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King Abdullah Petroleum Studies and Research Center

Behavioral Aspects of Energy Transition: A KAPSARC-Energy Systems Catapult (ESC) Joint Methodological Report

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About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

This publication is also available in Arabic.

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Summary

Innovation in energy transitions invites a new way of understanding the energy industry, its ultimate products and services, and how to analyze them. This paper reports KAPSARC's and Energy Systems Catapult's (ESC's) work on alternative ways of understanding the impact of new energy technologies on markets and consumer behavior.

The key messages are:

Technological innovation and industry player's responses to it are shifting electricity provision from that of a commodity to a service market, i.e., shifting the focus from selling kilowatthours (kWh) to selling energy services.

New energy technologies and services enable the creation of new markets, as the technologies offer the potential to address consumers' unfulfilled preferences. New market opportunities can also arise as unplanned consequences of the deployment of some technologies.

If the electricity industry will operate as a services market, what can it learn from similar markets? Insurance, telecommunications and other markets based on shared economies offer various lessons for designers of the electricity-as-a-service market.

Other markets with similar structures can provide information on the behavior of industry players, which can then be modeled in 'hypothetical' electricity service markets. These virtual experiments can be used to gain insights into the required structure of markets, the products they could offer and the inferred prices of these products.

Digitalization, i.e., big data analytics, is an essential enabler of market creation. It can be used to create tailor-made, granular products and enable effective price discrimination for users. Such individualized pricing has important implications for economic research, methods and regulations.

Having a theoretically driven understanding of consumer behavior can help design policies around how people behave so that they deliver societal goals successfully.

Background

Who are we?

KAPSARC was founded as a non-profit institution for independent research into global energy economics. Based in Riyadh, KAPSARC develops economic frameworks to help align energy policy objectives and outcomes effectively. KAPSARC researchers collaborate with leading international research centers, public policy organizations, and industrial and government institutions to share knowledge, insights and develop pioneering analytical frameworks.

Energy Systems Catapult (ESC) is an independent, not-for-profit center of excellence that bridges the gaps between industry, government, academia and research. ESC was set up to accelerate the transformation of the United Kingdom's (U.K.'s) energy system and ensure U.K. businesses and consumers capture the opportunities of clean growth. ESC collaborates with industry, academia and government to overcome the systemic barriers of the current energy market and help unleash the potential of new products, services and value chains.

Why this report?

KAPSARC Energy Transitions and Electric Power team and ESC have been working on two different aspects of technology disruption in the power sector, the 'servitization' of electricity. These two strands of research have converged on similar solutions for addressing technological disruption in the power sector. This report synthesizes KAPSARC's and ESC's mutual learnings and aims to foster new research in the area.

Our Work: KAPSARC

KAPSARC's work on innovation in electricity transitions has focused on unbundling services in the electricity sector (KAPSARC 2016) and developing the microeconomic foundation for a reliability service. Our research has investigated the experiences of industries resembling the electric power sector and those involved in the sharing economy that have recently faced technological disruptions. In Fuentes (2016), we argued that reallocating risk across the electricity market, and the apparent paradox between (spare) capacity and price signals (scarcity) could open up a new role for incumbent electricity firms.

In Fuentes and Bracamontes (2016), we contend that a high penetration of distributed energy resources (DERs) would further fragment the power sector, both in its services and value chain. This idea is partly based on the two-market approach for decarbonized electricity systems outlined in Keay, Rhys and Robinson (2017). The authors propose creating separate power markets where consumers would be able to select from two different service contracts for electricity 'on demand,' which would be more expensive and generated from renewable sources.

In Fuentes, Blazquez and Adjali (2019), we analyzed the viability of creating a market for reliability as a service. The reliability solution proposed is based on electricity firms' idle generation capacities being repackaged and repriced as insurance. This idea leverages Helms' (2016) asset transformation proposal, which argues that asset transformation shifts tangible assets into intangible assets, a major input factor for the value proposition of changes in underlying business models. In Fuentes and Segupta (2019), we formalize some of the assumptions in an agent-based model and use this model as an intermediate solution for establishing new markets.

Our Work: Energy Systems Catapult (ESC)

ESC's mission is to unleash innovation and open new markets to capture clean growth opportunities. ESC's work has focused on creating a demand-pull for energy systems innovation by helping to remove barriers and opening new markets. ESC provides 'hands on' support to innovators in the sector to test and commercialize new processes, products and business models.

One key market is spatial thermal comfort. Decarbonizing heat is one of the biggest challenges the U.K. faces in transforming its energy system to meet its carbon reduction targets. Heating for buildings accounts for nearly a fifth of the U.K.'s emissions, and its 27 million domestic households will need to rapidly adopt new low-carbon heat solutions if the country is to meet its carbon budgets and achieve its clean growth ambitions.

However, three key challenges should be addressed to achieve widespread adoption of low-carbon solutions:

> Comfort - Consumers want good experiences when buying and using their heating. This can be a challenge because there are many low-carbon options available, and the best solution varies according to the home and the area it is in. Consumers' awareness of options is also limited. Heat pumps, for example, might suit well-insulated homes; district heating might be the best solution in dense urban areas, and hydrogen might be the best solution if the gas grid has been repurposed.

> Convenience - Consumers want the installation of a heating system to be quick and easy. Today, around a third of U.K. households only replace their existing heating systems when they break. In this case, low-carbon heating may not be viable if consumers have to spend weeks preparing their homes before they can install new systems and restore their heating.

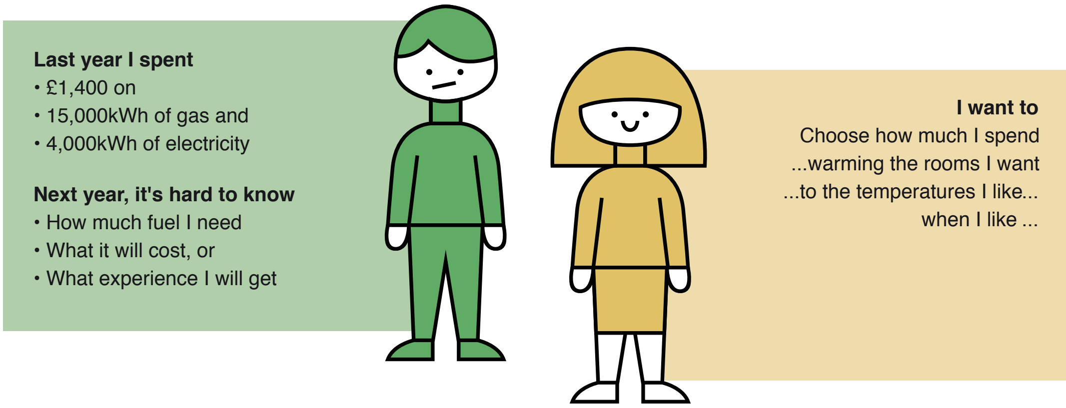
> Control - Consumers want to control how much they spend on heating. However, 'heating' is not a product they take from the shelf and is perceived in different ways. Some consumers spend time adjusting their thermostats to match the times when they are home.

> Cost - Conventional approaches to 'protecting' the fuel poor have focused on the needs of the energy system, not those of the consumer, with interventions rooted in regulation and policy, and rarely innovative. One key concern is cost, including purchase, installation and running costs. There is a need to ensure fuel poverty is not exacerbated during the low carbon energy transition.

Is it possible then to provide a market solution to heating, as opposed to only focusing on 'end-of-pipe' solutions? ESC researchers observed a group of U.K. households whose consumption patterns were continuously monitored by sensors connected to ESC's servers. They found that this group ideally want to purchase outcomes (services) such as a warm home, rather than units of fuel. Consumers who buy 'heat-as-a-service' (HaaS) choose how much to spend on the outcome they want - feeling warm and comfortable when and where they want in their home. Consumers may be willing to pay more for outcomes and services they value more (see Figure 1).

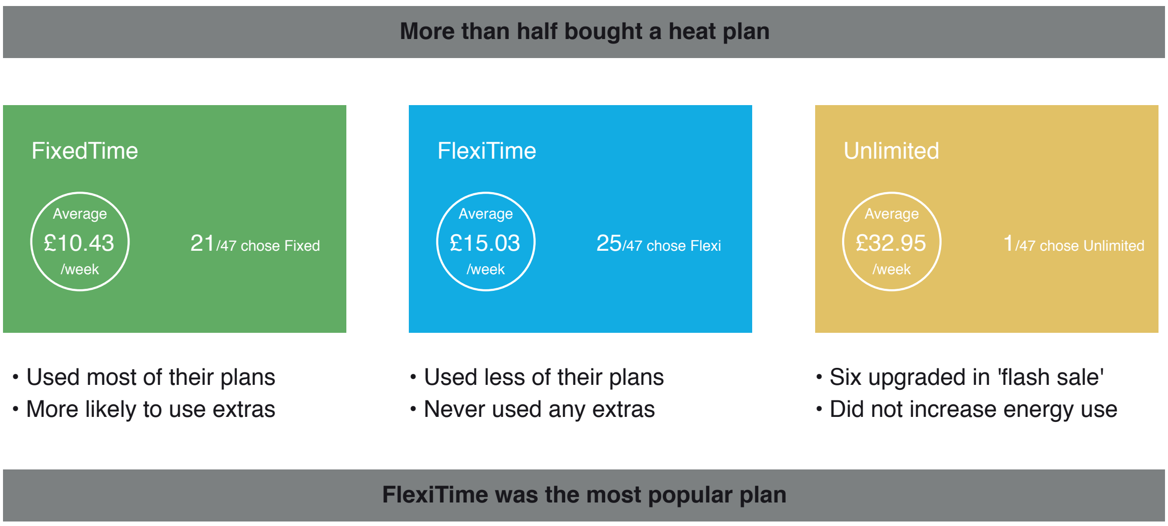
This 'living lab' allows ESC researchers and decision-makers to identify which bundles/outcomes create more value for consumers. Figure 2 offers an illustrative heating plan based on this research. HaaS could also unlock value for energy retailers who can attract and keep more customers by offering them better services. Manufacturers could use data to improve the design of their products, and governments and the energy system could use it to cut carbon emissions and save energy.

Figure 1. Current value proposition vs. consumer demands.



Source: ESC.

Figure 2. Examples of potential heating plans.



Source: ESC.

Common Elements

KAPSARC's Energy Transitions and Electric Power team and ESC have been working on two different aspects of technology disruption in the power sector. These two strands of research have converged on similar solutions for addressing technological disruption. This section identifies these similarities, allowing us to provide a framework for other energy transition practitioners to develop their products and services.

From commodity to services

Both research streams support the idea of moving away from the electricity industry's traditional business model of selling a commodity, the KWh, and adopting a service-focused approach that consumers can understand. Ultimately, reliability insurance and HaaS sell guaranteed outcomes, something that individuals can relate to and value.

Data-driven business model

The creation of new markets in energy services lies in a product design that is less standardized, more personalized, and with a pricing structure more closely aligned with the maximum willingness-to-pay for their preferences. Big data and analytics and the codification of consumer behavior can help to design products customized to consumer preferences. Digital and data technologies allow service providers to define and sell products based on the outcomes consumers demand. This gives them considerable freedom to manage the capacity required to deliver these services. However, retailers shoulder more risk as they commit to delivering services, but they do not control consumer usage. As such, they need to optimize this risk across the whole of their portfolios. Big data and data analytics give retailers subject to capacity constraints significant advantages when optimizing their portfolios.

Product structure

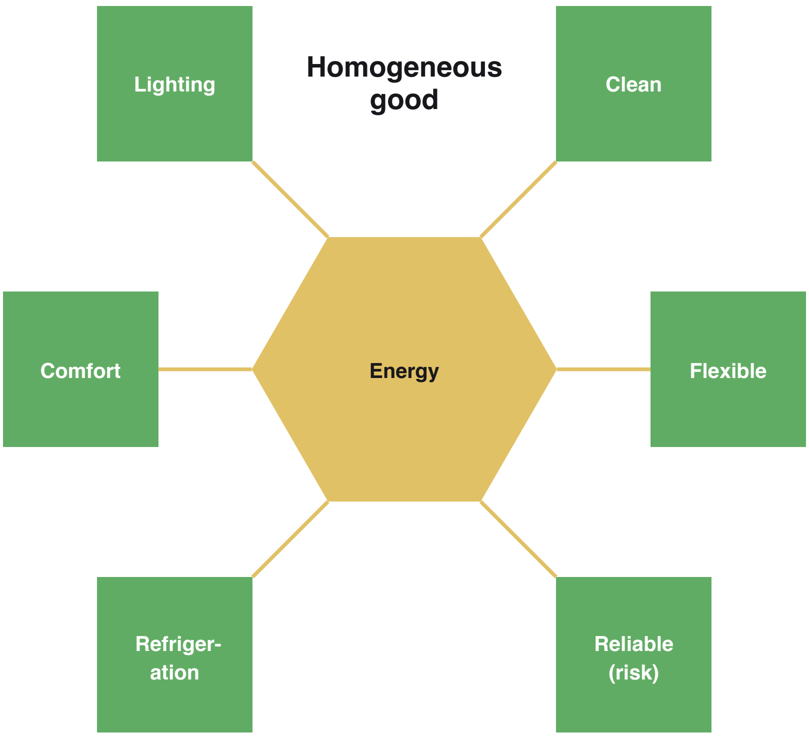
In the resulting business model, energy providers bundle heterogeneous, instant and intangible services into ad hoc products. The pricing of these products is structured into at least two parts: basic services (access) and other premiums, and within a multiple tariff structure. For example, in the reliability insurance business model KAPSARC has developed, the insurance product can include categories such as the time of day when the electricity must be supplied and seasonal demand. It can also include the number of blackouts to be covered per year, the fixed quantities of energy per event, among other potential eventualities. Categories in the HaaS scheme might include a guaranteed temperature at certain times of the day, the number of rooms to be heated and the number of heating hours, with pre-determined prices for the consumer. Big data and data analytics can provide more granular analysis to help design customized products that maximize value to both consumers and suppliers.

A Microeconomic Foundation for a New Paradigm

The concept of externalities is central to the microeconomic foundation of our work. An externality is a cost or benefit incurred by a party who has no control over the creation of that cost or benefit, the classic example being pollution. These costs or benefits are not reflected in pricing mechanisms, a phenomenon known as missing markets. This report focuses on the lack of pricing mechanisms for externalities and provides a theoretical framework for enabling such provision.

Foxon (2015) has argued that electricity has multiple value streams that are difficult to monitor, capture and compensate for (see Figure 3). It is therefore difficult to reflect many of these value streams in conventional pricing mechanisms. Consumers value electricity because of its use in powering lighting, warmth, refrigeration, and/or because it is clean, on-demand and reliable. Consumers rarely see electricity as a homogenous good, i.e., in terms of kWh. These services and features of electricity are the 'externalities' we would like to internalize in our market paradigm. Economic theory has created tools to internalize externalities such as imposing a (Pigouvian) tax, or by assigning property rights to create a market.

Figure 3. Electricity seems like a homogenous commodity when in reality it has multiple attributes.

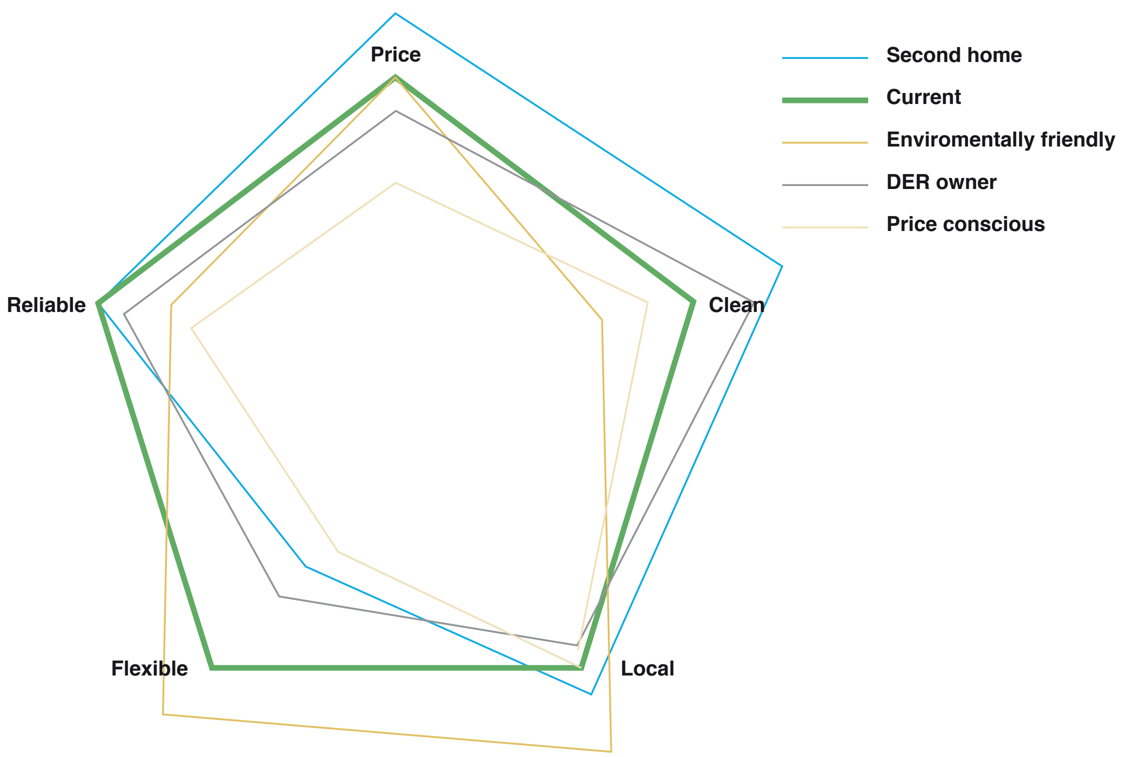


Source: KAPSARC.

Electricity has been traded as a homogenous commodity, with the features and attributes of the abovementioned services uniformly priced in kWh. These attributes have conventionally been seen by the electricity market as a byproduct of electricity provision, inseparable from it, and have come at no extra cost (KAPSARC 2017). Pearce (2000) argues people might think that some goods (externalities) are unmarketed because they are abundant and have negligible prices. For example, consumers expect that there will be electricity whenever they turn on the lights. They are only cognizant of the price they pay for a kWh but take the reliability of the service for granted. However, the provision of reliability has a different supply-demand dynamic than the provision of the commodity. By pricing different features of electricity provision separately, consumers can find ways to reflect their personal preferences and determine the quality and the level of provision of these features.

Disruptive of distributed energy resource (DER) technologies can, to some extent, help to overcome problems associated with unbundling and rebundling attributes related to electricity as a service. These technologies can capture complex values regarding energy usage (Hall and Roeslich 2016). Creating specific markets for these attributes could be key to offering solutions that mirror consumer preferences as closely as possible.

Figure 4. Different preferences for electricity attributes.



Source: KAPSARC.

Figure 4 shows individual preferences loosely matched by the homogeneous electricity provision. The green line indicates the current provision of electricity, representing the bundled attributes of the commodity: price, reliability, cleanness, flexibility and whether or not it comes from local sources. Customers may have different preferences for each of these attributes, causing areas of oversupply for some of these attributes, and areas of undersupply for others. For example, the preferences of purely price-conscious customers might differ from those of more environmentally aware consumers. By the same token, a person might have a different preference for the supply of electricity for their second home.

A market for these electricity attributes would enable products to be customized to match consumer preferences. As Lehr (2013) puts it, we can move from the paradigm of “have we paid the correct amount for what we got?” to a new paradigm, proposed here, which is “are we paying for the experience that we wanted?” (Lehr 2013, p.50).

Experimenting Without Tears — Methods of Transitioning From KWh to Services

So far, this paper has argued that technological disruption will cause markets to shift from selling kWh to selling services. Designing new markets for which limited experience exists is a challenging task. A multitude of unforeseen interactions may occur between consumers and energy retailers in new market environments. Unveiling consumer preferences in these emerging markets could be a considerable challenge.

Creating markets from scratch poses two main difficulties. The first is establishing a logically consistent set of micro-foundations upon which a market can be designed. The second is the lack of empirical data on how consumers react to various designs. The exact form new markets take and the outcomes they produce is always uncertain.

KAPSARC and ESC have developed different approaches to test various propositions relating to our market models in a controlled, experimental environment to try to reduce uncertainty. KAPSARC's agent-based model (ABM) addresses the uncertainty around market form, while ESC's real-life experiment addresses outcomes of various market structures. Both approaches can be dubbed experiments 'without tears,' as they have negligible real-life implications and their consequences can be reverted easily. These virtual experiments can be used to gain insight into the required structure of markets, their products and infer prices for hypothetical services.

KAPSARC used a computer-simulated agent-based model to explicate the complex web of interactions between households, utility companies and policymakers when the electricity market sells reliability and continuity of service rather than a commodity. ESC developed a 'living lab' consisting of a limited number of real-life users whose consumption patterns and preferences were centrally monitored. The results from this lab were used to design and test products and services for domestic thermal comfort in the U.K.

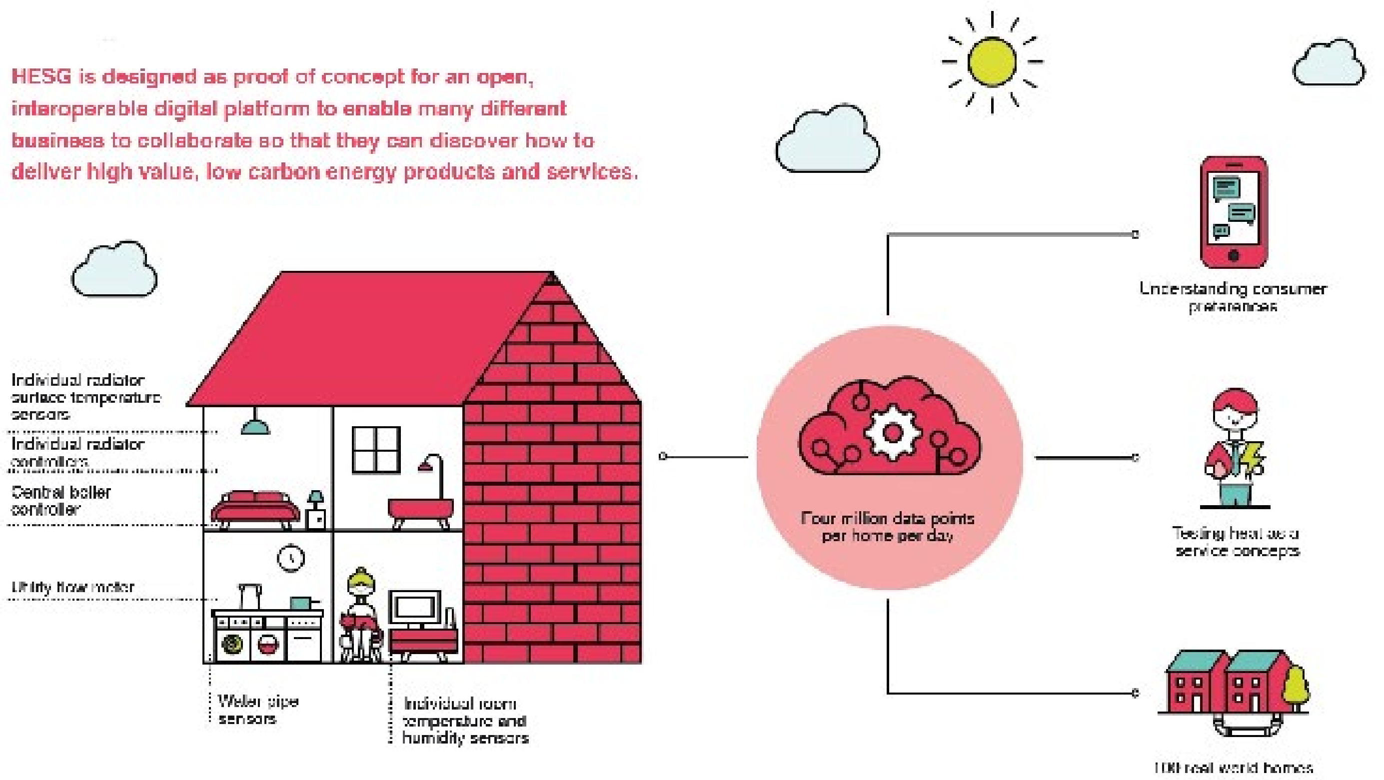
Predicting behavior ex ante in a setting with many players whose actions are intertwined is very difficult. Furthermore, the lack of an existing market forces researchers to simulate such interactions under various institutional parameters. For instance, how would individual risk averseness shape products or reliability services? An ABM is well suited to circumvent these difficulties, as it simulates the actions and interactions of autonomous agents (both individual and collective entities such as organizations or groups) to assess their effects on the system as a whole. It combines elements of game theory, complex systems, computational sociology, multi-agent systems and evolutionary programming.

The ABM establishes a predetermined structure where agents interact. This is a deductive approach, where the researcher sets the structure and parameters of the interaction. Agents interact over a specified set of turns, subject to parameters such as budgetary constraints, prices, the cost of photovoltaic (PV) installation, and so forth. The parameters are easy to manipulate at the outset, and the resulting patterns of behavior are easily observable. Equally importantly, these simulations show the sensitivity of different types of behavior to variances in certain parameters. After running a sufficient number of scenarios, the researcher is often able to generalize findings and theorize patterns of interaction between variables, which would otherwise be hard to derive through the use of closed-form solutions. An ABM allows researchers to discern questions regarding the broad structure of new markets and some of the wider regulatory implications, especially at scale. It is difficult, however, to perform micro-level deductions, such as detailed product designs or understanding real-world consumer reactions, with an ABM. The validity of ABM simulations is determined by the quality of their assumptions: ‘garbage’ assumptions lead to ‘garbage’ results. The lack of empirical insight into micro-level consumer behavior in these new markets makes this a considerable risk. ESC’s Living Lab offers a way to transpose the macro approach of the ABM into micro applications.

A living lab is a user-centered research tool, which can be utilized to capture and understand distinctive consumption and environmental patterns, understand consumer behavior, and develop and test innovative products, services and business models in transparent real-life scenarios. The end-user involvement is the main feature that differentiates living labs from other user-centric methods. Other user-centric methods engage end-users in a continuously collaborative exchange to achieve specific goals using existing technology uncritically, rather than addressing the technology itself.

ESC’s Living Lab comprises a group of U.K. households with advanced zonal heating controls, whose consumption patterns are continuously monitored by ‘internet of things’ (IoT) sensors connected to ESC’s digital integration platform. The Living Lab is underpinned by a cloud-based digital platform, the Home Energy Services Gateway

Figure 5. Schematic of the interaction between consumers and a digital platform.



Source: ESG.

(HESG), which uses extensive in-home IoT sensors/actuators, advanced data science and machine-learning algorithms, providing residents with room-by-room temperature control from a mobile app. HESG is an open, technology-agnostic platform that draws on over 4 million data points per home per day and offers interoperability between energy service providers and device manufacturers, enabling them to test new products, services and business models directly with consumers.

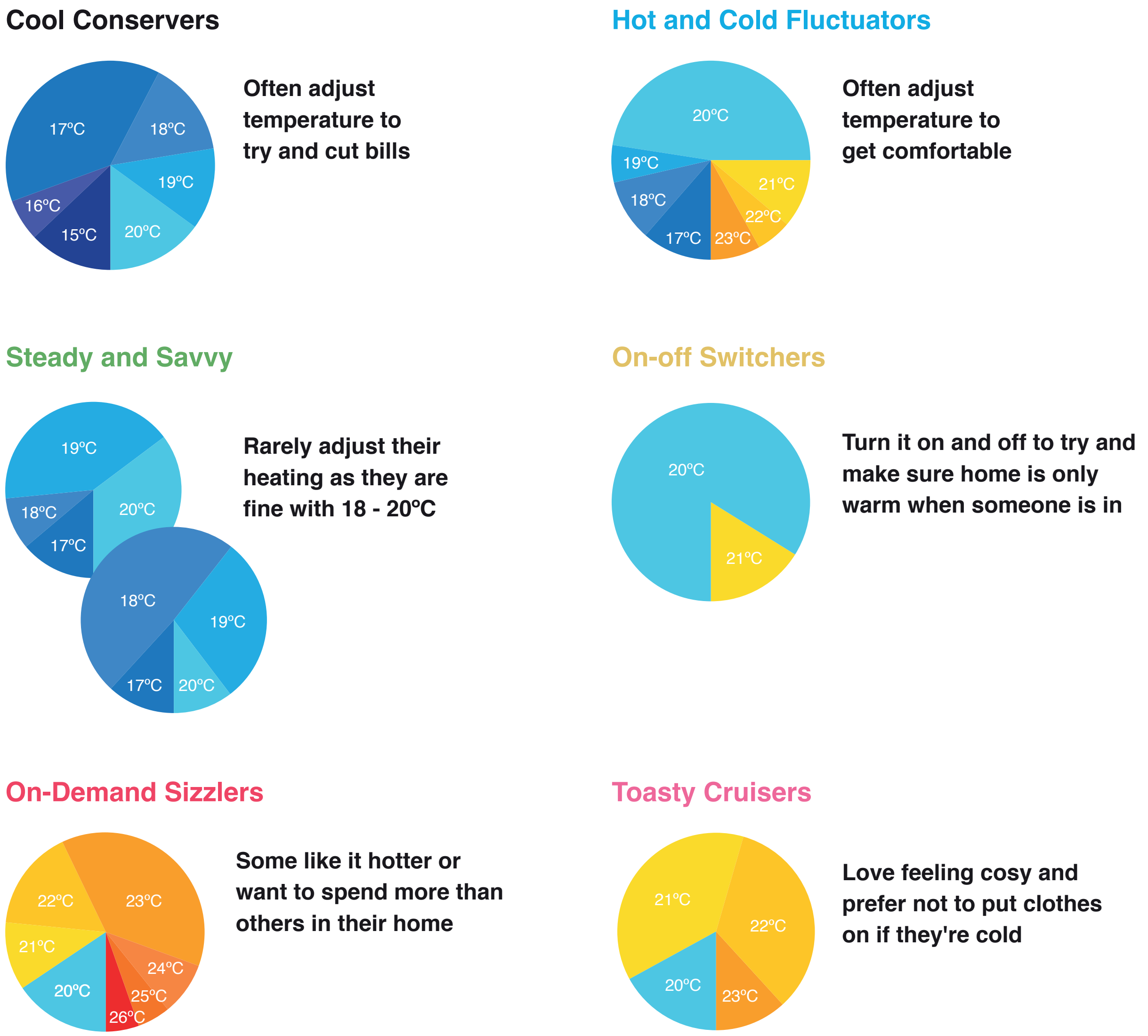
The ability to conduct such data-intensive real-life experiments opens new horizons. Proof of concept tests of innovative products, services and business models can provide detailed insights into consumer expectations and real-world behaviors. Real-time usage information can be enhanced by follow-up surveys, interviews and focus groups to derive a complete picture of users' experiences of and reactions to various service offerings. The recruitment of the sample from the sampling frame can be adjusted to suit the research/policy question at hand, minimizing the risk of unwanted bias. Capable, reliable hardware and technology play critical roles in creating value out of information. The ESC's Living Lab also provides a robust, government-backed test bed with which to validate hardware and technology performance. Finally, the controlled setup provides a safe and secure environment for end-users (experiment subjects).

Paradigm Shift: How to Extract Value From Heterogeneity?

In this section we argue that there could be a paradigm shift in the way we manage energy transitions via business solutions, and that this change could be driven by big data analytics. These solutions would be as personalized as possible, instead of a one-size-fits-all service. For this change to happen, new methods are needed to deal successfully with heterogeneity (Rose 2016).

Using means as a critical decision variable makes sense for mass production, or mass provision. It has been widely thought that, in order to make informed decisions, it was necessary to focus only on a limited number of parameters, which would render a solution that suits the majority, and dispensing with more granular information (Harford 2019; Stigler 2016). This approach made sense in markets with

Figure 6. How to distinguish between different types of consumers.



Source: Energy Systems Catapult 2019.

limited product differentiation. However, services such as those discussed in this paper aim to respond to the idiosyncratic needs of consumers. As such, averages would cancel out potential deviations and prevent individual needs being identified. In an era of big data and increasingly powerful computers, using averages to standardize products and services appears a waste of valuable resources. New technologies record transactions, the contexts and the processes in and through which those transactions took place, and allow meaningful correlations to be drawn from this array of data.

New markets in energy services could be based on products that are less standardized, more personalized, and with a pricing structure more closely aligned to consumers' maximum willingness to pay for their preferences. These changes would require a shift from using methods based on averages to methods that can incorporate heterogeneity in their analysis. We therefore need a method that extracts value from heterogeneity, makes sense of the vast amounts of data, and can analyze rational and irrational behavior. The method should be able to interpret individual circumstances.

Using its Living Lab, ESC has been able to discern the heterogeneity of users' needs and the value they attach to services. For example, consumers' responses to and their subsequent real-world usage of HaaS provides invaluable insight into the potential for personalized or user-configurable service propositions. Figure 6 identifies six types of heating consumers, building on ESC's data on consumer responses during initial Living Lab trials. These groups of consumers will naturally ascribe different values to different aspects of heating services, such as reliability, the speed of service when a breakdown occurs, and marginal pricing.

Conclusion

Innovation in energy transitions requires a different way of understanding the energy industry, its products and services, and calls for new methods of analysis. This paper reports the lessons learned from KAPSARC's and ESC's attempts to find alternative ways of understanding the impact of new energy technologies on markets and consumer behavior.

Technological innovation drives the 'servitization' of electricity business models, i.e., from selling kWh to selling energy services. This opens up the possibility of new markets that could satisfy unfulfilled consumer needs. However, the challenge is how to create markets for which there is little empirical evidence. One solution is to implement lessons learned from similar markets. This can allow us to create test beds for hypothetical electricity service markets. These virtual experiments can be used to gain insight into the required market structure, the products required and to infer prices for these hypothetical services. Big data analytics is an essential enabler of market creation, as it facilitates the design of granular products and allows effective price discrimination for users. Such individualized pricing has important implications for economic research, methods and regulations. A theoretically driven understanding of consumer behavior can help design policies that successfully deliver societal goals at least cost because they go with the grain of human behavior.

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Notes

Notes

About the Authors

Rolando Fuentes

Rolando is a Research Fellow at KAPSARC, where he researches business and regulatory models in the Innovation in Electricity Transitions program. He has extensive experience in the energy and environmental sectors as an academic and policymaker. Rolando holds a B.A. (Hons.) from Tec de Monterrey, an M.Sc. from University College London and a Ph.D. from the London School of Economics. He was awarded a U.K. government Chevening Scholarship in 2001.

Emre Hatipoglu

Emre is a Research Fellow at KAPSARC. Before joining KAPSARC he was Associate Professor at Sabanci University, Istanbul, where he was the coordinator of the International Studies (B.A.), Conflict Analysis and Resolution (M.A.) and European Studies (M.A.) programs. He is a Fulbright Senior Scholar and served as a member of the advisory board at Columbia University’s Sabanci Center for Turkish Studies from 2016 to 2019.

Thamir Alshehri

Thamir is a Senior Research Associate in the Energy Transitions and Electric Power program, currently focused on creating data-driven tools to identify and evaluate different energy market scenarios, as well as using ‘big data’ technologies to better understand the impact of behavior and the environment on energy consumption. Thamer is interested in using technologies to facilitate better energy public policy and energy economical systems. He previously worked as a lecturer in Australia and has entrepreneurial and industrial experience from working on award-winning projects such as the Burj Khalifah Building Management System.

Matt Lipson

Matthew is Business Leader for Consumer Insight at Energy Systems Catapult. He helps bring industry, academia and government together to accelerate the development of new technology-based products and services in the energy sector.
Matthew has spent the last 20 years working with universities and businesses for DECC, the Committee on Climate Change, the Energy Technologies Institute, and Orange (amongst others) to design energy policies and commercial propositions that people love. He is now using his experience to help others design delightful, intuitive low-carbon product and service experiences.
He is currently focusing on harnessing the emerging ‘smart,’ connected home to decarbonize home life. Matthew holds a B.Sc. in Psychology from Sheffield University, an M.Sc. in Environmental Technology from Imperial College and a Ph.D. in Neuroscience from Oxford University.

Scott Milne

Scott Milne is Head of Insights at Energy Systems Catapult, providing whole systems analysis that builds on multiple capabilities across the organization, including modeling, engineering and policy.
In May 2019, he published “Living Carbon Free” for the U.K. Committee on Climate Change as part of their net zero advice to the U.K. government. This report explored what a net-zero target might mean for individual households.

Scott also leads ESC’s work on national energy systems scenarios, including the 2018 edition of “Options, Choices, Actions,” describing alternative pathways toward a low-carbon U.K. energy system.

He has delivered a variety of whole-system analysis projects for external clients, including modeling for the U.K. government’s “Techno-Economic Appraisal Of Small Modular Reactors.” He also led the ESC’s contribution to the update of the U.K. government’s “2050 Calculator” tool. He completed a Ph.D. in Energy Economics at the University of Surrey in 2011.

Simon Pearson

Simon is the Business Leader for Digital and Data at Energy Systems Catapult and is an experienced leader and technologist with a background in energy, telecommunications, digital broadcast and information and communications technology. Simon is responsible for the strategy, roadmaps, delivery and operation of a set of digital and data assets, and capabilities designed to support innovators, government and other industry stakeholders. Energy Systems Catapult aims to support innovation and provide insights and evidence to help inform and shape the energy sector’s digitalization strategy and facilitate the transformation to a low-carbon energy system. Simon and his team are involved in a range of initiatives, including the Energy Data Taskforce and ongoing evolution of ESC’s Living Lab, which provides a real-world environment to help innovators market test innovative new energy products and services with consumers in real-world homes.

About the Project

This report is part of KAPSARC's Innovations in Electricity Markets project. Rapid technological innovations in low-carbon, demand-response and storage technologies can lead to a more efficient and secure electrical system. However, achieving the full potential of these innovations requires new approaches to policy, regulation and business models. If regulatory reforms, market design, and systems do not keep pace with technological deployment, the outcome could be a less secure electricity market and a longer low-carbon transition period. The right balance between market arrangements and the regulation of the power sector, to successfully manage the sector's transformation, is yet to be found. Policymakers must balance the need for innovation and competition while enabling capital deployment for low-carbon sources of electricity. A market design appropriate for the energy transition must provide efficient price signals and enable a flexible and adequate competitive supply. New technologies allow consumers to contribute to a more flexible and less costly electricity system, responding to wholesale market price signals. This could enable a better balancing of electricity generation with energy services and storage, increasing the system's flexibility to integrate variable renewables and improve the security of the electricity supply. Regulating distribution networks should, in principle, enable distributed energy resources to participate in local and wholesale markets. There are presently no clear solutions to these challenges.

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