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Futures

FINDING THE RIGHT MIX FOR A CARBON-NEUTRAL FUTURE

"Data-driven insights must guide our decision-making." **P.05**

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ABOUT THE COVER

Infinite energy: Leveraging diverse resources is key for a carbon-neutral future.

COVER IMAGE
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King Abdullah Petroleum Studies and Research Center

ABOUT KAPSARC

Founded in 2007 as an energy research center, the King Abdullah Petroleum Studies and Research Center (KAPSARC) has since evolved into an advisory think tank with a focus on global energy economics and sustainability.

Based in Riyadh, KAPSARC is a community of experts using human ingenuity, knowledge, and research to tackle the pressing global energy challenges of the 21st century.

Through a range of advisory services, the center provides day-to-day insights and consultancy services using a multidisciplinary team approach to drive long-term value and deliver actionable results at scale.

ABOUT FUTURES

Welcome to the inaugural issue of **Futures.** This magazine is dedicated to exploring the forefront of energy and sustainability research. In this edition, we delve into key areas such as energy economics, oil and gas, renewables, climate change, transportation, and innovative solutions. Our aim is to provide valuable insights and showcase the pioneering work of KAPSARC's experts. Join us on this journey as we uncover the latest trends, technologies, and strategies shaping the future of energy and sustainability. Thank you for being part of our community and supporting our mission to drive positive change.

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IN-DEPTH ▸

Futures

NOTE FROM THE PRESIDENT

The challenge of climate change requires a transformation of our energy systems. As we transition to a decarbonized world and new forms of energy, the effects will be felt by almost everyone in their everyday lives. This understandably can give rise to misconceptions, political biases and culture clashes, as we have seen happen in various countries undergoing their own energy transitions.

That's why research and data are crucial to navigate this landscape.

Decades worth of data have allowed us to identify and track climate change; to pursue possible solutions and adapt our strategies when necessary. Take decarbonization as an example, it is a complex and dynamic process with many potential pitfalls, as well as valuable opportunities, as the world reach its optimal energy mix. To ensure that our path toward a carbon-free energy landscape is effective, we must rely on data-driven insights to guide our decision-making, from identifying emerging technologies to evaluating the effectiveness of policies.

All forms of energy generation involve complicated supply chains and have their own varied maintenance, operational and end-of-life requirements. What might seem like a straightforward solution may cause indirect emissions increases or other unintended negative impacts. Meanwhile, certain technologies or strategies that initially appeared problematic may prove to be more promising than expected. Such hard-to-decipher factors can only be revealed through data and research.

KAPSARC's Circular Carbon Economy Index is one example of the power of data in guiding our priorities and investments. This tool shows how 125 nations, including many oil and gas producing countries, are stacking up on circular carbon economy practices including renewable energy development, nuclear energy, green hydrogen, and sinking of carbon emissions.

The analysis shows that Saudi Arabia is a world leader in green hydrogen production and natural carbon sinking. The Kingdom's score for carbon sinking in the global index is over 90 out of 100, based on criteria developed for the project, compared to a global average score under 30.

On the green hydrogen front, while many countries have yet to begin production, the Saudi project Neom is slated to produce 8 tons of green hydrogen a day.

The index also measures countries' ability to accelerate toward more success in decarbonization efforts, considering factors such as policy, investment, socioeconomic context and business environment. Globally, scores are relatively low in knowledge, technology and innovation, indicating a need for more focus on these areas.

Research and data will play a crucial role in identifying the most effective ways to produce, transmit and consume energy without emissions, maximizing economic and social benefits while minimizing associated costs and harms.

—Fahad Alajlan, President

Fahad Alajlan
President of the King Abdullah Petroleum Studies and Research Center (KAPSARC)

SHAPING THE FUTURE OF ENERGY

Agile, timely, and anticipative, KAPSARC's energy economics and sustainability research programs are finding solutions to support domestic and global energy transitions.

▶ KAPSARC is using satellite technology to measure methane emissions in the Gulf.

As the world steps up efforts to meet net-zero transition targets, we face a continually evolving set of domestic and international policy questions. This is reflected by the diversity of topics covered in this magazine, and each reader should find various pieces falling in their own area of interest. KAPSARC's recent research achievements in energy economics and sustainability showcase how our findings and insights can inform global policymakers and support a just and orderly transition.

Energy policy questions are not the only elements in flux. The accelerated development of artificial intelligence is increasingly turning knowledge into a commodity, presenting us with urgent questions surrounding accessibility and ethical use. This technological revolution will profoundly impact the way experts can maximize the value they add to global and domestic policy debates. More than ever, the ability to identify relevant policy questions and address them analytically by transforming data into innovative insights will be critical to our success. This aligns particularly well with KAPSARC's long-standing efforts to build a suite of models that cover a broad set of global and domestic policy issues.

Expanding modelling capabilities

We will continue to strengthen our modelling and analytical capabilities. For instance, we plan to build new models to better understand the impact that changes to domestic energy transportation have on energy consumption, and the effects of climate-related trade policies on energy markets. We will also start to use our new global energy model to produce long-term scenarios reflecting alternative perspectives and assumptions.

"The accelerated development of artificial intelligence is increasingly turning knowledge into a commodity, presenting us with urgent questions surrounding accessibility and ethics. This trend will also profoundly impact the way experts can maximize the value they add to global and domestic policy debates."

Embracing innovation

We will continue to augment our research capabilities by incorporating cutting-edge technologies alongside traditional methods. Our recent partnership with leading satellite data company Kayrros has expanded our environmental intelligence capabilities, including satellite-based approaches for greenhouse gas measurements and climate action. In a unique collaborative study, KAPSARC and Kayrros published the first measurements of elusive methane emissions in Saudi Arabia from 2019 to 2023, using satellite technology. We have now extended this work beyond Saudi Arabia to include other Gulf countries.

Harnessing artificial intelligence

If used in the right way, AI offers us the opportunity to address new questions and advance our potential to solve complex problems. Harnessing the power of AI to enhance KAPSARC's analytical and research work, we have established a dedicated working group, hosted workshops, and tested new tools to enhance our research efforts. These tools include AI-powered solutions that improve efficiency at various stages in the research process.

As we navigate the complex landscape of energy transition, KAPSARC remains committed to providing evidence-based insights and innovative solutions.

—Axel Pierru, Vice President of Knowledge and Analysis at KAPSARC

Axel Pierru
Vice President of Knowledge and Analysis at KAPSARC

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TOWARD A CARBON-NEUTRAL KINGDOM

Analyzing the long-term impact of Saudi Arabia's climate-related initiatives.

Days before the COP26 climate change summit, Saudi Arabia made a historic commitment to achieving net-zero emissions by 2060[1] and to reducing its greenhouse gas emissions by 278 million tons per annum by 2030[2]. These goals are particularly challenging given the energy-intensive economic engine of the Kingdom.[3]

To navigate this complex landscape, KAPSARC researchers Puneet Kamboj and Mohamad Hejazi, in collaboration with researchers from the Pacific Northwest National Laboratory in the United States, have analyzed the overall energy system of the Kingdom in the coming decades. Their

findings offer invaluable insights into the potential challenges and opportunities that lie ahead as the country moves toward meeting its climate targets[4].

Steps toward sustainable development

As part of its Saudi Vision 2030, the government has announced and invested in several initiatives to reduce the country's carbon footprint.[2] These efforts have yielded positive results, but significant challenges remain.

Two energy price reforms in 2016 and 2018 raised domestic fuel prices and contributed to a decrease in electricity and gasoline consumption. Additionally, energy efficiency improvements in residential buildings further reduced electricity consumption between 2014 and 2018.

To further accelerate its energy transition, the country has invested in several renewable energy projects and committed to have 50% of its power capacity from renewable sources by 2030.[2] Other actions include the Circular Carbon Economy National program, Saudi Arabia's Energy Efficiency Program, and the development of a new metro system in the capital and other cities.[2,5]

Several studies have examined the effect of carbon-mitigation initiatives on single sectors of the Saudi economy, but a comprehensive analysis was lacking. Kamboj and Hejazi's report, 'Long-Term Decarbonization Pathway for Saudi Arabia to Reach Net Zero GHG Emissions by 2060,' and paper 'The path to 2060: Saudi Arabia's long-term pathway for GHG emission reduction' are some of the first works to quantitatively assess the long-term implications of various climate-related initiatives and policies across different sectors.[4,6]

Modelling Saudi Arabia's energy system and its emissions

The team adapted the Global Change Analysis Model—which has already been validated to model climate policies and emissions globally—to simulate Saudi Arabia's current and future energy system and its emissions.

"Our model shows that reaching net zero by 2060 will demand a collective effort, a solid long-term strategy and strong collaboration among the government, the private sector and broader society."

The model includes a detailed representation of the energy sector with an exhaustive list of resources and technologies for both supply and demand sectors. It covers processes converting energy resources into energy carriers like electricity and hydrogen, which are used in residential and commercial buildings, transportation, and industrial sectors.

The researchers simulated four scenarios based on some of the current climate mitigation initiatives and potential future efforts.

In the 'current policy' scenario, the team assumed that rapid decarbonization of electricity generation, energy price reforms, and energy efficiency measures would be implemented. These actions could reduce carbon emissions by 185 million tons of carbon dioxide equivalent ($MtCO_2eq$) by 2030 from a counterfactual baseline constructed by the authors.

However, the suite of implemented measures in the current policy scenario fall short of the 2030 target of 278 $MtCO_2eq$.

Also, in the current policy scenario, total greenhouse gas emissions will rise to 1,127 $MtCO_2eq$ by 2060. While this is 18% lower than a 'No policy' scenario, it's still far from achieving net-zero emissions. This underscores the urgency of developing and implementing additional decarbonization strategies.

"It is important to note that this is an active and evolving area in the country with many new initiatives, which are not accounted for in our report and paper. In particular, the scenarios for the study were designed two years ago and the calculations do not include some recent announcements in the Kingdom," explains Kamboj, KAPSARC's Climate and Sustainability researcher and lead author of the study.

The 'Nationally Determined Contributions (NDC)' scenario shows that if important improvement commitments made to reduce greenhouse gas emissions from 2020 to 2030 continue until 2060, an annual emission decline of 1.2% can be achieved. However, reaching net zero by 2060 would require a more ambitious annual emission reduction rate of 3.3% between 2030 and 2060 as described in the 'NZ 2060' scenario.

"Achieving economy-wide net-zero greenhouse gas emissions will be complex and challenging for Saudi Arabia. It will require a substantial reduction in emissions across all sectors of the economy, including the power sector, buildings, industry, transport, and resource production," says Hejazi, who is executive director of the Climate and Sustainability Department at KAPSARC.

Electrifying the economy

Power generation, transport, buildings, and industry all play vital roles in Saudi Arabia's pursuit of net-zero emissions by 2060. Electrifying the economy and reducing hydrocarbon use are critical steps in this journey.

For example, the model indicates that increasing renewable energy capacity can save 140 $MtCO_2$ emissions by 2060. "Decarbonizing electricity generation is a low-hanging fruit, as solar and wind technologies are mature and relatively cheap," explains Kamboj.

Shifting to public transport can cut emissions by 136 $MtCO_2$ emissions, implementing fuel efficiency standards can reduce emissions

GIUSEPPE CACACE/AFP VIA GETTY IMAGES

by 81 $MtCO_2$, and the adoption of electric vehicles can save an additional 78 $MtCO_2$, while in buildings sector, implementing measures to lower energy consumption in residential and commercial buildings can further contribute to 55 $MtCO_2$ emission saving.

The complete decarbonization of the industrial sector, however, is a monumental challenge. Strong sectors of Saudi Arabia's economy, such as the production of petrochemicals and fertilizers, continue to rely on oil. The Kingdom is working to can be reduce emissions through energy efficiency improvements, switching to cleaner fuels wherever applicable, and adding carbon capture and storage (CCS) technologies to capture emissions from combustion of hydrocarbons.

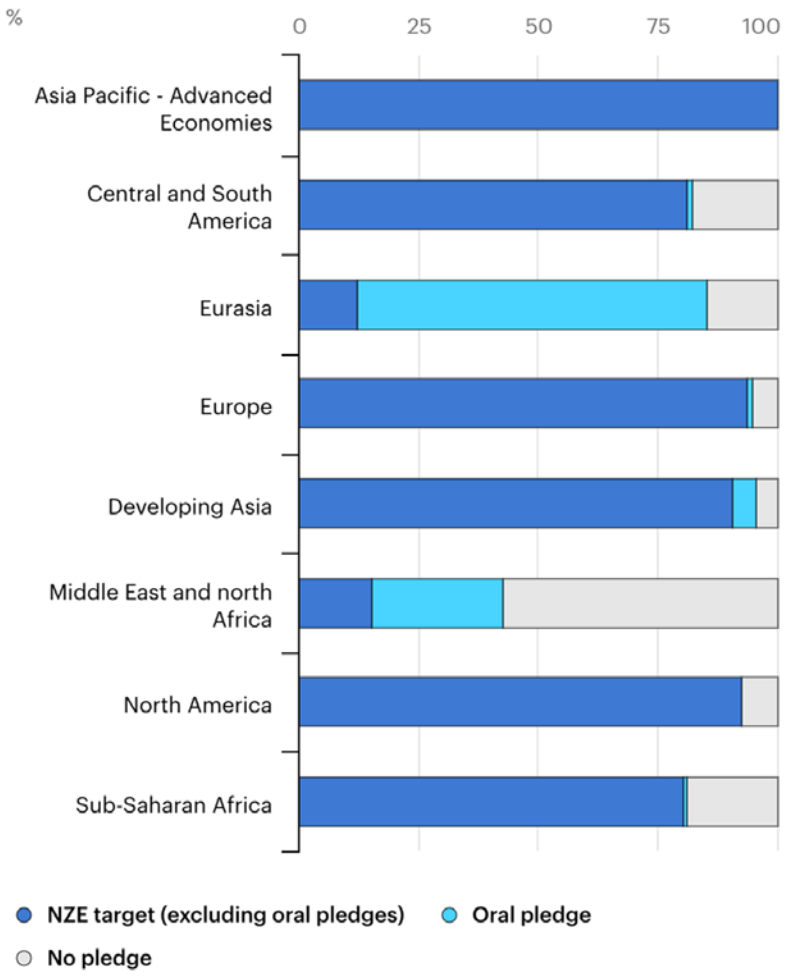
"Despite the challenges, even carbon-intensive industries can reduce their footprint by 2060. The petrochemical industry could reduce emissions by up to 56 $MtCO_2$ emissions, while the cement sector has the potential to cut emissions by 41 $MtCO_2$," says Kamboj.

Finally, since hard-to-decarbonize sectors will remain a part of Saudi Arabia's energy mix for a long time, the researchers stress the importance of developing energy-efficient carbon dioxide removal (CDR) technologies that are also cost effective. According to the model, CDR would allow the removal of an extra 371 $MtCO_2$ per year from the atmosphere, helping to achieve the net-zero goal.

"It is important to explore alternative net-zero scenarios including ones that do not require large scale deployment of removal technologies such as direct air capture (DAC) in case their costs do not drop rapidly as anticipated or hoped," says Hejazi. "It is also important to investigate future fuels such as e-fuels, e-methane, and ammonia, which are not currently included in our modelling framework for Saudi Arabia but are essential to ensure scalability when these technologies become necessary in the transition."

By promoting renewable energy, investing in research and development on carbon removal technologies, as well as fostering collaboration, Saudi Arabia can chart its path toward a low-carbon future. Beyond environmental benefits, transitioning to net-zero emissions could create new opportunities for economic growth, job creation, and technological innovation. "Our model shows that reaching net zero by 2060 will demand a collective effort, a solid long-term strategy and strong collaboration among the government, the private sector and broader society," concludes Kamboj.

Regional coverage of long-term Net Zero Scenario pledges, 2030



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"Despite the challenges, even carbon-intensive industries can reduce their footprint by 2060."

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2. UNFCCC (United Nations Framework Convention on Climate Change). 2021. Nationally Determined Contributions Registry. https://unfccc.int/NDCREG
3. Country Analysis Brief: Saudi Arabia https://www.eia.gov/international/content/analysis/countries_long/Saudi_Arabia/pdf/saudi_arabia_2023.pdf
4. Kamboj, P., Hejazi M., Qiu, Y., Kyle P., and Iyer G.; Long Term Decarbonization Pathway for Saudi Arabia To Reach Net Zero GHG Emissions by 2060.
5. https://www.vision2030.gov.sa/en/projects/saudi-green-initiative/
6. Kamboj, P., Hejazi, M., Qiu, Y., Kyle, P., and Iyer, G.; The path to 2060: Saudi Arabia's long-term pathway for GHG emission reduction. *Energy Strategy Reviews* **55**, 101537.

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An appetite for change in energy use

A lab-based study of individuals' attitudes toward energy efficiency strategies for buildings provides a blueprint for real-world initiatives.

Buildings are responsible for around 40% of global energy demand and generate approximately 30% of energy-related greenhouse gas emissions. The benefits of making buildings more energy efficient are well established, yet the adoption of appropriate energy efficiency measures is disappointingly low. "This is an important paradox," says Fateh Belaïd at the King Abdullah Petroleum Studies and Research Center (KAPSARC), who worked with Véronique Flambard, a professor at Lille Catholic University, to assess the role of social norms and personal motivation in thwarting appropriate action.

The researchers chose an innovative laboratory-based approach to study the issue, using feedback from a sample of 306 participants. By investigating the subjects' attitudes in detail, they hoped to uncover effective strategies to overcome behavioral biases and encourage greener decisions.

They focused on two specific factors influencing the participants' energy choices. The first was peer pressure;

▲ Targeted information significantly boosts confidence in energy-efficiency benefits, increasing preference for energy-saving habits.

they wanted to know if neighbors' choices can influence a person to use energy more efficiently. The study also examined a 'confidence message,' which reflects whether a person's neighbors who chose energy efficiency options have been satisfied with and would stick with their choice.

"We sought to bridge the gap between awareness of issues on sustainable building options and actions that will really promote sustainable choices, with an overarching aim of supporting personal changes to mitigate the effects of climate change," says Belaïd.

The findings reveal that targeted information significantly boosts confidence in energy-efficiency benefits, increasing preference for energy-efficient options. Social norms and motivational messages emerge as powerful catalysts for energy-saving behavior. The evidence supports a call for much wider and long-term strategies to educate future generations about the environmental value of energy conservation. This will be vital for achieving carbon neutrality in the built environment.

The researchers now plan to build on the research, initially with a new lab-based experiment to assess people's willingness to pay for energy conservation solutions and environmental policies, even if they may increase energy prices.

"We need to explore and encourage the economic trade-offs consumers must be willing to accept for sustainability," Belaïd says. "We also want to conduct experiments to validate our laboratory findings in real-world settings, and refine strategies for promoting energy efficiency across diverse populations and contexts."

● Belaïd, F. and Flambard, V., Boosting buildings energy efficiency: The impact of social norms and motivational feedback. *J. Econ. Behav. Organ.*, **215**, 26-39, 2023.

Predicting future global oil demand from buildings

A comprehensive modelling study offers insights into the future energy needs of the world's built environment.

The building sector accounts for one-third of the world's annual energy consumption, making it one of the largest consumers of energy resources. With the rapid global growth of urbanization and industry, and a continued rise in population, the demand for energy in the building sector is expected to increase by around 65% between 2018 and 2050.

Conscious that seeking sustainable, environmentally friendly methods of generating and using energy will be critical to limit the extreme effects of climate change, KAPSARC researchers Fateh Belaïd and Mohammad Aldubyan used a detailed modelling approach to predict global oil demand for energy consumption by buildings in the coming decades. Their approach provides a valuable tool to guide energy use planning and management for all stakeholders.

SIMON DAWSON/BLOOMBERG VIA GETTY IMAGES

◀ Construction site in Jeddah, Saudi Arabia.

"Our study highlights the importance of efficient and sustainable long-term energy planning for the buildings sector."

"Conducting this study now is crucial due to the significant energy consumption and emissions stemming from this sector," says Belaïd. "Understanding future oil demand for residential, commercial and industrial buildings is essential for guiding energy policy and helping to address climate change."

Through their model, the researchers, who are both research fellows in the Climate and Sustainability Department at KAPSARC, provide a detailed projection of potential demand for oil in the buildings sector. They have covered eight regions across the globe, forecasting up to 2050 and focusing on the consumption of four different fuel types: liquefied petroleum gas (LPG), kerosene, gas and diesel oil (excluding biofuels), and fuel oil.

The complexities of energy use in buildings

Overall energy use in any given building is determined by the utilities it needs for its intended purpose. Different performance variables, such as size, building materials and insulation, as well as the building's age, play a key role. Understanding the consumption behaviors of each building's occupants and the influence of the local environment and climate is also critical. This means that predicting building energy consumption levels is inherently complex and dependent on multiple, ever-shifting variables.

Belaïd and Aldubyan's study uses advanced multivariate forecast modelling, specifically Autoregressive Integrated Moving Average with Exogenous variables (ARIMAX), to forecast energy use trends.

"The ARIMAX model helps predict how much energy buildings will use by examining historical patterns and considering the influence of important external factors such as weather, gross domestic product, population and oil prices," says Belaïd. "It delivers accurate energy-use forecasts by combining the historical data with these external factors. This data-driven approach also offers deep insights into regional and global trends over time."

As with any modelling approach, the results are only as robust as the data that is put in to train and run the model. In the building sector, many existing datasets are convoluted and at times incomplete, Aldubyan explains.

"Detailed and consistent data on building energy use is often limited or unavailable, especially for older datasets and those from certain, often poorer, regions," he adds. "Variations in data-collection methods and reporting standards across different sources and countries can lead to inconsistencies in the final model output. Additionally, differences in building energy sources and practices across regions and over time add an extra layer of complexity to the analysis."

For this study, the researchers delved into 48 years' worth of historical data (1971-2019) from credible sources including the World Bank, the UN Population Division of the Department of Economic and Social Affairs, and the International Energy Agency. While their model results are as robust as they can be within current parameters, the team acknowledges that long-term pro-

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▶ Construction in the Riyadh financial district, Saudi Arabia.

jections cannot account for future policy changes or technological disruptions that could drastically alter the outcomes. "Our results should be interpreted as useful pointers toward potential trends, not guaranteed predictions," Aldubyan says.

Following the trends

The model has yielded useful insights into fuel use trends in buildings for the coming decades. For instance, demand for LPG use in buildings is projected to grow steadily, with the sector drawn to the fuel's affordability, versatility and relative cleanliness compared with traditional fuels such as coal and wood. Similarly, gas and diesel oil use will increase between now and 2050.

While the global demand for fuel oil in buildings has declined consistently in recent decades, the team's projections suggest that this trend has stabilized and will likely remain static in future. Based on current estimates, the global demand for kerosene in buildings is on a consistent downward trajectory, projected to continue for the foreseeable future.

The KAPSARC researchers hope that their results will prove valuable to stakeholders in both the building and energy sectors.

"Our study highlights the importance of efficient and sustainable long-term energy planning for the buildings sector," says Belaïd. "We would urge stakeholders to collect and use detailed, high-quality data to understand regional trends and fuel-specific use; and make use of accurate models like ours to anticipate potential challenges. The development and adoption of energy efficient technologies and practices is also vital."

Such practices include developing programs to encourage building occupants to adopt energy-saving behaviors. It is also crucial that energy systems in buildings are inherently flexible, so that managers can adapt energy use quickly in response to changing conditions.

Looking ahead

"The adaptability of the ARIMAX model allows for continuous updates to projections, and we will continue to refine the model with new, high-quality data," says Aldubyan. "There are also areas within these initial results that warrant further investigation."

For example, the detailed segregation of oil demand by fuel type and geographical region could be expanded to include more granular data at the city or even the individual building level. Additionally, the team would like to examine the impact of specific policy interventions and emerging technologies that could reduce oil consumption in the building sector.

"Further exploration of the behavioral factors influencing energy demand, and how they can be effectively managed, would also pave the way for more comprehensive energy management strategies," concludes Belaïd.

● Belaïd, F. & Aldubyan, M. Projecting global oil demand for the buildings sector. KAPSARC (2024).

DID YOU KNOW?

- The building sector accounts for one-third of the world's annual energy consumption.
- The demand for energy in the building sector is expected to increase by around 65% between 2018 and 2050.

How to fortify power grids against extreme weather

Understanding how electricity systems respond to extreme weather events is key to developing more resilient infrastructure.

Extreme weather events can quickly overwhelm power grids, leading to blackouts that put lives at risk. KAPSARC researchers have reviewed power-grid planners' assessment and response to extreme weather events to find improvements for systems resilience.

In February 2021, severe winter storms known as the 'Great Texas Freeze' had devastating consequences as record-low temperatures quickly overwhelmed the state's power grid. The breakdown damaged the distribution infrastructure, with many power plants simply unable to cope with the extreme cold combined with a surge in demand for heating. Electrical grid operators attempted to prevent a total system collapse by implementing rolling power blackouts, however millions of people were left without electricity for days, resulting in many deaths.

"It is paramount that electricity markets are designed to cope with power system resilience to extreme events," says Marie Petitet, who led the KAPSARC team, together with Burçin Ünel from the New York University School of Law. Liberalized capacity markets are designed to ensure that there is sufficient generating capacity available to meet peak demand: providers are paid to maintain a certain level of generating capacity.

Texas was considered a role model in this type of market design, but the Great Texas Freeze has revealed frailties.

"We looked at the resiliency of power systems to extreme weather events, in the context of climate change, and showcased current actions undertaken in the United States and Europe to better prepare power systems for extreme events," explains Petitet. "We have also provided recommendations for policymakers that could improve power systems' resiliency through capacity markets."

The team suggests enhancing methodologies to model, forecast and understand how extreme events can lead to power outages. "System planners and operators have to anticipate what could be an extreme event in their region and how the current or future power system could react," says Petitet. "Their role is to prepare the power system to avoid outages during such events by adapting market rules, reinforcing the network, or investing in more generation units."

- Petitet, M; Ünel, B. and Felder, F.A. Making electricity capacity markets resilient to extreme weather events. *Economics of Energy and Environmental Policy*, **12** (2), 49-67 2023.

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Driving the transition to energy-efficient homes

A new study into household energy-saving solutions provides valuable insights and implications for policymakers aiming to promote investment in energy efficiency.

The building sector is a crucial contributor to greenhouse gas emissions, responsible for about 26% of global energy-related CO_2 emissions in 2022. Enhancing the energy performance of residential buildings to reduce energy demand is a cornerstone for policymakers in many countries.

However, despite the evidence of economic and environmental benefits of energy-efficiency investments, households in many countries have been slow to invest in energy-efficient technologies.

In a recent study, KAPSARC research fellow Fateh Belaïd and Camille Massié from Lille Catholic University investigate the behavioral obstacles to investing in energy efficiency in the French residential sector.

Belaïd says targeting the residential sector offers substantial low-cost potential for energy

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savings and reduction of related carbon gas emissions.

"Promoting and disseminating energy renovation on a massive scale would provide benefits, such as reducing energy poverty and local environmental impacts, reinforcing energy security and improving comfort," says Belaïd.

The researchers developed a statistical model to investigate the determinants of energy renovation behavior, including the decision to renovate and the energy efficiency measure adopted. They applied this model to analyze data from a survey of 3,000 French homeowners that was conducted in 2018.

The survey identified the four most frequently stated barriers to energy efficiency investments as "satisfaction with the current state of the dwelling (65%), recency of the dwelling (24%), too high of a level of investment required (22%), and prioritization of investments (21%)."

Risk-related reasons (being insecure about the financial profitability of the project, the quality of work, or the revaluation of the value of the property) are identified as a barrier to energy efficiency investments in 25% of cases, the study found.

But while 71% of respondents were pessimistic about investing in energy efficiency, believing it to be a risky investment, environmentally conscious respondents were 75% more likely to undertake energy renovation measures, which highlights the importance of raising awareness and promoting environmental consciousness as a way to encourage energy efficiency investment.

In line with previous research, the analysis confirms that risk aversion decreases the likelihood of investing in energy efficiency measures. "Mitigating this risk aversion effect is crucial to make energy renovation economically attractive to reluctant households," says Belaïd.

The authors suggest a number of policy tools to foster energy efficiency investments, including accurate energy labels; company labels or certificates to provide a quality guarantee; better support for households during installation; and more readily available subsidies and financial incentives to lower upfront costs, improve affordability and mitigate the risk of uncertainty.

- Bélaïd, F. and Massié, C., Driving forward a low-carbon built environment: The impact of energy context and environmental concerns on building renovation. *Energy Economics*, **124**, 106865, 2023.

HOW WELL-PLANNED SHADE REDUCES THE IMPACT OF HEATWAVES

Building height and trees can make a significant difference to the street-level experience of heatwaves.

▼ Shading and tree height were found to affect street temperature.

With global temperatures increasing significantly, features such as building height, trees and surface types can reduce the urban heat island effect, according to a study of heatwaves in three cities in the United States.

An international team of researchers along with Mohamad Hejazi, executive director for the Climate and Sustainability Department at KAPSARC, used advanced technology to map mean radiant temperature during three heatwaves in three US cities in the summer of 2021. By combining remote sensing and satellite data, a microclimate model along with LiDAR (a high-resolution mapping tool), they were able to create a detailed map of hourly heat-exposure in Des Moines in Iowa, Boston in Massachusetts, and Riverside in California, during the heatwaves and on non-heatwave days.

The team found that overall, the central urban areas of these cities were around 5°C hotter during heatwaves than the surrounding rural areas. But exposure during heat waves varied substantially across the urban landscape and between the cities.

The most significant factor affecting radiant temperature was the amount of sky exposure at street level. This was largely influenced by

the heights of buildings; taller structures blocked more sunlight, resulting in lower radiant temperatures on the ground.

"Heat exposure in urban canyons of downtown areas was high due to the relatively low building height-to-street-width ratio, which resulted in a limited shading effect in the studied cities," the study found. Around two-thirds of the variance in mean radiant temperature could be attributed to this sky view factor.

The influence of surfaces and trees was less definitive. In the more humid Boston, trees were associated with a greater reduction in street-level temperatures during heat waves compared to in the hotter and drier Riverside. However, Riverside's impervious surfaces, such as concrete and tarmac, significantly increased the impact of heat waves.

While the urban heat island effect is already well studied, Hejazi says the significance of this analysis was its ability to explore the phenomenon in much greater detail. "We zoom in to investigate the implications of various urbanization and urban landscapes on heat exposure at high resolution. We look into neighborhoods and talk about different densities, and tree coverage within the city, then you start to get into shading effects and the ratio of how tall your building is to what the size of the building is," Hejazi says. "That's the unique three-dimensional geometry that we were able to capture in our analysis."

- Hu, J.; Zhou. Y.; Yang, Y.; Chen, G.; Chen, W.; Hejazi, M.; Multi-city assessments of human exposure to extreme heat during heat waves in the United States. *Remote Sensing of Environment*, **295**: 113700, 2023.

FAYEZ NURELDINE/AFP VIA GETTY IMAGES

Modelling net zero for Saudi Arabia signals a bright future

An economic model of various net-zero strategies will position Saudi Arabia on the path to sustainability.

Climate change is projected to increase the likelihood of heatwaves and droughts, while rising sea levels and intense storms will put those on the coast at risk. These changes in extreme weather patterns will affect agriculture, damage buildings and infrastructure, and potentially lead to mass migration. While there is an urgent need to tackle the causes of these changes, the move away from carbon-based energy sources was always thought to be too expensive.

Now, research by Olivier Durand-Lasserve, acting executive director of KAPSARC's Energy Macro and Microeconomics Department, finds growing evidence of long-term financial benefit from investing in technologies that support the move to net zero—using energy sources with dramatically reduced carbon emissions, with the balance taken up through carbon capture and storage.

Assessing Saudi Arabia's net-zero challenge

The Middle East is particularly at risk from the impacts of climate change. It's already hot and arid, which means it requires more energy to stay cool and produce drinkable water. While climate change is likely to make this worse, the Kingdom also has great potential: sunny days are perfect for solar power and hydrogen generation.

In 2021, Saudi Arabia announced a raft of pledges aimed at steering the country toward reaching net zero by 2060. Key questions remain about how best to deliver on this promise and which route would be the least risky and expensive. Durand-Lasserve's report plots possible net-zero emissions trajectories for Saudi Arabia and analyzes their expected economic consequences, as well as exploring the broader challenges of reducing emissions in an oil-reliant economy.

"I wanted to describe what net zero could look like in Saudi Arabia. What would the path be to reduce emissions? What would be the technologies used and what would be the impact on the non-oil sector?" explains Durand-Lasserve. "I also wanted to understand how much the future of energy in Saudi Arabia depends on the choices made in the King-

YAORUSHENG/ MOMENT/ GETTY IMAGES

WEIQUAN LIN/ MOMENT/ GETTY IMAGES

dom, and how much depends on the future of global oil demand and the global oil market."

A model future

Durand-Lasserve built a large mathematical model comprising approximately 25,000 equations representing market fundamentals, or the factors that influence the production, consumption, and utilization of different types of energy. It also represents the non-energy sectors of the economy. The large amount of data needed to build the model was collected from various sources that are publicly available.

The model projects CO_2 emissions and economic growth under a Saudi economy in a baseline scenario with limited climate action. More interestingly, the model can project future emissions, energy, and economic outcomes that would result from a very disruptive policy shock, such as implementing the net-zero target.

In his 'no-policy' scenario, Durand-Lasserve assumed the Saudi energy sector continued under the status quo. In particular, energy prices are fixed by the government, which does not incentivize consumers to save fuel. The second scenario assumed a limited policy action to mitigate CO_2 emissions. It consists of deregulating domestic energy prices that adjust upward to the international level, resulting in reduced domestic energy demand and emissions. The third scenario represents net-zero emission by imposing an annual cap on the amount of carbon dioxide released, and this cap scales down to zero by 2060.

The model explores various options to determine which technologies should be deployed, and it also computes how much financial support should be given to different technologies.

The model assessed the lowest cost mix of technologies and attempted to represent the incentives that might be needed to reach net zero, including adjusting energy and carbon prices. "Generally, I attempted to make scenarios that are coherent with rational economic choice, where agents make decisions based on the available technology options and their costs," explains Durand-Lasserve. "I also represented the system of administered domestic energy prices as it exists today in Saudi Arabia."

Technology investment

Achieving net zero requires considerable energy efficiency gain, an early transition to a net-zero electricity system before 2050, and a transformation of transportation sectors with hydrogen and electrification. To achieve this requires investment in even more costly and complex technology.

"One key factor will be the ability to scale up carbon capture technologies," Durand-Lasserve adds. "These technologies can be very important in the Kingdom. But they are not yet mature, and there is large uncertainty about their cost, discouraging investors."

Assessing this risk is Durand-Lasserve's next step. "By including uncertainty in the analysis, I would like to see what policy may help the Kingdom hedge against the risk that some technologies are more costly or take longer to deploy than expected."

Understanding and even predicting these unexpected bumps in the road is crucial. The move to net zero is not just about saving the planet, but about building a more prosperous and resilient future, and many nations, including Saudi Arabia, have already begun the transition.

● Durand-Lasserve, O. Net zero emissions in Saudi Arabia by 2060: Least-cost pathways, influence of international oil price, and economic consequences. KAPSARC, 2023.

KAPSARC'S NET-ZERO SCENARIOS PROJECT

- A drastic transformation of the energy sector.
- Power generation becomes carbon-neutral by 2045 thanks to renewable, gas with CCS, and nuclear technology.
- Electricity and clean hydrogen represent two-thirds of the energy consumption of the transportation sectors by 2060.
- Abatement in industry occurs due to fuel switching, clean hydrogen, and a large deployment of CCS.
- DAC emerges as a new energy-intensive technology. By 2060, it consumes the equivalent of 25%.

Simulating the impact of groundwater overuse

Increasing dependence on underground extraction is depleting natural aquifers, transforming water into a finite resource. By modelling 900 future scenarios, researchers are revealing the global impact of this unsustainable trend.

Many assume freshwater is an unlimited resource, thanks to its constant renewal through the natural water cycle. However, growing reliance on groundwater extraction from natural underground aquifers is causing rapid depletion.

Mohamad Hejazi, executive director for the Climate and Sustainability Department at KAPSARC, working with an international team, sought to determine likely future scenarios for groundwater use. Their study highlights the limits to groundwater extraction in different regions across the world, and suggests that groundwater must be treated like any other depletable resource.

"There is a myth that water scarcity can be dealt with by simply pumping groundwater to meet demand," says Hejazi. "We wanted to demonstrate that many places have already witnessed their peak and decline in terms of groundwater supply."

Around one-fifth of the world's food is grown using groundwater irrigation. These agricultural uses comprise 43% of groundwater consumption, and are particularly important in arid regions. However, many underground aquifers are not refilled within a human lifetime, and some are 'fossilized,' or cut off entirely from the surface water cycle. The costs of extracting from certain aquifers, and the associated damage to the environment, often outweigh the value of the water extracted.

"As groundwater levels fall and extraction costs increase, the practice becomes increasingly precarious," says Hejazi. "We are not saying that groundwater resources will run out, but the costs associated with extraction make it a finite resource."

To examine groundwater extraction futures, Hejazi and co-authors fed data related to 235 water basins worldwide into the Global Change Analysis Model. The model simulated 900 possible future scenarios, accounting for the dynamic interactions between regional factors such as the economy and land use, and wider global factors including socioeconomic, climate, and sustainability strategies.

In one-third of the basins, the majority of the 900 scenarios resulted in peak and decline patterns. These basins included many regions currently serving as the breadbaskets of the world, and potentially expose around 44% of the world's population to groundwater stress.

In the water-scarce Middle East, populations are already highly dependent on groundwater and non-traditional water sources such as desalinated water. Hejazi and his team are confident their findings can instigate planning to safeguard populations against severe groundwater depletion.

"There will be food price implications alongside other emerging vulnerabilities," he says. "We need to plan for these scenarios now, as part of our wider commitments to net zero and sustainable living goals."

- Niazi, H.; Wild, T.B.; Turner, S.W.D.; Graham, N.T.; Hejazi, M.; Msangi, S.; Lamontagne, J.R.; & Zhao, M. Ground peak water limit of future groundwater withdrawals. *Nature Sustainability* **7**, 413-422 (2024).

ALAN HOLDEN / 500PX / GETTY IMAGES

A recipe for expanding global access to clean cooking

Enhanced collaboration across sectors can expand access to liquid petroleum gas, paving the way for clean cooking targets by 2030.

Liquid petroleum gas (LPG) could help billions of people to transition from traditional fuels to sustainable solutions for cooking, a KAPSARC-led team suggests[1].

As of 2021, 2.3 billion people worldwide cannot access clean fuels and technologies for cooking, according to a World Health Organisation report. Without a substantial increase in investment, by 2030 some 1.9 billion people will remain without access[2]. To reverse this trend and achieve universal clean cooking by 2030 requires at least $10 billion yearly investment—nearly a hundred times as much as the current funding shortfall—advises the UN-supported nonprofit organization Clean Cooking Alliance, which advocates for better practices.

Cheaper and more accessible than modern fuels, traditional cooking fuels such as charcoal, coal and wood are commonly used in low-income and rural communities. However, typically they derive from biomass, which contributes to deforestation and considerable amounts of greenhouse gas emissions annually. Their combustion in open fires and inefficient stoves also produces harmful particulates and gases that deplete indoor air quality, causing severe respiratory infections and heart disease, especially in women and children.

Fuels such as LPG and natural gas are more sustainable for cooking. Liquified under pressure for easy storage and transportation, LPG is a flammable hydrocarbon gas mixture that consists of propane, n-butane, and isobutane. Despite being derived from fossil fuels, it burns relatively cleanly without soot and emits lower levels of greenhouse gas than traditional cooking fuels. There are, however, many challenges preventing households from making the switch to this fuel.

Clean cooking

Fateh Belaid, Aayushi Awasthy, and Mohamad Hejazi, who manages KAPSARC's Climate and Sustainability Department, have now identified various barriers to the adoption of clean fuels and technologies. Working with colleagues from the UN's Economic and Social Commission for Western Asia, the researchers have focused on the least-developed countries in the Arab region, Comoros, Djibouti, Mauritania, Somalia, Sudan, and Yemen, and Madagascar in Africa. Looking at successful introduction of clean cooking in other regions, the researchers have

◀ A lack of adequate supply chains for cylinder deliveries and refills restricts clean cooking access in remote and rural areas.

SAYED AKBER HOSHEN/ ISTOCK EDITORIAL / GETTY IMAGES PLUS - MINISERIES/ E+/ GETTY IMAGES

suggested LPG solutions to help transition to clean cooking.

"High energy poverty, limited infrastructure, and financial resources make these countries vulnerable and in urgent need of intervention," Belaid says, adding that they are key areas for international development efforts aimed at achieving affordable and clean energy by 2030.

About 80% of communities living in sub-Saharan Africa, the least-developed Arab countries, and Madagascar face considerable deficits in access to clean cooking technologies. The researchers found that, over the last two decades, there has been a decline in the adoption of clean cooking fuels in favor of biomass-based fuels, which will could heighten severe health risks and environmental issues. Households using clean fuels for cooking still rely on biomass to supplement their energy needs.

The main barrier to adoption in these countries is the high cost of clean cooking fuels and equipment. Financing gaps and insufficient financial resources also deter low-income households from purchasing fuel and equipment or businesses from creating large distribution networks.

Another barrier to adoption is geography. The lack of adequate supply chains for cylinder deliveries and refills restricts clean cooking access in remote and rural areas. Adoption is also impeded by limited awareness about the health and environmental benefits of clean cooking, Awasthy notes further hurdles in uptake such as a lack of strong policies, financial incentives, and subsidies for clean cooking initiatives.

Global efforts to adopt sustainable energy

The researchers suggest several targeted actions to improve clean cooking access. These actions, Hejazi says, include offering subsidies and financial incentives to increase affordability of clean cooking technologies, developing infrastructure to support supply chains and distribution networks, running public awareness campaigns on the benefits of clean cooking, and issuing supportive regulations and standards to promote market shifts.

Innovative business models can address the economic barrier of LPG. PAYG has emerged as a convenient way to provide access to LPG at lower cost. In this model, companies act as service providers that install the cylinder, remotely monitor fuel consumption, and pro-

DENIS-HUOT MICHEL / HEMIS/ ALAMY STOCK PHOTO

▲ Production of cheap cooking fuels like charcoal can contribute to deforestation and considerable amounts of gas emissions annually.

vide refills when required. Customers pay for LPG as they use it instead of purchasing full cylinders. They can also top up their supply through small mobile payments.

The introduction of smart meters in informal settlements in Nairobi, Kenya is a successful example. Residents had relied on traditional cooking fuels until the implementation of smart meters in 2020. This was a game changer that enabled LPG access by eliminating the upfront expense of a cylinder and allowing incremental fuel payments via mobile banking. Residents are also now enjoying safer kitchens and improved indoor air quality. Despite a decline in income during COVID-19 lockdowns, 95% of households enrolled in the program maintained their subscription.

Access to financial services can be improved by offering low-interest loans through microfinance and government-backed programs. India initiated the Pradhan Mantri Ujjwala Yojana program, which provides clean cooking access by installing natural gas pipelines in urban areas and LPG connections for rural households. Despite mixed results, the program resulted in 71% clean fuel adoption in 2021 and established 80 million LPG connections for low-income households.

Algeria, whose clean cooking access reached almost 100% in 2021, has developed LPG infrastructure for domestic and vehicle use. With support from a private–public partnership, the country has constructed a pipeline to improve LPG distribution and has promoted LPG as a cheaper and cleaner alternative to gasoline. "The program, complemented by energy subsidies and incentives, showcases how substantial investment and strategic planning with a people-centric approach can bring about tangible benefits in energy diversification," Belaid says.

"Collaboration across sectors is essential for achieving universal clean cooking goals by 2030," Awasthy says. One successful example is India's program, which rests on a partnership between the government, oil companies, financial institutions, and non-governmental organizations to provide subsidized LPG connections to rural households. Similarly, Keny's PAYG model involves public–private partnerships and community organizations to offer affordable plams via mobile payment platforms.

1. Belaid, F., Awasthy, A., Hejazi, M., Sedaoui, R., Ansari, M. & Ratka, S. Role of LPG in enabling a just and inclusive energy transition in Africa and the Arab region. KAPSARC/UNESCWA Report 14 December 2023.
2. https://www.who.int/news/item/20-01-2022-who-publishes-new-global-data-on-the-use-of-clean-and-polluting-fuels-for-cooking-by-fuel-type

DID YOU KNOW?

- Developing countries rely heavily on charcoal to produce biomass which contributes to the deforestation of around 3 billion kilograms of renewable wood.
- The process is equivalent to 32 million tons of greenhouse gas (GHG) yearly emissions.

Futures

“As groundwater levels fall and costs increase, water extraction becomes increasingly precarious.”

MOHAMAD HEJAZI

THE FUTURE OF OIL: THE ECONOMICS OF ENERGY TRANSITION

With advances in energy transition, weighing the costs and benefits of investment projects is crucial.

As global energy transitions progress, oil-producing countries are embarking on a journey of economic and energy policy transformation. Seeking to diversify their economies, these nations face a daunting challenge: navigating a future shrouded in uncertainty. With fluctuating oil prices and a host of unknowns about future oil demand, choosing the right investment projects is complex and calls for careful evaluation.

"The economies of oil-dependent countries are going through a transformative journey, and there is a need to measure the costs and benefits of public investment projects in these countries," says Fatih Karanfil, an economist based at KAPSARC.

To help major oil-exporting countries make better-informed investment decisions, Karanfil and Axel Pierru, Vice President of Knowledge and Analysis at KAPSARC, published a study that focuses on assessing public discount rates. Key to any cost-benefit analysis is accurately calculating public discount rates, Karanfil says. This involves evaluating future economic benefits and risks and comparing them with present-day values.

PANTHER MEDIA GMBH / ALAMY STOCK PHOTO

"Due to their reliance on oil, special treatment is needed when you compute a public discount rate in oil-dependent countries," he explains. "By exploring how oil price volatility and the relationship between oil prices and gross consumption (all goods and services) in the country affect public discount rates, we aimed to provide clearer guidance for policymakers in these countries."

Karanfil and Pierru looked at 18 oil-reliant countries, considering economic uncertainties and risks associated with oil price volatility. The study is the first to examine how oil dependence can affect the public discount rate and notes that oil-dependent countries face unique challenges when considering energy transition projects. For example, increasing energy efficiency could result in reduced domestic demand, freeing up more oil for exports. "These dynamics, which do not exist for non-oil-dependent countries, are an additional risk factor for oil-dependent countries," Karanfil says.

"If oil revenues are the engines of your economy and your investment impacts domestic demand for oil and alters oil exports, then you are introducing an oil-related risk into your project's evaluation," Karanfil says. "We aim to increase understanding of how to account for this risk, especially considering how dependent their economy is on oil prices. This helps ensure policymakers are making informed investments that will be beneficial in the long run."

Calculating a risk premium

To address the unique risks faced by oil-producing countries, the economists calculated a 'risk premium' for projects that impact domestic oil consumption or use oil as an input. Assuming the per-capita gross consumption growth would continue at its historical pace for these 18 countries, they determined the risk premium—the difference between the risk-free discount rate—for cash flows not correlated with gross consumption, and the risk-adjusted discount rate, for oil-related cash flows.

For each of the oil-dependent nations, ranging from OPEC and major oil-exporting countries, Karanfil and Pierru analyzed the economic uncertainty created by dependence on oil, including the volatility of oil prices.

"For all the countries we analyzed, except one small oil producer, we find that the risk premium is positive. This is not surprising, as higher oil prices lead to increased consumption of goods and services in the country," Karanfil explains.

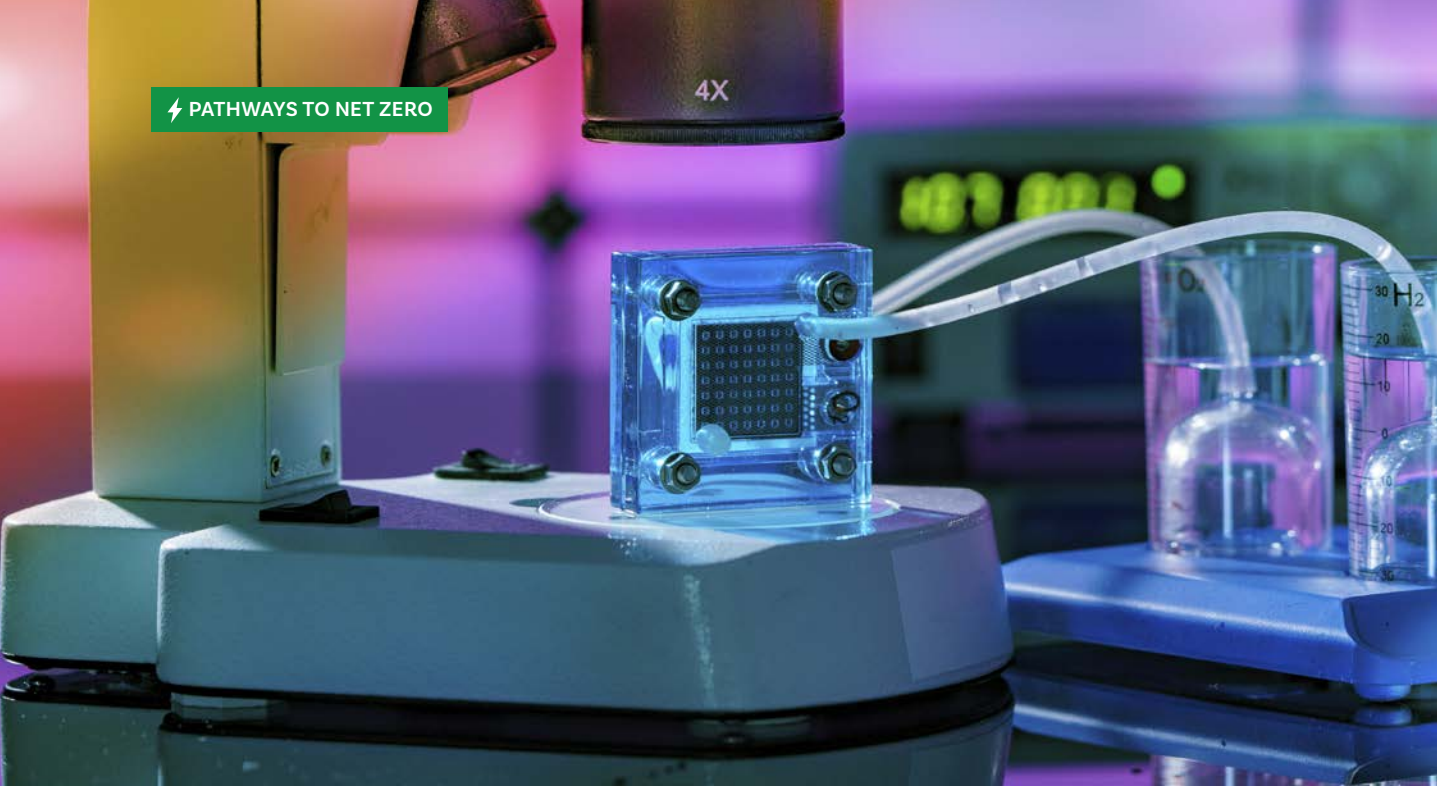
The average risk premium was 1.4%, according to the team's analysis. Qatar had the highest risk premium, followed by the United Arab Emirates, Chad, Russia and Kuwait. At the lower end were several African oil-dependent countries, including Algeria, Cameroon and Gabon. Sudan was the only country whose risk premium was negative.

These positive risk premiums offer a helpful resource for government officials and private entities looking to make sound economic decisions about which projects to invest in as the energy transition accelerates, Karanfil says. "A positive risk premium means a higher public discount rate. As a result, this premium acts like a safety buffer, ensuring that only projects truly worth the risk are undertaken."

The team also found that the more a country diversifies its exports, the higher the public discount rate. Most oil-exporting countries still only export a small number of other products, despite efforts by some, such as Saudi Arabia, to diversify their economies in recent years.

◀ Despite efforts to diversify their economies, most oil-exporting countries still only export a small number of other products.

● Karanfil, F; Pierru, A., Energy Transition in Oil-Dependent Economies Public Discount Rates for Investment Project Evaluation. KAPSARC discussion paper, 2024.



WLADIMIR BULGAR /SPL /GETTY IMAGES

▲ Potential uses for hydrogen include fuel cells for power generation.

The unexpected impact of mineral price shocks

Unanticipated changes in the price of critical minerals can have complex flow-on effects on the price of oil and lead to inflation.

The transition to renewable energy is heavily reliant on critical minerals, yet sudden increases in the price of these essential commodities can have significant impacts on inflation and oil prices, which can frustrate the transition to a sustainable economy.

A new study by economist Jennifer Considine and colleagues from the King Abdullah Petroleum Studies and Research Center (KAPSARC) sheds light on the complex interplay between critical minerals prices, oil prices, and inflation.

Using historical data going back to 1979, the researchers analyzed the relationships between these factors in 29 countries. They explored how price increases in critical minerals affect inflation and oil prices, and in turn how changing oil prices impact the price of critical minerals.

Critical minerals are those that are of strategic importance to technological development, particularly around renewable energy, and which are also at high risk of supply disruption. The list includes metals such as nickel and zinc, rare earth metals, and even radioactive elements and isotopes.

"It's one of the first empirical attempts to see whether an increase in critical mineral prices actually causes inflation, how these things relate to each other, and how critical minerals prices relate to oil prices," Considine says.

The team found that an increase in the price of critical minerals can lead to a significant increase in inflation in most countries. This was particularly evident in the UK, which not only had the highest share of renewables among the countries analyzed, but imports most of its critical minerals, making it vulnerable to price shocks.

In contrast, the increase in critical minerals prices had very little effect in China, which Considine attributes to the country's preparedness for changes in the critical minerals market. "They have been thinking about this for quite a long time, and they've put their supply chains in place with long-term contracts at lower prices," she explains.

Furthermore, the analysis also found that spikes in oil prices can lead to increases in critical minerals prices as well as inflation. "Critical mineral prices cannot respond quickly to price signals because it takes oil to mine them, and this can result in an increase in inflation," she says.

The analysis highlights pitfalls for nations looking to implement economic or trade policies, such as tariffs, that could cause the price of critical minerals to rise, she highlights. "Without a clear understanding of the industry dynamics, adopting policy tools can lead to unexpected or unwanted consequences."

● Considine, J.; Galkin, P.; Hatipoglu, E.; Aldayel, A.; The effects of a shock to critical minerals prices on the world oil price and inflation. *Energy Economics*, **127**: 106934, 2023.

Advancing the transition through energy efficiency

A novel analysis shows that enhancing energy efficiency could potentially reduce the Kingdom's carbon emissions by 20%.

Achieving net-zero emissions requires a multifaceted approach, and increasing energy efficiency is key. A study published in *Energy Economics* presents one of the first analyses of the potential contributions enhancing energy performance could make to help Saudi Arabia's quest for carbon-neutrality by 2060.

The study suggests that enhancing energy efficiency has the greatest impact on reducing emissions when it takes place in sectors with mid-range carbon intensities—the amount of carbon dioxide emitted per unit of economic output. Focusing on industries that fall within the middle 50% of carbon emissions, rather than those with the highest or lowest levels, can yield the most substantial results in terms of emissions reduction.

"Energy efficiency is one of the cheapest options to deal with climate issues and reducing emissions," says energy and environmental economist Fateh Belaid, from the King Abdullah Petroleum Studies and Research Center.

Belaid and colleagues first analyzed 50 years of data, from 1970 to 2020, to understand how energy efficiency and carbon intensity had changed in Saudi Arabia over those years, and the effect of these variations on carbon emissions. They were then able to model how changes in energy efficiency might affect carbon emissions in the future across a variety of carbon intensity levels, and what contribution this might make to Saudi Arabia's path to carbon neutrality.

Their study found that even with only moderate improvements in energy efficiency, Saudi Arabia might reduce its overall emissions by around one-fifth.

Belaid says certain sectors have greater potential for energy efficiency improvements than others. He highlights the building sector—the second-highest energy consumer in Saudi Arabia after industry—as a significant contributor to carbon emissions, accounting for 28% of energy consumption in Saudi Arabia.

"Building sector emissions are hard to abate because the renewal of the built environment is very low," he adds. However, there are numerous initiatives already underway in Saudi Arabia to reduce energy use in buildings, from retrofitting schools and government buildings and improving their energy efficiency, to environmental performance labels for insulation and white goods.

Despite energy efficiency efforts, Belaid says progress has been slowed by several factors. "There are technological challenges, but at the end of the day, it's the cost that's the main barrier," he explains. "The payback of energy efficiency solutions takes a minimum 10 to 15 years so people don't see the benefits."

- Belaïd, F.; Massié, C.; The viability of energy efficiency in facilitating Saudi Arabia's journey toward net-zero emissions. *Energy Economics* **124** (106765), 2022.

▼ Twisted tower, Burj Rafal, Riyadh Saudi Arabia

FIRAS ABBARA/ SHUTTERSTOCK.COM

A blueprint for a sustainable oil industry: Saudi Arabia's example

Through innovative technologies and strict regulations, Saudi Arabia is setting a new standard for the global oil industry, providing a blueprint for sustainable production with a much smaller methane footprint.

VINCE STREANO/ CORBIS DOCUMENTARY/ GETTY IMAGES

▶ Saudi Arabia has taken significant steps to reduce methane emissions, capturing natural gas released from oil fields and using it in part to generate electricity.

Decarbonized oil production may sound like an oxymoron, but Antoine Halff, senior researcher at the Center on Global Energy Policy at Columbia University and former chief oil analyst at the International Energy Agency, explains that it is indeed possible, and Saudi Arabia is leading the way by taking strict measures to prevent accidental methane leaks during oil extraction.

Methane is a far more potent greenhouse gas than carbon dioxide in the short term. It frequently leaks into the atmosphere in the course of extracting fossil fuels, including oil and gas. Saudi Aramco has taken significant steps to reduce methane emissions, capturing natural gas released from oil fields and using it in part to generate electricity.

Using novel satellite technology, Halff's analytics firm, Kayrros, worked with KAPSARC to peg the Kingdom's oil field methane emissions at 780 kilotons in 2022[1], only a quarter of what the International Energy Agency had estimated for the nation.

The findings put Saudi Arabia second only to Norway in terms of methane emitted during oil production. However, Saudi Arabia leads the way in avoiding flaring, the burning off of methane that releases carbon dioxide. As The Economist noted, Saudi Aramco has since 2012 "flared less than 1% of this potent planet-cooking compound, compared with perhaps 4% that America's shalemen set alight."

Clarifying the difference between flaring and venting, Halff explains, "Venting means releasing methane into the atmosphere. Flaring means burning the methane

and turning it into CO_2, which is a lesser evil in the short-term (but still a big problem in the longer term). Flaring also releases some methane, because flares are not fully efficient, but their main output is CO_2."

Halff notes that at COP21—the 2015 United Nations climate talks that yielded the Paris Agreement—"there was almost no discussion of methane, because while we were painfully aware of the problem of fast-rising methane concentrations in the atmosphere, we had very limited visibility on the precise sources of methane emissions.

Since then, Kayrros and KAPSARC have made great strides in the capacity to track methane, and have gained a much deeper understanding of where it comes from. "Saudi Arabia is unique among oil and gas producers, in terms of avoiding it," says Halff, explaining that this is "due in part to policies that actually were adopted by Saudi Arabia even before we could measure methane."

Other countries could emulate Saudi Arabia's practices, says Halff, attributing Aramco's low oil field methane emissions not to their rock formations, but rather to technology and standards.

"It's really a question of operating practices. If I had to speculate about the reason why Saudi Arabia is doing so well, I'd say it has the culture of operational excellence in general."

More ways to decarbonize

Another key strategy to decarbonize the oil industry is to reduce greenhouse gas emissions from petrochemicals. Electric vehicles alone present a massive and growing need for advanced plastics, which are produced from hydrocarbons, Halff notes.

"Saudi Arabia is very much at the forefront of developing advanced petrochemicals, and plastics," he notes. "The refineries in the system are very integrated with petrochemical facilities. The idea of capturing the value of oil as a material to transform into all kinds of sophisticated products is central to the country's economy."

"The idea of capturing the value of oil not only to burn for energy but as a material to transform into all kinds of sophisticated products is front and center in Saudi Arabia's economy."

Powering petrochemical processes with electricity produced from alternative sources instead of natural gas is one way to decarbonize the sector.

Saudi Arabia aims to produce half of its power through renewables by 2030, up from only about 3% today. The country has an abundance of sun and wind, but there are also challenges, including the sand and dust that coat solar panels during frequent windstorms.

"There's clearly a very ambitious effort to develop green energy not only for domestic use, but even for export," Halff says.

Capturing the green hydrogen opportunity

To power its own economy, Saudi Arabia is investing in renewable energy and blue hydrogen—fuel produced from natural gas, where the associated carbon emissions are captured and sequestered underground. While the practice is still in its early stages commercially worldwide, Saudi Arabia is creating a carbon sequestration hub at Jubail, on its east coast, that aims to store up to 9 million tons of carbon dioxide per year by 2027[3]. The country is also pioneering technology to extract carbon dioxide from the atmosphere and use or sequester it.

"How much of what's being undertaken in Saudi Arabia can be emulated and replicated elsewhere, and how much is very unique to Saudi Arabia's specific circumstances and unique asset base?" Halff asks.

Along with its copious oil reserves and technical know-how, Saudi Arabia's political structure and the ability to make executive decisions about how to manage its oil resource differs from many countries. But, Halff continues, "there are also a lot of things that can be emulated, in terms of methane abatement and low methane-intensity production. Saudi Arabia is in a position to lead the rest of the industry in showing how oil can be produced with a much smaller methane footprint and much more responsibly."

And even as the country invests heavily in renewables, oil will likely remain synonymous with Saudi Arabia.

"It's often said that if the world really weans itself from fossil fuels, there will always be residual oil consumption," says Halff. "Saudi Arabia is positioned to be the last man standing because of its reserves, its low production costs, its very good operating practices and its management of the resource. Few other countries can claim to be in the same position."

1. https://www.kapsarc.org/news/kapsarc-and-kayrros-unveil-saudi-arabias-methane-emission-landscape-using-satellite-technology/ and https://www.kapsarc.org/research/publications/using-satellite-technology-to-measure-greenhouse-gas-emissions-in-saudi-arabia/
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Antoine Halff
Co-founder and chief analyst at environmental intelligence company Kayrros and Adjunct Senior Research Scholar at the Center on Global Energy Policy, Columbia University.

Could geothermal boost Saudi Arabia's energy transition?

Investment in geothermal energy sources could boost renewable power generation, create jobs, and enhance technological advancement across Saudi Arabia.

▲ Geothermal energy could be key to overcoming challenges of water scarcity and heat waves in Saudi Arabia.

SHAIFULZAMRI/ MOMENT/ GETTY IMAGES

"Geothermal energy stands out as a potential asset for the country amid challenges of water scarcity and heat waves."

For decades, electricity generation in Saudi Arabia has relied predominantly on hydrocarbons. To meet its Vision 2030 energy transition targets, Saudi Arabia aims to displace one million barrels of liquid fuels per day of domestic consumption and increase the share of renewables to make up half of the country's power capacity by 2030.

While solar and wind power have received considerable attention and investment, there has been less focus on geothermal energy. This gap prompted KAPSARC researchers to examine the current status of geothermal energy in the Kingdom and the potential for expansion in this sector.

"Geothermal energy stands out as a potential asset for the country amid challenges of water scarcity and heat waves," says Mohammed Aldubyan at KAPSARC's Climate and Sustainability Department. "It could be used to power water desalination plants and achieve district cooling, an efficient way to air-condition public buildings by chilling water using ground source heat pumps." Aldubyan worked on the review with colleague, Majed Alsuwailem, at KAPSARC's Oil and Gas Department, and Osamah Al-Momen at energy technology company Baker Hughes.

"Recent pilot projects, like the geothermal exploration well at KAUST, assess the potential of this source and technology applications for cooling and electricity generation," adds Alsuwailem.

The western part of Saudi Arabia, characterized by tectonic and volcanic activities, presents opportunities for geothermal energy due to high heat flow from the Earth's depths. Tapping into this heat energy is challenging, due to high upfront costs, technical limitations, as well as limited supportive policies and regulations hampering advances. However, the team believes that Saudi Arabia is well placed to harness geothermal energy using the expertise of the extensive oil and gas exploration workforce alongside the existing energy infrastructure across the country.

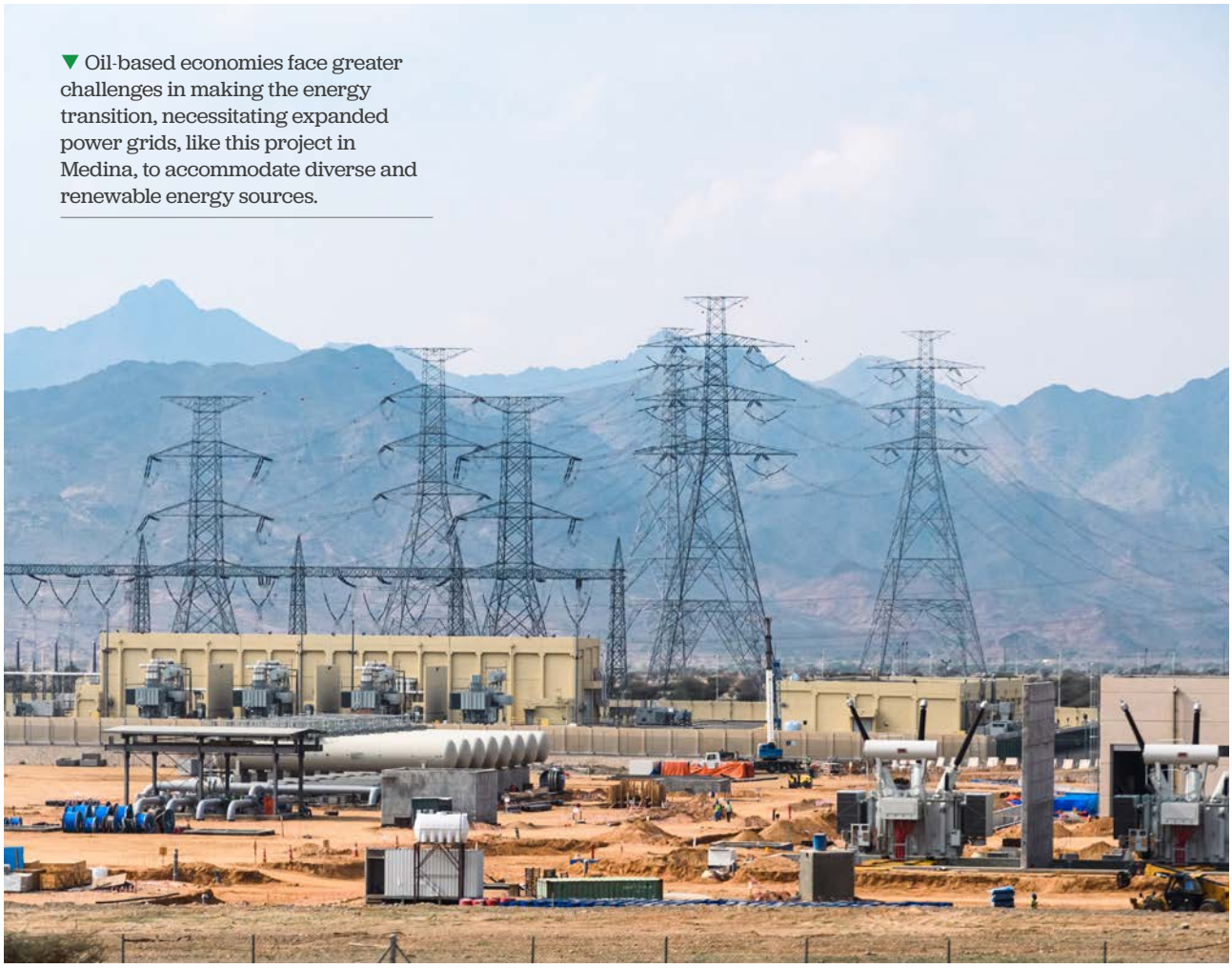
"About half of all electricity used in buildings goes toward cooling, and geothermal energy could significantly reduce this consumption," says Al-Momen, regional senior manager for Strategy and Market Studies at Baker Hughes. "Reducing the share of hydrocarbons in Saudi Arabia's energy mix will avail more crude oil and other liquids for other uses, including refined products and chemicals."

Investing in geothermal will also create jobs, attract investment, and promote advancement in energy technologies and expertise. "Fostering both competition and collaboration promotes innovation by driving technological advancements and efficiency," says Aldubyan. "Collaboration among stakeholders lowers risks and costs in geothermal development and encourages a dynamic and competitive energy market."

- Alsuwailem, M.; Aldubyan, M. & Al-Momen, O. Geothermal – Saudi Arabia's next energy vector? KAPSARC, April 15, 2024.

Understanding electricity demand in Saudi Arabia's government sector

A look at how income, electricity prices, and weather conditions can determine regional consumption patterns.



▼ Oil-based economies face greater challenges in making the energy transition, necessitating expanded power grids, like this project in Medina, to accommodate diverse and renewable energy sources.

DOF / ISTOCK / GETTY IMAGES PLUS

The evolution of electricity prices over the last 40 years

Pre-1984
Different regions in Saudi Arabia use different electricity pricing structures.

November 1984
KSA government introduces nationally consistent tariffs that differentiate industrial and non-industrial sectors.

1985
Tariffs are adjusted for residential, commercial, and government sectors.

1992-2000
Government continues to revise tariffs.

2016
Government adopts new pricing reforms to reduce electricity consumption across the nation, with government customers usually facing higher rates compared to others. Price for the government sector is fixed at 0.32 Saudi riyals per kilowatt-hour.

2016
In tandem, KSA introduces subsidies and incentives that encourage energy efficiency and the use of renewable sources.

2004
Government sector electricity prices in Saudi Arabia are regulated by the Electricity and Cogeneration Regulatory Authority (ECRA). Price continues to be fixed at 0.32 Saudi riyals per kilowatt-hour.

The government sector significantly influences Saudi Arabia's energy demand, playing a crucial role in the country's efforts to achieve a sustainable energy transition, diversify its energy mix, and reduce reliance on fossil fuels—outlined in Saudi's Vision 2030[1]. Previously, KAPSARC has looked into the Kingdom's total electricity consumption for residential, commercial, and industrial sectors,[2,3,4] However, a key gap has been the analysis of regional data for the government sector.

To address the lack of information, KAPSARC research fellow Jeyhun I. Mikayilov and researcher Information Management Lead Abeer Al Ghamdi produced 'Impacts of Regional Electricity Demand in Saudi Arabia. A Study of the Government Sector.' The study[5] aims to investigate the factors influencing electricity demand across the central, eastern, southern, and western regions, taking into consideration income, climate, and regional development characteristics.

"Recognizing regional variations in government electricity consumption offers crucial insights into the effectiveness of energy policies and helps craft targeted strategies to enhance energy efficiency, conservation, and sustainable practices across the country," say Mikayilov and Al Ghamdi.

"Recognizing regional variations in government electricity consumption offers crucial insights into the effectiveness of energy policies and helps craft targeted strategies to enhance energy efficiency, conservation, and sustainable practices across the country."

The study looks at how government electricity use is influenced by income, electricity prices, and weather conditions. It includes data from the Saudi Arabia Electricity Corporation (SEC) from 1990-2004, and from the Saudi Arabian Monetary Authority (SAMA) from 2005-2021.

Between 2017 and 2022, the government sector in Saudi Arabia accounted for 13% of the Kingdom's total electricity consumption. A significant portion (83%) of this electricity use is allocated to air-conditioning, ventilation, heating, lighting, and refrigeration systems.6 The country's central region, which hosts numerous government institutions, stands out as the highest electricity consumer in this sector.

Mapping the Kingdom's electricity use

Income was shown to play a significant role in the government sector's electricity demand. Generally, higher income corresponds to higher electricity consumption. However, changes in income have a smaller impact on electricity demand in the more established eastern and central regions of the country. This suggests that as areas grow economically, the increase in energy use eventually reaches a saturation point and levels off.

Using estimated customer and region-specific electricity demand models, the study also calculated how sensitive each region is to changes in income and electricity prices. Overall, the southern region is the most responsive to changes

How a 1% increase in income and electricity prices might affect each region

CENTRAL REGION

1% Income Increase → **0.51%** Electricity Demand Increase

1% Electricity Price Rise → **0.27%** Electricity Demand Decrease

EASTERN REGION

1% Income Increase → **0.41%** Electricity Demand Increase

1% Electricity Price Rise → **0.19%** Electricity Demand Decrease

SOUTHERN REGION

1% Income Increase → **1.10%** Electricity Demand Increase

1% Electricity Price Rise → **0.23%** Electricity Demand Decrease

WESTERN REGION

1% Income Increase → **0.89%** Electricity Demand Increase

1% Electricity Price Rise → **0.33%** Electricity Demand Decrease

in income, while the western region demonstrates the highest responsiveness to price changes across regions. These results align with the development levels of the regions, and support previous findings published in 2023 by KAPSARC's Mikayilov and his colleague Abdulelah Darandary.[3]

Toward energy efficiency

Hot weather conditions increase government electricity consumption, especially in the central region as higher temperatures lead to greater electricity usage, likely due to air conditioners in public facilities. Riyadh alone accounted for about 36% in 2021, making the capital the highest electricity consumer in the government sector.

"To support efficient energy use, the Saudi government established the National Energy Service Company, which aims to retrofit 110,000 government buildings and 35,000 public schools for energy efficiency. This activity is now in progress and it would be interesting to repeat our study after the completion of this big effort," the authors explain.

Finally, education and awareness programs that encourage government employees to be more mindful of their energy consumption behaviors are recommended to help foster a culture of energy responsibility within the government sector.

1. Saudi Vision. 2030. https://www.vision2030.gov.sa/thekingdom/explore/energy/.

2. Gasim, A. A., Agnolucci, P., Ekins, P. and De Lipsis, V., Modeling final energy demand and the impacts of energy price reform in Saudi Arabia. *Energy Economics*, **120**, 106589, 2023.

3. Mikayilov, J.I. and Darandary, A., Modeling and projecting regional electricity demand for Saudi Arabia. 2023.

4. Hasanov, F.J., Joutz, F.L., Mikayilov, J.I. and Javid, M., KGEMM: A macroeconometric model for Saudi Arabia. 2022.

5. Mikayilov, J.I. and Al Ghamdi, A., Impacts of regional electricity demand in Saudi Arabia: A Study of the government sector. 2024

6. Damoom, M. M., Hashim, S., Aljohani, M. S. and Saleh, M. A. Adding sustainable sources to the Saudi Arabian electricity sector. *The Electricity Journal* **31** (4), 20-28, 2018

▼ KSA is promoting efficient energy use across its government sector.

NANDO VIDAL/ ISTOCK / GETTY IMAGES PLUS

The startups shaping the energy landscape

Startup trends offer insights that could boost green tech development and use.

JOHNNYGREIG/ E+/ GETTY IMAGES

Innovative technologies will be crucial as the world transitions to a sustainable future, but which technologies will lead the way? A study that identifies innovation trends among electricity startups could help policymakers anticipate upcoming innovation trajectories and cultivate a regulatory environment conducive to innovation, accelerating the shift.

"Innovations that are emerging from startups now will define the landscape of the industry in the next 8-10 years," says Rolando Fuentes, formerly a senior economist at KAPSARC, and now at Tecnológico de Monterrey in Mexico.

Analyzing 320 electricity startups across 36 countries in collaboration with KAPSARC researchers, Dongmei Chen and Frank Felder, Fuentes found that a large proportion of startups placed a clear focus on decarbonization. Among decarbonization startups—which accounted for more than 40% of the firms examined in the study—an overwhelming number pursued innovations to photovoltaic (PV) technology to generate power from solar energy.

Startups were innovating in various areas, including more resilient, lighter, and efficient materials, as well as enhancing installation and maintenance processes. Fuentes believes the abundance of startups working on carbon-reducing technologies reflects a strong alignment with global sustainability goals.

Innovations in digitization technology were the second most common among electricity startups. Artificial intelligence was a common area of development, with startups using AI technologies to optimize operations and improve efficiency, by balancing the grid, for example. Additionally, many of them were working on data mining, blockchain technologies, and digital platforms that connect electricity sellers and buyers. These will ultimately reshape how electricity is generated, distributed, and consumed globally, Fuentes says.

"While digitalization is widely recognized as important, the degree to which it can animate markets and reduce barriers to participation may be more pronounced than previously understood, suggesting a transformative potential that could significantly alter industry dynamics," Fuentes explains.

And while some startups focused on electricity storage, such as improving battery life and charging speed, the innovations were incremental rather than revolutionary. "This contrasts with the expectation that storage solutions would lead to significant breakthroughs in energy management and distribution," Fuentes says.

The analysis also revealed that startups, most notably in PV technology, were striving to innovate in the confines of existing business models and regulatory frameworks rather than seeking disruptive transformation. This does not align with the typical narrative of startups as agents of radical change, according to Fuentes.

"The regulatory environment significantly impacts the business models that startups can pursue. Well-designed regulations can enhance innovation, while restrictive regulations may hinder the development of new technologies," he explains. "By responding strategically to these trends, policymakers and business leaders can drive the transition to a sustainable energy future, fostering economic growth and environmental sustainability."

- Fuentes, R.; Chen, D.; Felder, F.A., Systematically mapping innovations in electricity using startups: A comprehensive database analysis. *Technology in Society*, **74**, 102282, 2023.

DECARBONIZATION MAKES WAVES IN MARITIME SHIPPING

Progress toward a low-emission global maritime shipping sector requires a concerted effort.

▶ Cargo ships and dry docks at Jeddah port.

As countries around the world tackle their own greenhouse gas emissions, the maritime shipping sector requires collective, concerted, and cooperative action by all nations to reach net-zero carbon emissions.

The complexity and expense of this goal are vast and an equitable sharing of responsibilities and costs should not disproportionately burden developing countries, according to KAPSARC researcher Rubal Dua, whose team is exploring ways to address this challenge.

"The work of our group is essentially to identify and prioritize the questions that can lead to impactful, policy-relevant research," says Dua.

Looking at maritime shipping decarbonization, Dua—with colleagues AHM Mehbub Anwar, Kannan Govindan, and Prateek Bansal—began by analyzing media reports on relevant topics, then reviewed academic literature, and finally conducted an expert-based prioritization by diverse delegates at the Transportation Research Board (TRB) 2024 conference in Washington, DC.

"Media discourse often does not get the credit it deserves in the scholarly world," says Dua. "Media reports frequently highlight emerging economic, policy, and sustainability issues before they are thoroughly investigated in academic literature. They also include perspectives from non-academic stakeholders, which are often underrepresented in scholarly work."

To vet and validate media reports, the issues raised were translated into techno-economic and policy research challenges that were then researched through a literature review to determine their real impact on achieving net-zero maritime shipping.

With this set of validated challenges, which includes alternative

fuels, carbon offsets and a carbon levy, the researchers engaged in live expert polling as part of a presentation on maritime shipping decarbonization at the TRB conference. The presentation drew a diverse crowd including maritime researchers, policymakers, industry practitioners, and representatives from government and academia.

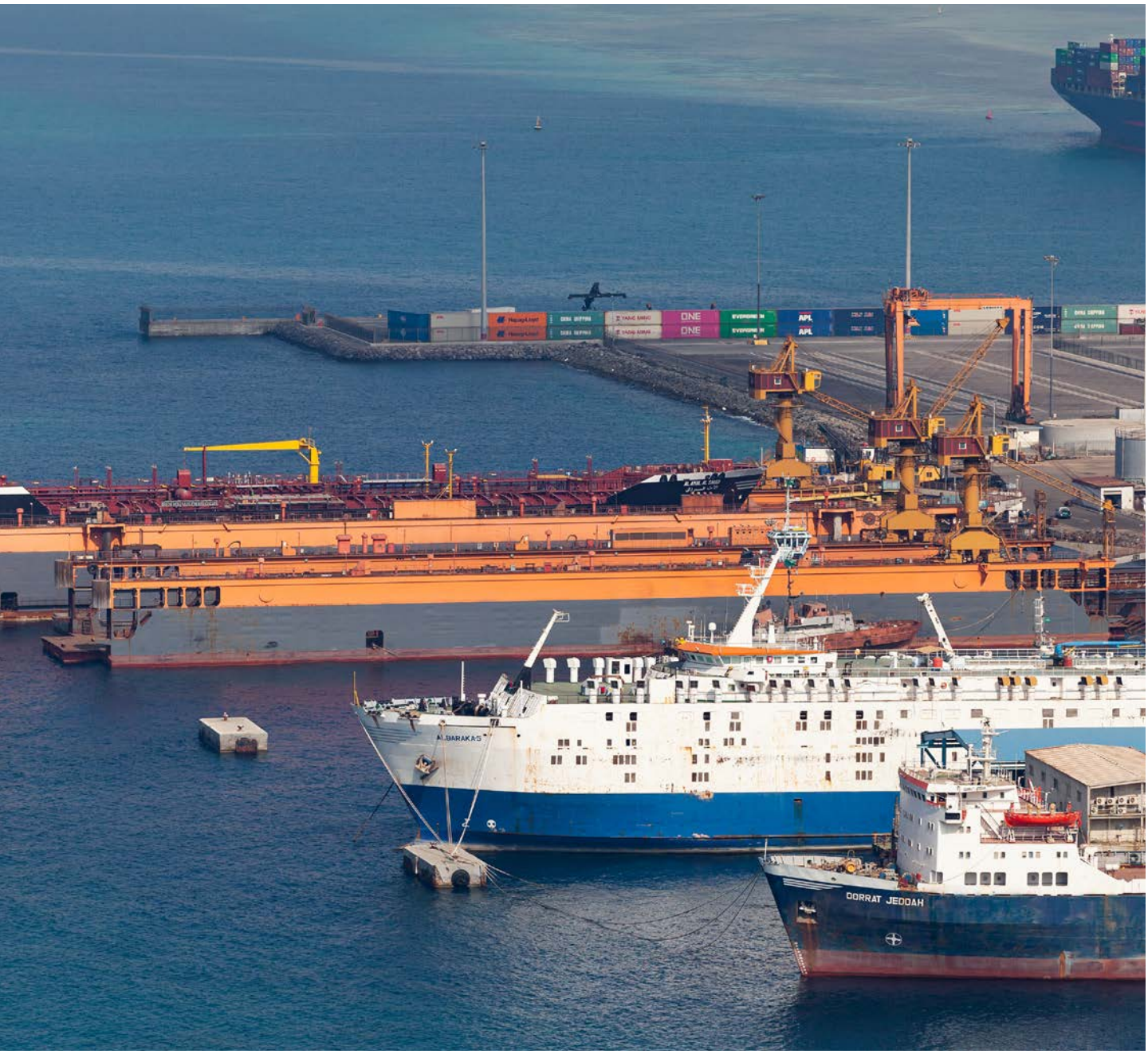
"The study, including the outcomes of the expert polling, highlights the crucial need for more in-depth research on how to fairly split responsibilities between developed and developing nations to reach net-zero greenhouse gas emissions in maritime shipping," says Dua.

"Media reports frequently highlight emerging economic, policy, and sustainability issues before they are thoroughly investigated in academic literature."

"The fairness debate is also about how we manage a potential shipping carbon levy, which might raise the prices of shipped goods and impact developing countries the hardest."

Current discourse suggests revenue raised by a shipping carbon levy be used to fund climate projects in developing countries, or that certain countries could be exempted from the levy altogether. "However developing countries are hesitant—many past promises of climate finance from developed nations have not been kept, making them wary of new commitments," Dua says.

- Dua, R. and Anwar, AHM M. Expert survey assessment of emerging maritime decarbonization challenges and priorities.



EUGENESERGEEV/ ISTOCK EDITORIAL / GETTY IMAGES PLUS

PATHWAYS TO NET ZERO

Decoding Saudi Arabia's commercial energy demands

Regional differences in energy demand across the Kingdom offer insights for tailored energy policies and infrastructure planning.

JEREMY SUYKER/BLOOMBERG VIA GETTY IMAGES

▲ Shoppers at Riyadh Park shopping mall in Riyadh, Saudi Arabia.

Significant regional variations in commercial electricity demand across Saudi Arabia have been identified and these patterns offer valuable insights for the Kingdom's policymakers and energy planners.

A KAPSARC study analyzed commercial electricity consumption patterns in Saudi Arabia's central, eastern, southern, and western regions from 1990 to 2021. The findings by researchers Jeyhun Mikayilov and Abdulelah Darandary demonstrate that regional economic development levels and commercial sector concentration strongly influence how electricity demand responds to changes in income and prices.

The southern region showed the highest income sensitivity, with a 1% increase in income, which led to a 3% rise in commercial electricity demand. This contrasts sharply with the more industrialized eastern region, which had the lowest income elasticity at 0.5%.

Price responsiveness also varied significantly across regions, with differences reflecting varying maturity and stability of commercial sectors. Commercial consumers in the western region were found to be most sensitive to price changes, with a 10% price increase resulting in a 12.5% demand decrease. Conversely, the eastern region was least responsive, with only a 1.8% demand reduction for the same price increase.

Assessing the impact of external shocks

The researchers employed advanced analytical techniques to capture the complex dynamics of electricity demand and to describe how external shocks, such as the COVID-19 pandemic and energy price reforms, impact commercial electricity consumption across different regions. This analysis provides valuable insights into the resilience and adaptability of regional commercial sectors in the face of significant economic disruptions.

"Our research underscores how important it is to recognize regional variations in commercial electricity consumption," says Darandary, emphasizing the significance of her team's findings for policy-makers. "By considering the unique social and economic characteristics of each region, policymakers can craft more targeted energy policies that drive efficiency and sustainability, ensuring that national energy policies have the desired impact across diverse regions."

As Saudi Arabia pursues its Vision 2030 goals of economic diversification and energy efficiency, KAPSARC's research provides insights to support evidence-based policy-making. By highlighting regional differences in commercial electricity demand, the study contributes to more effective energy management strategies that help to balance economic growth with sustainable resource use across the Kingdom, supporting its transition to a knowledge-based economy.

● Mikayilov, J.I. and Darandary, A. Commercial electricity demand modeling: Do regional differences matter for Saudi Arabia? *Energy Rep.* **10**, 2826–2836 (2023).

Futures

"By including uncertainty in the analysis, I would like to see what policy may help the Kingdom hedge against the risk that some technologies are more costly or take longer to deploy than expected."

OLIVIER DURAND-LASSERVE

BILL LYONS / ALAMY STOCK PHOTO

Shifting electricity use between seasons could save money and energy

Load shifting from peak summer months to low-demand winter also boosts export potential.

In Saudi Arabia's scorching summers, electricity use can be double what is consumed in winter. A KAPSARC study suggests that shifting a portion of industrial electricity use from summer to winter could bring significant financial savings and improve revenue from exports1.

The Kingdom's electricity use has grown 3.3% annually in the past decade. Managing demand growth could relieve the need to expand on generation, transmission, and distribution infrastructure, while still allowing for economic growth. The costs of electricity generation vary widely over seasons, with demand in summer being met with expensive liquid fuels to compensate for additional use. Power supply in winter months, on the other hand, runs on cheaper natural gas and requires the operation of fewer power plants.

Benefits of load shifting

One way to adjust demand is load shifting, in which industries transfer some of their electricity use from peak to off-peak times. The team simulated the effects of load shifting across seasons in four major energy-intensive industries in Saudi Arabia: aluminium, chemicals, cement and steel.

They found that shifting at least 15% of usage from peak to off-peak seasons could yield significant savings and reduce the need for oil and gas in power generation, freeing them for export. "There's some real money that could be saved through managing industrial electricity demand in Saudi Arabia," says Frank Felder, a visiting researcher at KAPSARC and a co-author of the study.

The high cost of electricity generation using crude oil makes load shifting an attractive option, with potential annual savings of up to $17.7 million at current fuel prices. Even greater savings of $239.4 million are projected when considering the opportunity cost of exporting the saved fuel at global prices, which is higher than the domestic subsidized price. This amounts to 8.1% of the total annual fuel cost for generating electricity. Shifting electricity use to winter could also lead to a reduction in carbon dioxide emissions of 584,000 tons per year.

Demand side management—where utilities encourage customers to modify their level and pattern of energy consumption to reduce peak demand by shifting their usage to off-peak times—is another strategy to enhance the overall efficiency and reliability of the grid. "Demand side management, if implemented efficiently, creates a win-win situation for the industry and the utility," says Amro Elshurafa, Executive Director of the Utilities and Renewables Department at KAPSARC and co-author of the study.

Optimizing energy usage

Piloting load shifting in a real-world setting is an important next step, the study suggests. The implementation depends on factors like labor, storage, and customer requirements, which vary by industry. For example, a cement facility producing large loads of cement and chemicals must consider the effect on the workforce when shifting production. This then affects when products can be delivered to clients. The facility may also require additional storage for surplus produced during off-season.

"Optimizing energy usage is an important part of the Kingdom's energy future, alongside introducing new technologies, increasing renewables, and interconnecting electricity trade within the Gulf Cooperation Council and Middle East/North Africa regions," says Felder.

● Soummane, S.; Elshurafa, A.M.; Alatawi, H. and Felder, F.A., Modeling cross-seasonal fuel savings from load shifting in the Saudi industrial sector and interlinkages to export revenues. *Energy Strategy Reviews* **47**, 101093, 2023.

Cost-effective methods of decarbonizing LNG

The Middle East could lead the way in decarbonizing the production of liquefied natural gas using carbon capture and storage technologies.

In 2019, the global gas market saw a groundbreaking new product: carbon-neutral liquefied natural gas (LNG). It was marketed as environmentally friendly, with carbon offset schemes used to compensate for emissions created during production, delivery and sometimes consumption. However, by 2022, the buzz around carbon-neutral LNG had faded after being heavily criticized by the media and stakeholders as a form of greenwashing.

Now, in an attempt to provide consumers with a transparent assessment, KAPSARC's Zlata Sergeeva and Colin Ward conducted an in-depth analysis of the costs and potential effectiveness of carbon capture, utilization and storage (CCUS) technologies for decarbonizing LNG.

"In recent years, we've seen various carbon neutrality pledges coming from industry participants, but these are not always supported by real decarbonization measures," says Sergeeva. "Understanding how companies can contribute to actual decarbonization and its associated costs is vital."

While carbon-neutral LNG deliveries have continued into 2024, these have not been officially announced by the companies or consumers involved. This lack of transparency creates issues with trust. Sergeeva and Ward suggest the best way for LNG producers to regain trust is to introduce transparent industry-wide emissions measurements and demonstrate their investment in real decarbonization technologies.

"Implementing measures such as CCUS is highly capital-intensive. Energy producers need guarantees that the demand for decarbonized hydrocarbons will remain for long enough to recover their investment," says Ward.

To assess the feasibility and cost of CCUS in LNG decarbonization, the team analyzed data from five key exporting countries: Algeria, Australia, Russia, Qatar and the United States.

Their analysis revealed that exploration, production and liquefaction, collectively known as the upstream phase, account for 21% of total emissions. Given that this upstream step often occurs at a single production site, implementing CCUS technologies there would be considerably more cost-effective than at other points in the supply chain.

"Deploying CCUS in certain countries, including the Middle East, will likely cost 50% less than in other countries due to differences in taxes, regulations, electricity and labor costs," says Sergeeva. "Existing infrastructure and labor skill sets can be leveraged, together with cross-industrial collaboration."

"Considering Qatar is already a major LNG provider, and several other Gulf Cooperation Council nations are planning on increasing their production, this study highlights that carbon-neutral LNG and CCUS could be a good market niche for new players in the Middle East to focus on," concludes Ward.

● Sergeeva, Z. & Ward, C. Carbon capture, utilization and storage (CCUS): Solutions to decarbonize LNG: Where, why and how much? KAPSARC Publication (2024)

▼ A ship carrying liquified natural gas docked in the Calcasieu River, Louisiana.

JON SHAPLEY/HOUSTON CHRONICLE/ HEARST NEWSPAPERS VIA GETTY IMAGES

Sensors in the sky: Satellite technology is a promising tool to measure emissions

A recent study explores how new satellite technology can measure methane emissions and help explain the highly divergent estimates for Saudi Arabia.

Every day, thousands of satellites pass through the sky over Saudi Arabia and most countries. The global number of satellites in orbit has surged from just over 2,000 in 2019 to almost 10,000 in mid-2024. Among these are dozens of satellites equipped with sensors capable of detecting sunlight scattered back to space by Earth's surface and atmosphere.

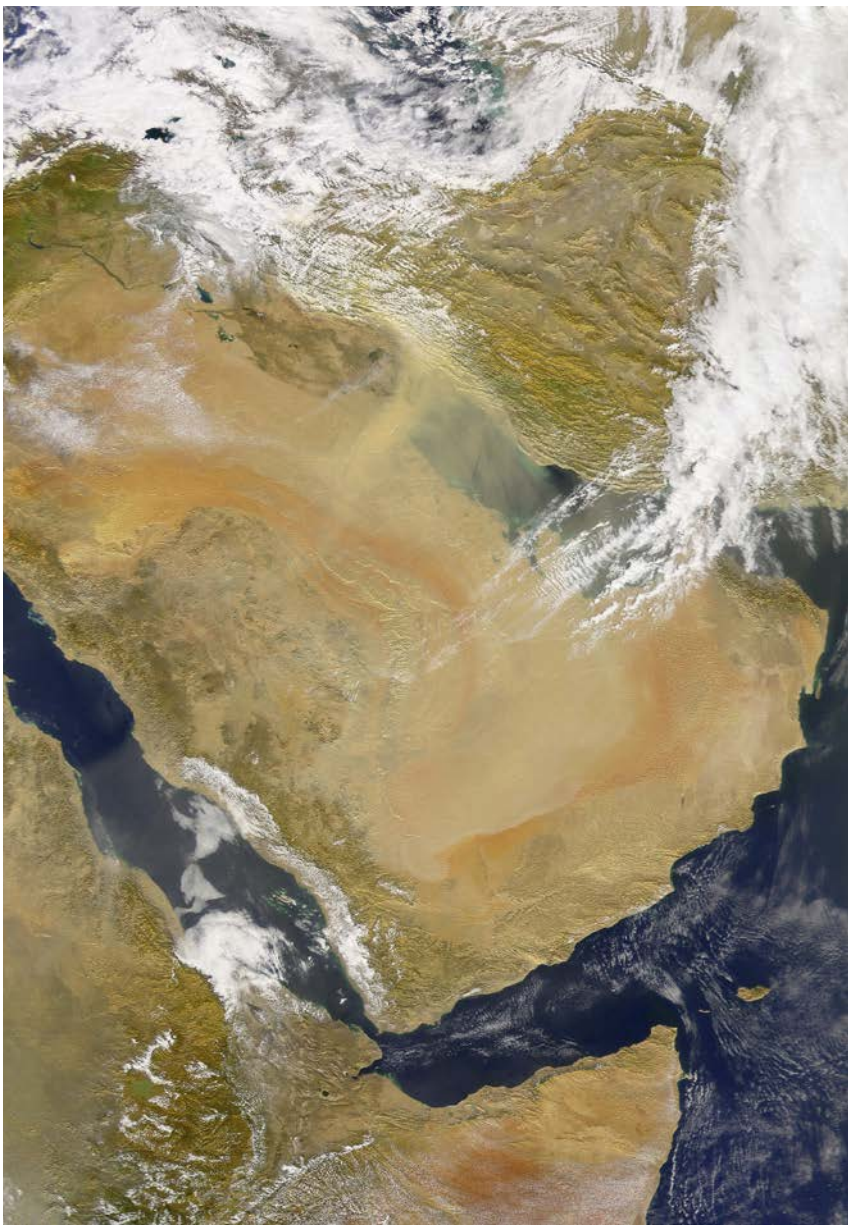
"Satellite-borne sensors can detect the unique spectral signature of methane emissions generated from a facility or urban area," says Abdel Rahman Muhsen, director of GIS Solutions at Saudi Arabia's King Abdullah Petroleum Studies and Research Center (KAPSARC). "These satellites pass over Saudi Arabia every day, and so can provide transparent and near-real-time measurements of methane emissions in a non-intrusive and cost-effective way, even for sites that are remote or difficult to access."

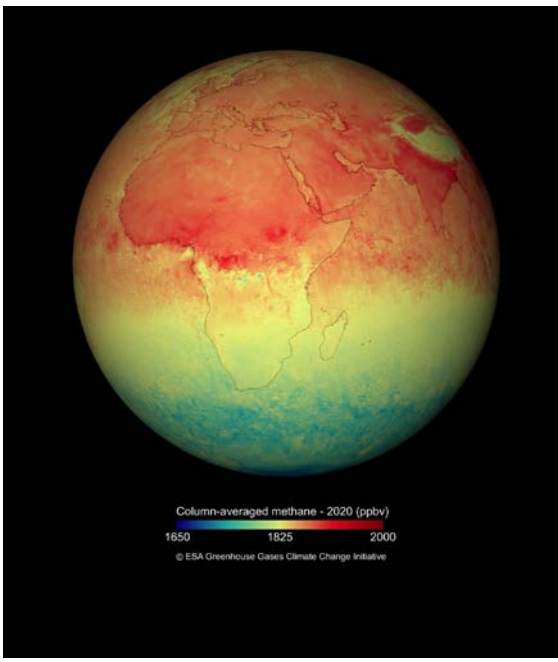
One of the core goals of the 2015 Paris Agreement is achieving year-on-year reductions in emissions of greenhouse gases (GHGs), such as CO_2 and methane. While direct measures like lowering industrial emissions and expanding systainable power generation can be implemented at the source, it has proven challenging to measure the overall emissions accurately at the country scale to gauge progress. With all countries required to submit detailed national inventories of GHGs under guidelines developed by the Intergovernmental Panel on Climate Change, finding ways to estimate emissions that all nations, including less developed ones, can achieve has become increasingly crucial.

"Estimating methane emissions is particularly challenging, which has led to wildly diverging emission estimates," says Anwar Gasim, a climate and sustainability researcher from KAPSARC. "Without good information on the level of GHG emissions, decision-makers cannot take effective action to meet climate goals," says Gasim, whose team has been working on a study into whether new satellite technology can be used to measure methane emissions and help explain the highly divergent estimates for Saudi Arabia.

From calculations to observations

Most countries and organizations estimate emissions using an activity-based method, where aggregate data, such as gasoline consumption,





▲ Data from the Copernicus Sentinel-5P satellite shows global methane concentration in the atmosphere in 2020.

◀ Dust and smoke over the Middle East.

ESA / CCI GREENHOUSE GASES PROJECT/ MODIFIED COPERNICUS SENTINEL DATA 2020 - STOCKTREK IMAGES/ GETTY IMAGES

is used to calculate emissions estimates based on a standard emission factor. For example, the standard factor used for gasoline is 2.3 kilograms of CO_2 produced per liter of gasoline burned. While not perfect, such calculations are backed by a lot of research and due to the similarity of gasoline combustion characteristics across uses, the potential error range in the estimate is minimal.

However, for more variable sources, such as waste and oil and gas production, emission factors can vary widely and no standard factor will fit every country, industry, or even specific locations.

"In the case of methane emissions from oil and gas production, factors can diverge drastically from country to country or even facility to facility, and using incorrect emission factors can lead to very large differences in emission estimates, which is what we have seen for Saudi Arabia," says Walid Matar from the KAPSARC research team.

Given that methane has 28 times the greenhouse-causing potential of CO_2, these differences are significant and crucial when determining the best strategies to tackle emissions at the source. For Saudi Arabia, for instance, calculated emission estimates from oil and gas are anywhere from as high as 3 million tons to as low as low as 0.4 million tons per year. Without precise data on where, when, and how much of these emissions are produced, an accurate count cannot be confirmed.

"Most countries are currently using the 2006 IPCC guidelines to estimate and report their emissions. It was updated in 2019, but still relies on the activity-based method," says Gasim. "Since 2019, satellite technology has developed significantly as a promising remote-sensing method with the potential to provide accurate emission data on a weekly or even daily basis."

KAPSARC's study used publicly available data from the Copernicus Sentinel-5P satellite launched by the European Space Agency in 2017, which captures a full global map of emissions every day, the Sentinel-2, and NASA's EMIT sensor onboard the International Space Station. The latter can provide emission estimates at resolutions as small as 20

meters on the ground, but pass over the area of interest less frequently, from every few days to once a week.

Getting clarity on methane emissions

By combining data from these different satellites, the researchers were able to better understand the pattern of methane emissions from different sources and areas in Saudi Arabia between 2019 and 2022. This involved extracting gaseous plumes detected by the satellite-borne methane sensors from the satellite images of areas of interest, and converting the plume images into quantifiable methane amounts. Emissions in the intervals between satellite passes were interpolated, while emissions for other known sources were extrapolated based on similarity with observed source areas.

The results paint a different picture of methane emissions than estimated by any of the previous activity-based methods, and highlight the inconsistency of their calculations.

While the International Energy Agency and the European Commission's Emissions Database for Global Atmospheric Research calculated methane emissions from oil and gas to be around 3 million tons per year and making up around two-thirds of the country's methane emissions,

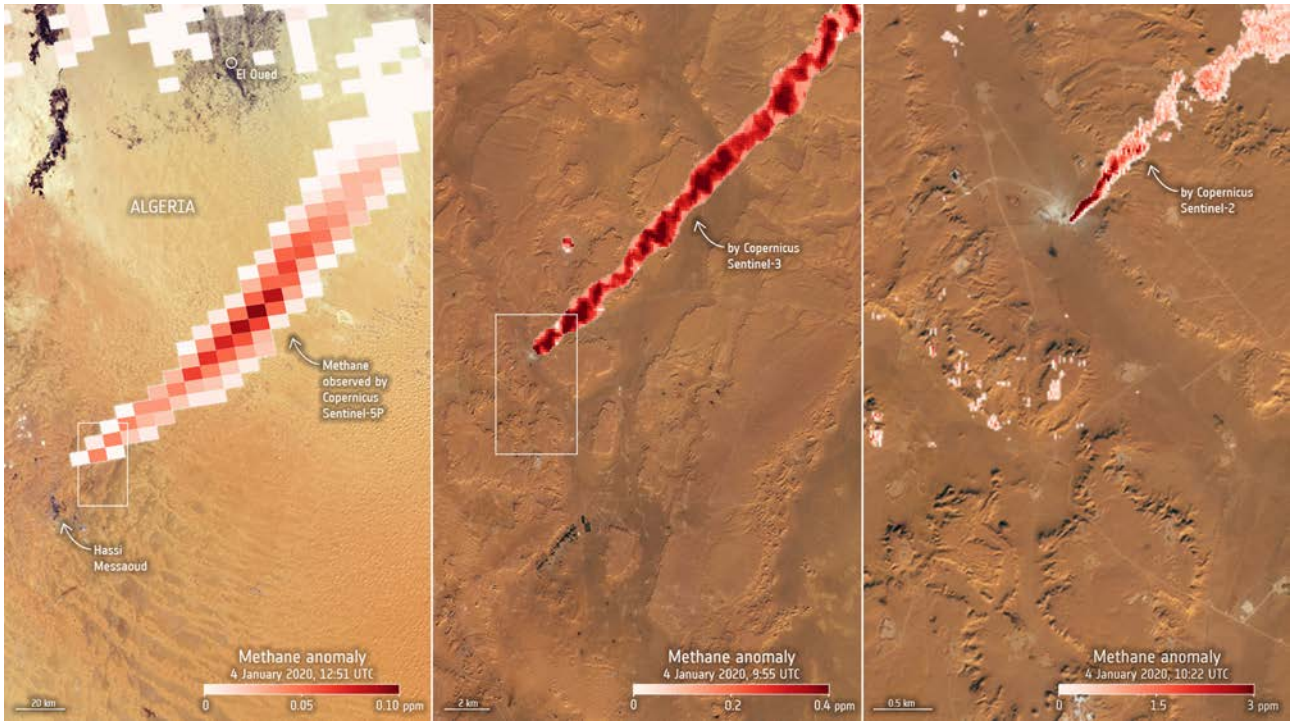
"Satellite technology will greatly increase the accuracy of methane emission estimates for many countries using publicly available data, which will help inform policymakers to design more effective policies and take more effective actions, meeting global climate and sustainability goals."

KAPSARC's satellite-based calculations estimate oil and gas emission to be less than 1 million tons per year and comprise about a quarter of total methane emissions. The findings show that urban, waste, and agricultural industries remain the major contributors to methane emissions and must be addressed in any emissions reduction strategy.

"The IPCC guidelines mention satellites as an early-stage technology with potential for measuring emissions, but satellite technology has progressed so quickly that is now a promising solution that offers high levels of data transparency and the ability for near-real-time emissions measurements," says Gasim. "Satellite technology will greatly increase the accuracy of methane emission estimates for many countries using publicly available data, which will help inform policymakers to design more effective policies and take more effective actions, meeting global climate and sustainability goals."

● Gasim, A., Matar, W. and Muhsen, A. Using satellite technology to measure greenhouse gas emissions in Saudi Arabia. KAPSARC Discussion Paper. November 2023.

▼ Tiered satellite observation of a methane leak in Algeria identified a continuous methane emission from a leaking facility for six days. The methane plume, detected by Sentinel-5P over Algeria on 4 January 2020, extended for more than 200 km northeast.



SRON/JPL/MODIFIED COPERNICUS SENTINEL DATA (2020)/ ESA

INSIDE THE GRID OF THE FUTURE

A new integrated assessment modelling study highlights the importance of strategic planning and investment in transforming Saudi Arabia's electricity grid.

A new study by the King Abdullah Petroleum Studies and Research Center (KAPSARC) maps out a trajectory to transform Saudi Arabia's electricity sector in line with the Kingdom's pledge to switch to renewables and reduce its reliance on fossil fuels[1].

The effort is part of Saudi Arabia's Vision 2030—a government diversification program and roadmap that aims to transform Saudi's economy and reduce the Kingdom's carbon footprint. In 2021, the government pledged more than $180 billion to reach net-zero emissions by 2060[2].

A critical component of this vision is decarbonizing the power system. "The electricity sector has to be the first sector to decarbonize. It is the lowest-hanging fruit for the Kingdom [and] the easiest emissions to remove from the economy," says Puneet Kamboj, the study's first author and a lead at KAPSARC's Climate and Sustainability department.

The Saudi government aims to reach 50% renewable energy capacity by 2030 by decommissioning liquid fuel power plants and transitioning to a mix of renewable energy and natural gas. However, this transition requires significant investments to upgrade the electric grid infrastructure, and address the intermittency of renewable energy sources as well as issues related to energy storage and grid stability.

Kamboj and his colleagues drew up a net-zero-emissions scenario for scaling up electricity generation requirements and grid capacity during the next few decades, "purely from an economic perspective," as Kamboj describes it, considering capital investment as well as fuel, operational and maintenance costs. The researchers break down the possible long-term implications for Saudi's electricity sector in trying to reach net zero while adjusting to rising demand for electricity as the country electrifies various sectors.

4KODIAK/ E+/ GETTY IMAGES

"We are trying to establish what hitting net zero by 2060 would entail," explains co-author Mohamad Hejazi, executive director for the Climate and Sustainability department at KAPSARC and the lead for the KAPSARC Climate Adaptation and Mitigation Partnership (CAMP) project.

The current state of Saudi Arabia's electricity sector

Saudi Arabia's electricity sector is one of the largest in the Middle East, with an installed capacity of approximately 94 gigawatts (GW) in 2023—more than half of which has been installed in the last decade.

In the past, natural gas and crude and heavy fuel oil were the predominant sources for electricity generation in the Kingdom.

In recent years, there has been a significant shift toward natural gas, which accounted for 57% of electricity generation in 2019, up from 34% in 2010.The reliance on fossil fuels may come with its own challenges, with nearly half of Saudi Arabia's CO_2 emissions in 2022 coming from electricity generation.

In 2021, Saudi Arabia set a target of reducing 278 metric tonnes of greenhouse gas (GHG) emissions by 2030.

Shihab Elborai, an energy and sustainability expert focused on the Middle East and North Africa, explains that the transition to renewables needs to come gradually. "The first step is to phase out the use of crude oil in power generation and replace it with gas," he says. "The surest way to derail the transition is to do so rapidly while undermining the current global energy system. You should not saw the branch while sitting on it."

The course to decarbonization

Researchers considered four scenarios to capture the long-term impacts of different policies and mitigation efforts on Saudi Arabia's electricity system, with growth in both the economy and population taken into account since both incur higher energy demands.

"The electricity sector has to be the first sector to decarbonize. It is the lowest-hanging fruit for the Kingdom [and] the easiest emissions to remove from the economy."

The four scenarios include varying degrees of renewable energy deployment, energy upgrades, and carbon pricing mechanisms.

The spectrum ranges from a no-policy scenario where no climate reforms or mitigation takes place to an aspirational economy-wide net-zero scenario where energy capacity from renewables is dramatically scaled up from 120GW in 2030 to a projected 600GW by 2060. The latter would require increasing annual rates of renewable power generation from 6GW to 16GW per year.

Around 11.4GW of renewable capacity is already under construction and is expected to be connected to the national grid soon.

▼ A drone point view of solar and thermal panels: Saudi Arabia's massive renewable energy push could influence the energy strategies of its neighbors.

The model includes greenhouse gas (GHG) emissions in all four scenarios. It also highlights the required capital needed. For instance, an expansion of renewable power grids, and in turn capacity, would require a whopping $500 billion investment to add new capacities from 2030 to 2060.

In the net-zero 2060 scenario that the study presents, carbon dioxide removal (CDR) technologies are highlighted as crucial in achieving net zero GHG emissions.

The KAPSARC model cites carbon capture and storage (CCS) and direct air capture (DAC) as the main technologies for capturing CO_2, either from the emission sources or the atmosphere—all energy-intensive operations.

One of the study's key findings is that achieving net-zero GHG emissions by 2060 will require a significant increase in the deployment of renewable energy technologies as energy requirements would double on the road to decarbonizing different sectors.

The integration of CCS technologies within natural gas power plants will be essential for reducing emissions.

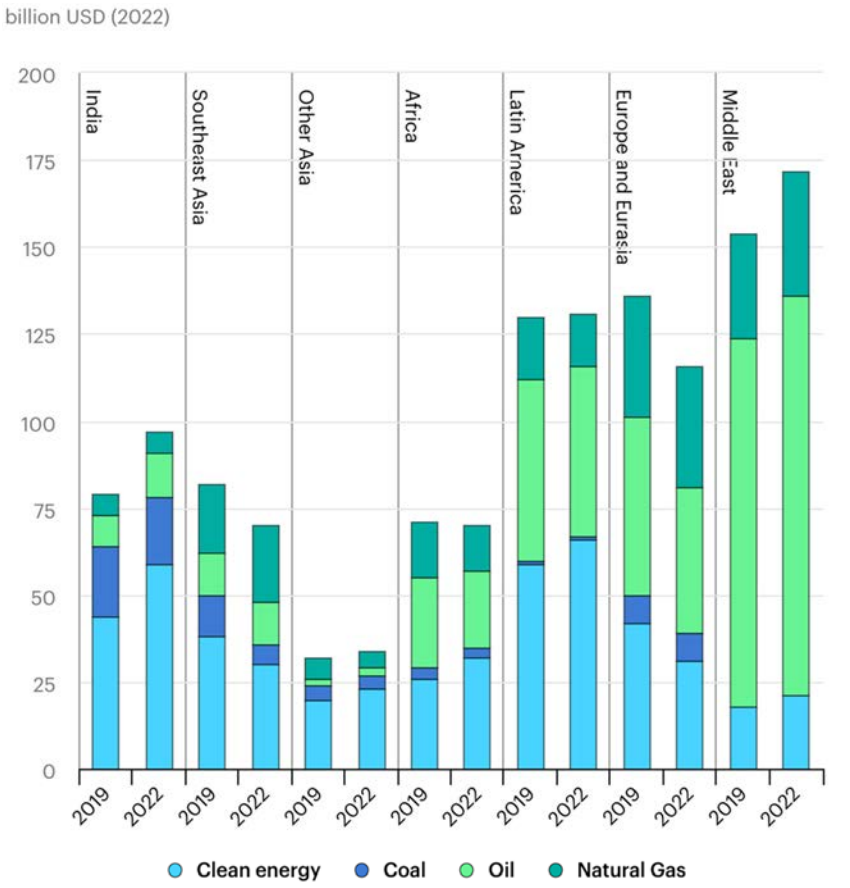
However, these technologies require substantial energy for capturing, compressing, transporting and storing CO_2. This in turn increases the overall electricity demand and may necessitate additional power-generation capacity. DAC, which uses chemical processes to capture CO_2 directly from the ambient air, is a similarly electricity-intensive option.

It is why the researchers say that this level of deployment may not be the most optimal or cost-effective approach. They suggest exploring alternative pathways that focus more on reducing residual emissions rather than relying heavily on carbon removal technologies.

Renewables: Challenges and opportunities

While renewable energy is expected to play a pivotal role in Saudi Arabia's transition to a sustainable electricity sector, solar power in particular has potential due to the Kingdom's abundant sunlight and other favorable geographical conditions. Several large-scale solar projects are already in various stages of development.

Energy investment in emerging markets and developing economies, 2019 and 2022



> "If we were to hit net zero, what would that entail?"

Wind power is another promising renewable energy source for Saudi Arabia. The Red Sea coast, with its high wind speeds, offers ideal conditions for wind farm development.

Harnessing these renewable resources is crucial, but not without challenges. According to Kamboj, the grid would need to be adaptable to the fluctuating energy supply to ensure a reliable and resilient system. "You need to have other sources of fuel that can balance that up and down in the renewable energy generation," he adds.

Advances in battery technology and grid management systems are also essential for storing excess energy and using it when supply is low.

Saudi Arabia seems to compare favorably with other oil-dependent nations in the Gulf region in terms of plans to cut emissions. Its massive renewable energy push may very well influence the energy strategies of its neighbors, some energy experts argue.[3]

Elborai explains that the sudden switch to renewables overnight may not be realistic, and emphasizes instead the need for a more gradual approach that invests in both conventional sources as well as renewables that will gradually reduce dependence on oil, moderate oil price volatility, and reshape supply-demand dynamics while maintaining energy security.

1. Kamboj, P.; Hejazi, M.; Alhadrami, K.; Qui, Y.; Kyle, P and Iyer, G., Saudi Arabia Net Zero GHG Emissions by 2060: Transformation of the Electricity Sector. KAPSARC, 2023.
2. https://www.bbc.com/news/world-middle-east-58955584.
3. https://www.energypolicy.columbia.edu/robin-mills/

CREATING A WALKABLE CITY FOR RIYADH'S NEW METRO

Shaded and safe walkways as well as cycling routes are needed to encourage people to shift from driving to using Riyadh's new metro.

Encouraging people to swap the comfort and freedom of their own cars and public transport is a key challenge facing city authorities globally. In Riyadh, the new metro system will open in late 2024, but willingness to use it depends on many complex factors.

"Saudi's Vision 2030 aims to create energy-efficient cities that will help meet net-zero targets," says Mehbub Anwar at KAPSARC's Department of Transport and Infrastructure. "However, of Riyadh's eight million daily trips, around 85% are made by car and only 2% by bus."

To understand people's willingness to shift from cars to the new metro, Anwar's team used a survey from the Royal Commission for Riyadh City (RCRC) involving 196 Riyadh-based drivers. They provided the participants with nine hypo-

▲ Saudi Arabia is hoping its $22.5 billion Riyadh Metro will help the capital transform into an energy-efficient city.

ROYAL COMMISSION FOR RIYADH CITY (RCRC)

thetical scenarios based on factors including travel times, fares, and walking/transfer requirements. By analyzing their choices, the researchers gained valuable insights. They also considered personal factors that might affect preferences, such as age, education, and employment.

They found that even a small reduction in travel time, just five minutes, would significantly encourage metro use. If walking to a metro station takes five minutes, along with lower travel time and cost compared to driving, there is a 65% chance that people will choose the metro. Reducing the walking distance to just one minute increases the likelihood to 75%. This highlights the importance of ensuring good pedestrian access to all metro stations.

"In Saudi Arabia, there's a strong push for transit-oriented development, which focuses on creating high-density residential or employment areas around metro stations to reduce walking distances," says Anwar. "This is vital in a country with a harsh climate and intense heat, which has understandably lowered the interest in walking and cycling."

Anwar recommends that shaded walkways between buildings should be improved, and new pedestrian access prioritized. He acknowledges that it can be difficult for people to switch as changing routines takes considerable effort. While the team found that people with higher education levels are more likely to choose the metro, they suggest that promoting environmental awareness could encourage more people to use it.

"Investing in the Riyadh metro is a timely move to challenge traditional habits, and improve not just our local pollution levels, but also our wider impact on the environment," says Anwar. "A low-impact, highly efficient public transport system must also be as appealing as possible."

● Anwar, AMH. M., Oakil, A.T., Muhsen, A., & Arora, A. What would it take for the people of Riyadh city to shift from their cars to the proposed metro? *Case Studies on Transport Policy* **12**: 101008 (2023).

▲ A study shows US car owners are abandoning EVs in favor of gasoline-powered vehicles.

WHAT'S DRIVING PLUG-IN VEHICLE ABANDONMENT?

Understanding why American electric vehicle owners are switching back to gasoline could help other countries develop more effective policies for EV adoption.

QILAI SHEN/BLOOMBERG VIA GETTY IMAGES

A new study has revealed a concerning trend in the United State, as a significant number of plug-in-electric vehicle (PEV) owners are switching their electric cars for gasoline-powered vehicles. The shift is raising questions about the future of the auto sector's energy transition.

Researchers from KAPSARC, Washington State University, National University of Singapore, and Strategic Vision in San Diego conducted comprehensive surveys of new car buyers in the United States to examine the reasons behind this pattern. Their findings suggest that about 35% of US households that disposed of a PEV opted to replace their vehicle with a gasoline-powered car at the time of their next purchase.

The findings are in line with other recent studies. A McKinsey survey showed that about 45% of EV owners in the United States were likely to switch back to gasoline-powered cars. Another study by Edmunds found that around half of Teslas are being traded in for gasoline vehicles.

"The main factors influencing this shift include concerns over electric driving range, the availability and convenience of charging infrastructure, particularly home charging, high PEV purchase price and battery replacement costs, and lower resale values of PEVs," says Rubal Dua, a research fellow at KAPSARC and the first author of the study.

In a bid to meet their climate goals, improve air quality and build cleaner transport ecosystems, countries worldwide have announced ambitious targets for PEV uptake. Norway wants PEVs to make up 100% of car sales by 2025, and the United Kingdom, and the European Union are pushing to achieve that by 2035.

"For countries aiming at increased PEV market penetration, it is essential to ensure that once consumers switch to PEVs, they continue to use them," says Dua. "Early adopters of PEVs often influence the adoption behavior of potential buyers; addressing their concerns can foster a more robust adoption rate globally."

The study also found that lower-income groups were more likely to give up their PEVs. That suggests that as electric cars reach a broader demographic, the abandonment trend could increase.

To encourage the adoption of PEVs, the study suggests that smart policies are also likely to be successful. In China, for example, government subsidies have been tied to driving range, addressing the concern of many drivers who typically want a minimum range of 330 miles.

Additionally, the study finds, linking subsidies to extended battery warranties and resale value guarantees can alleviate other common buyers' concerns.

To help lower-income buyers, the research suggests that subsidies be capped at a certain income level, and be applied to lower-priced PEVs. That would encourage automakers to manufacture more affordable electric vehicles.

- Dua, R.; Edwards, A.; Utkarsh, A.; and Prateek, B., Are American electric vehicle owners quitting? *Transport Research Part D*, **133** (2024).

TO FUND OR NOT TO FUND?

Researchers investigate how cost-benefit analysis can help decision-making in petrochemical investments.

Building petrochemical plants demands billions of dollars in investment. It would be imprudent for any government or state-owned enterprise to finance such infrastructure without clear assurance of significant societal benefits.

Traditionally, policymakers have used cost-benefit analysis (CBA) to quantify the environmental and social impacts of large-scale infrastructure projects. Sectors that have widely adopted the use of CBA include public transport, utilities, waste management, energy, education, research, healthcare, and information technology.

Researchers from KAPSARC have found that CBA may also be applied in assessing large-scale construction projects in the petrochemical sector. By using hypothetical ethylene production plants in Saudi Arabia, China, and Malaysia as a case study, they show that CBA provides relevant information and useful insights, especially when the projects are conducted in heavily regulated markets.

◀ Applying CBA is beneficial in assessing large-scale construction projects in the petrochemical sector.

TEPPAKORN TONGBOONTO/ ISTOCK EDITORIAL / GETTY IMAGES PLUS

"The CBA standards for specific sectors could contribute to methodological transparency and help address potential conflicts of interests."

"The authors' approach aligns well with evolving industry trends by broadening technology analysis to include adoption readiness factors," notes energy policy and economics expert Steve Griffiths, who is Professor and Vice Chancellor for Research at the American University of Sharjah. "By considering economic, environmental, and social benefits alongside financial returns, this work provides a more complete basis for making final investment decisions."

A versatile tool

The petrochemical industry often operates in a regulated market structure. To achieve their social development goals, many countries have implemented price controls for input fuels, feedstocks, and electricity—either through government-set prices, price caps or other non-market control mechanisms. On a global level, the sectoral interventions can further be exacerbated by foreign trade barriers, fixed exchange rates, and interest rates set by the government.

"Many industries confronting investment decisions, particularly with emerging decarbonization technologies, stand to gain from the CBA approach," explains Griffiths. "Unlike traditional NPV-focused methods, CBA incorporates broader factors such as emissions reduction, energy efficiency, and regulatory alignment that can significantly shape financial and strategic decisions."

Given the significant role of the petrochemical industry in global economies and development objectives, one can argue that the desired outcomes of governments may not be limited to their financial performance. New projects may bring macroeconomic gains—such as employment, economic diversification, and improved trade balance—as well as environmental benefits such as reaching sustainability targets set by authorities.

"The CBA standards for specific sectors could contribute to methodological transparency and help address potential conflicts of interests," says study lead author Philipp Galkin, a visiting researcher specializing in the economic and policy aspects of energy supply and trade.

Cost estimation for large industrial facilities, particularly those in the oil and gas and petrochemical industries, can be done at many different levels of detail with varying levels of accuracy. The researchers applied a capacity-factored cost estimate in the study. Though this may not have the highest accuracy, it can support the assessment at screening level.

The team assumed that the ethylene production plants—regardless of their location—use the same technologies and feedstocks, are the same size, and are constructed in the same year. In other words, the only items that needed to be adjusted in the CBA for each country are construction and operation costs, including natural gas tariffs, and electricity and shipping costs.

Additionally, environmental factors are represented by the pollution costs, quantified based on the projected levels of certain pollutants and large particles pro-

duced by the project, and climate costs, calculated based on the CO_2 and NH_4 emissions from a comparable project.

A risk assessment was also performed for both traditional financial plans and CBA-adjusted projections. Using a sensitivity analysis, the researchers were able to identify critical factors and applied a qualitative risk assessment framework following European Commission guidelines for risk factors which were too difficult to quantify.

"The starting points for this work were good, leveraging a number of quantifiable model parameters for which reliable data were available," says Griffiths. "By integrating into the model energy costs, like those of electricity and natural gas, and environmental impacts, a solid framework is established for model-based investment decisions."

Highlighting the impact of CBA for project evaluation

The team found that the general principles of CBA are applicable to the evaluation of petrochemical investments, especially in markets that are heavily regulated and where the government is a major investor.

A case in point is Saudi Arabia, where CBA adjustments significantly affected the results. Here, the net present value (NPV) of the ethylene plant—which typically cost $7 billion to $30 billion—was reduced by $7.1 billion when CBA was applied. In addition, applying a cost-benefit analysis can help identify critical risk factors that may not be evident at the financial planning stage and quantify potential impacts—such as ethylene price, natural gas, and electricity tariffs.

"CBA is very useful for government-affiliated investors, where long-term strategic aspects are to be included," says Galkin. "Net present value isn't everything, and CBA also allows for a wider range of non-financial considerations."

The researchers found that in the case of a joint international project, the perspectives of investors on certain CBA costs and externalities may not concur. The CBA standards for specific sectors could contribute to methodological transparency and help address potential conflicts of interests.

While CBA has been applied by private companies to assess petrochemical investments, such estimates and methodologies largely remain inaccessible to the public due to the sensitive and largely classified nature of investment and financing decisions. KAPSARC's study represents the first transparent case study of applying CBA principles to public-sector petrochemical investments.

The authors were also able to show the impact of CBA on potential project outcomes. The most beneficial project location from the purely financial NPV perspective—Saudi Arabia—would yield negative NPV if CBA principles are applied. The resulting outcome would still be more favorable than developing the project in China, however, it would make Saudi Arabia a less attractive project location than Malaysia.

"Enhancing industrial capacity collaboration with partner countries is a critical element in China's Belt and Road Initiative," explains Dongmei Chen, a research fellow at KAPSARC's Oil and Gas department.

▼ The Shaybah mega-project, the first and only oilfield development in Saudi Arabia's vast Al-Rub al-Khali desert, produces some 600,000 barrels of oil per day.

BILAL QABALAN/AFP VIA GETTY IMAGES

"This aligns well with the strategic priority of Saudi Vision 2030, which envisions the important role the petrochemicals sector could play in economic diversification," adds Chen, who served as head of the Institute of Industrial Productivity China Office and director of the Climate Change and Energy Program for World Wide Fund for Nature, China, before joining KAPSARC.

With China and Saudi Arabia recently sealing $65 billion in deals, CBA can help ensure that good investment opportunities will not be missed.

Limitations and future research

KAPSARC's CBA framework offers valuable insights for analyzing potential projects in sectors of the economy beyond its traditional applications. Its relevance becomes particularly pronounced in these contexts.

In an environment where non-financial factors—including energy security, climate goals and local content priorities—increasingly drive economic policy and investment, CBA provides a broader assessment of the project outcomes and can help align the interests of investors and policymakers.

While other methods could arguably provide better visibility for certain outcomes of specific projects, at present, CBA remains the most established method applied for these purposes and is already a compulsory requirement for project approval and financing in many countries and international institutions.

But CBA methodology does have several inherent limitations. Quantifying the environmental and social impacts of large-scale infrastructure projects using CBA remains difficult if not controversial. Assigning a monetary value or 'price tag' to non-financial impacts, such as energy security and climate goals, is more art than science, often giving investors a false sense of accuracy. Moreover, analysts tend to use a high discount rate when calculating the NPV, which can undermine benefits that accrue over longer periods of time.

The goal of this study was to illustrate the usefulness of CBA in assessing petrochemical investments and not necessarily to advise potential investment decisions, for which a much more detailed and sophisticated financial planning and forecasting process would be required.

"The paper's most significant contribution is its comprehensive investment evaluation approach, which can reveal previously overlooked economic, social, and environmental costs and benefits," concludes Griffiths. "This research provides an excellent framework for evaluating investments not just in petrochemicals, but potentially across many other carbon-intensive industries."

Further research in this domain can focus on developing industry guidelines which would apply standardized CBA principles in the project planning process.

DAVID GYUNG/ ISTOCK EDITORIAL / GETTY IMAGES PLUS

▲ CBA provides a broader assessment of project outcomes and can help align interests of investors and policymakers.

"Enhancing industrial capacity collaboration with partner countries is a critical element in China's Belt and Road Initiative. . . . Saudi Vision 2030 envisions the important role the petrochemicals sector could play in economic diversification."

● Galkin, P., Chen, D. and Ward, C. Cost-Benefit Analysis for Petrochemical Projects, 2023.

LIGHTFIELDSTUDIOS/ ISTOCK / GETTY IMAGES PLUS

Income growth fuels electricity demand in middle-income countries

Income stability, price, and electricity demand could help shape long-term energy policies for growing economies.

As the world races toward a carbon-netral economy, countries are electrifying everything from transportation to manufacturing. This surge in electricity consumption is prominent in rapidly growing middle-income countries, creating a new energy demand landscape.

In a study published in 2023, Fakhri Hasanov, a senior principal researcher at KAPSARC, and collaborator Brantley Liddle, from the National University of Singapore, analyzed the impact of income changes and electricity pricing on demand over time in middle-income countries. They emphasize that such insights are crucial for accurately forecasting demand and devising economic policies. Previous studies on the topic have primarily focused on high-income OECD countries.

The researchers analyzed electricity consumption, income and pricing data from 31 countries spanning nearly 50 years. This comprehensive study, the most extensive of its kind for middle-income countries, revealed a strong correlation between income growth and increased electricity use. They found that for every 10% increase in income, electricity consumption rose by about 8% , showing a direct link between economic growth and energy demand. "This may seem encouraging for climate change mitigation policies focused on increasing the electrification of energy services," the authors say.

Changes to electricity pricing, on the other hand, had less of an effect. When the price increased by 10%, electricity demand only decreased by 0.9% on average. This suggests that industries and households in middle-income countries do not significantly alter their electricity usage when prices rise, indicating low sensitivity to price changes.

Overall, the parameters of the relationship between income, prices, and electricity demand remained stable over time in the middle-income countries studied, with some variations among specific nations. "In the context of middle-income countries, the stability of the parameters of this relationship implies that policymakers can rely on this information when designing long-term energy, economic and environmental strategies without worrying about significant variability over time," the researchers say.

The patterns differed from prior research tailored to high-income OECD countries. In these nations, additional income increases electricity usage, but the effect slows over time due to saturating demand and improvements to energy efficiency.

The study's results could be used to refine electricity demand models to reflect the characteristics of middle-income countries. These models, in turn, would inform policy-making, such as setting appropriate electricity pricing, planning expansions to infrastructure and assessing the potential impacts of economic growth on electricity demand, the authors say. "This also supports the development of long-term strategies for energy supply, demand management, and climate change mitigation in middle-income nations."

- Liddle, B. and Hasanov, F., Are the income and price elasticities of economy-wide electricity demand in middle-income countries time-varying? Evidence from panels and individual countries. *Environmental and Ecological Statistics*, **30** (4), 827–849, 2023.

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