyer, Y. O. 2022. "Ratcheting of Climate Pledges Needed to Limit Peak Global Warming." *Nature Climate Change* 12: 1129–1135. DOI: 10.1038/s41558-022-01508-0

IEA (International Energy Agency). 2019. "Multiple Benefits of Energy Efficiency." Accessed November 2023. https://www.iea.org/reports/multiple-benefits-of-energy-efficiency.

IMF (International Monetary Fund). 2023. "World Economic Outlook: GDP, Current Prices." Accessed July 2023. https://www.imf.org/external/datamapper/NGDPD@WEO/OEMDC/ADVEC/WEOWORLD/SAU.

Kamboj, P., Hejazi, M., Qiu, Y., Kyle, P., and Iyer, G. 2023. "Climate Adaptation & Mitigation Partnership." Accessed November 20, 2023. https://apps.kapsarc.org/camp/home.

Krarti, M., Aldubyan, M., and Williams, E. 2020. "Residential Building Stock Model for Evaluating Energy Retrofit Programs in Saudi Arabia." *Energy* 195. https://doi.org/10.1016/j.energy.2020.116980.

Krarti, M., Dubey, K., and Howarth, N. 2017. "Evaluation of Building Energy Efficiency Investment Options for the Kingdom of Saudi Arabia." *Energy* 134 (September): 595–610. DOI: 10.1016/j.energy.2017.05.084

Matar, W. 2015. *Modeling Residential Electricity Consumption and Efficiency within an Economic Framework: Insights Gained by Using an Engineering-Based Approach.* Riyadh: King Abdullah Petroleum Studies and Research Center.

Ministry of Energy. 2023. "Saudi Energy Efficiency Program." Accessed October 2023. https://www.moenergy.gov.sa/en/OurPrograms/SPFEE/Pages/TargtedSectors.aspx.

Oliver Fricko, P. H. 2017. "The Marker Quantification of the Shared Socioeconomic Pathway 2: A Middle-of-the-Road Scenario for the 21st Century." *Global Environmental Change* 42 (January): 251–267. DOI: 10.1016/j.gloenvcha.2016.06.004

Saudi Arabia. 2022. *Fourth National Communication (NC4) of Kingdom of Saudi Arabia.* United Nations Framework Convention on Climate Change.

Saudi Vision 2030. 2016. "Environment & Nature." Accessed September 2023. https://www.vision2030.gov.sa/en/progress/environment-nature/.

SEEC (Saudi Energy Efficiency Center). 2023. "Data and Statistics." Retrieved September 2023. https://www.seec.gov.sa/en/data-and-statistics/.

UN-Habitat. 2018. *Saudi Cities Report 2018.* Riyadh: UN-Habitat.

WERA (Water and Electricity Regulatory Authority). 2022. *Annual Statistical Booklet for Electricity.* Riyadh: Water and Electricity Regulatory Authority.

Yang Ou, G. I.-Z. 2021. "Can Updated Climate Pledges Limit Warming Well below 2°C?" *Science* 374, no. 6568 (November 4): 693–695. DOI: 10.1126/science.abl8976

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About the Project

This study is a part of the Climate Adaptation and Mitigation Partnership project.

The CAMP project is timely and crucial for Saudi Arabia, given the mounting risks associated with climate change impacts, the urgency of moving toward a low-carbon future while maintaining economic growth nationally and the potential economic ramifications of global mitigation efforts on the Saudi energy sector and economy. Against this backdrop, the CAMP project investigates (1) the climate conditions in Saudi Arabia, (2) the sectoral impacts and role of adaptation measures and (3) the pathways of the Saudi economy to achieve a low-carbon future or climate neutrality by the mid-century. (4) The study will also adopt the circular carbon economy concept in characterizing the Saudi government's efforts to decarbonize its own economy while meeting its growth aspirations.

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