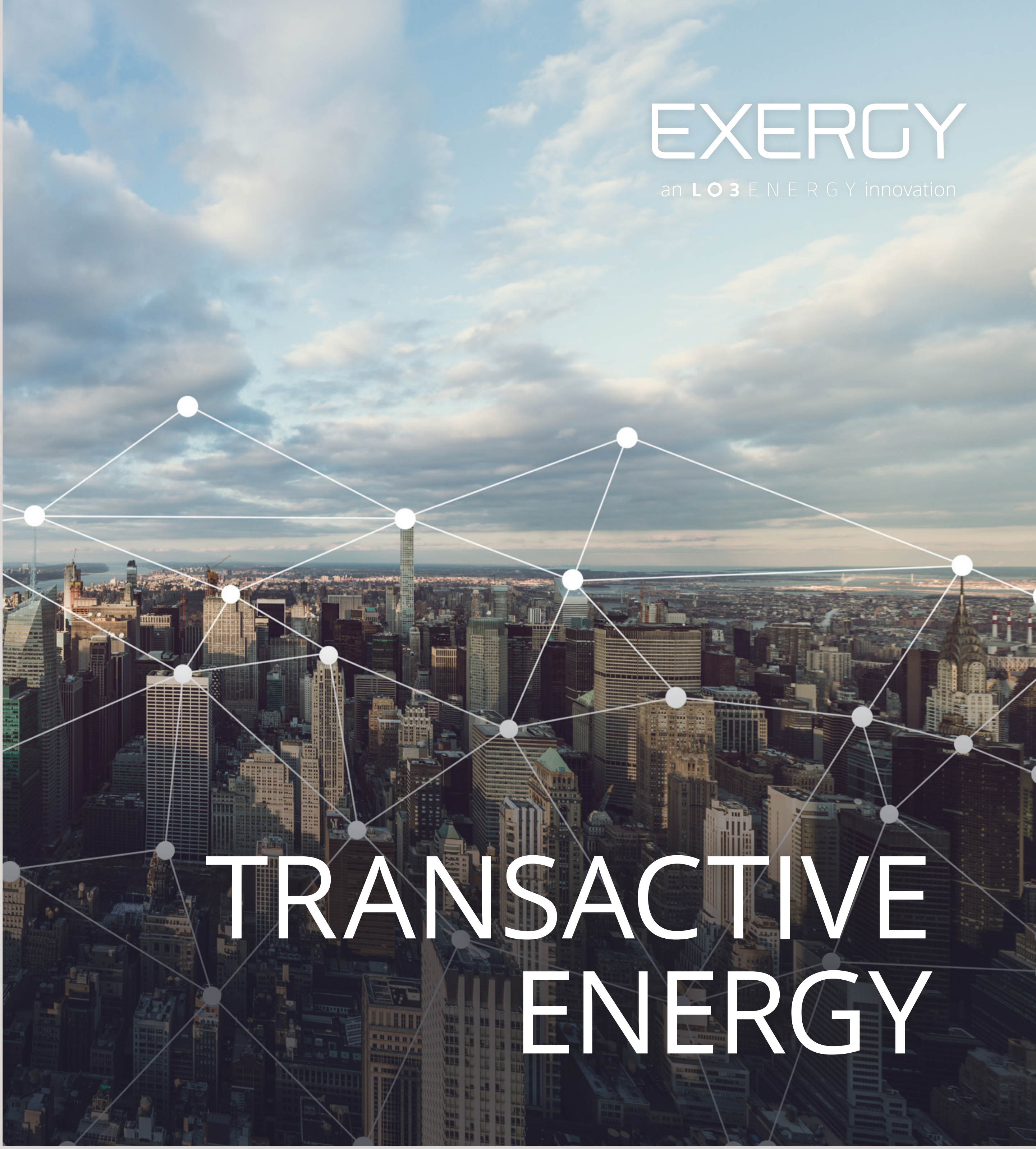

EXERGY

an LO3 ENERGY innovation

TRANSACTIVE ENERGY

A New Approach for Future Power Systems

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Introduction

International policies aimed at addressing climate change combined with advances in power generation technologies and information and communications technologies (ICT) have triggered a profound transformation in energy sectors around the world. This transformation is driven by three key disruptive forces: (1) decarbonization, (2) decentralization and (3) digitalization.

Decarbonation: Steep declines in the cost trajectories for renewables are shifting supply sectors from their traditional fossil fuel and nuclear foundations toward wind and solar power. According to Bloomberg New Energy Finance (BNEF), between 2000 and 2018, 1000 gigawatts (GW) of wind and solar generation capacity has been installed globally. And they expect the next million to be reached in just 5 years for half the cost.[1] BNEF also predicts USD 8.4 trillion will be invested globally in solar and wind power between 2018 and 2050, with zero emissions technologies expected to contribute more than 70 percent of energy supply globally by the end of this period. This is already beginning to create significant problems for electric power systems. Integrating large volumes of variable renewable power generation into power grids is making it harder for system operators to balance supply and demand. It's also driving down future returns available for all generators in wholesale energy markets, who face threats to their viability as large volumes of zero variable cost capacity enter the market and drive wholesale prices lower.[2]

Decentralization: Customers are installing more rooftop solar and batteries as their costs decline and customer preferences change. The cost of solar panels has fallen 70 percent since 2010 with a further 71 percent cost reduction expected by 2050, while battery costs have fallen by 80 percent since 2010 and are expected to fall a further 66 percent by 2030. Rooftop solar plus battery storage will reach cost and performance parity with grid-sourced electricity by 2021 in Australia and 2022 in the European Union, with other nations expected to follow soon after. Electric vehicles (EVs) will reach cost and performance parity with combustion engine vehicles over the next decade – which is expected to increase EV sales around the world from 1 million today to more than 30 million per annum by 2030.[3] BNEF is expecting by 2040 some 559 million EVs will be driving on roads around the globe, making up 33 percent of the global car fleet.

Digitalization: The International Energy Agency (IEA) expects 1 billion households and 11 billion smart appliances will actively participate in interconnected electricity systems by 2040.[4] Perhaps the most important implication of digitalization is that it creates unprecedented opportunities for customers to become more informed, engaged and active in how they source and manage the use of their energy resources. They will become more demanding and expect smart connected products and smartphone access to energy information anywhere, anytime.

1 Bloomberg New Energy Finance (BNEF), "New Energy Outlook 2018", June 2018 https://about.bnef.com/new-energy-outlook/
2 Sivaram Varun, Taming The Sun Innovations to Harness Solar Energy and Power the Planet (MIT Press Cambridge MA 2018) pp 68-71
3 Bloomberg New Energy Finance (BNEF), New Energy Outlook 2018, June 2018, https://about.bnef.com/new-energy-outlook/
4 International Energy Agency IEA, "Digitalization and Energy", November 2017, https://www.iea.org/digital/

Smart solutions challenge the existing received wisdom about how energy systems need to work. Traditional regulatory models focused predominantly on a centralized supply – where electricity is distributed over long distances from large remote power stations to consumers. In a future world of technologically empowered consumers where new and more efficient technologies will enable dramatic opportunities for innovative new business models at the grid edge, supply-led models are no longer fit for purpose. Models that can utilize the power of technologies in the hands of consumers have the additional benefit of reducing energy system costs in a number of ways which will be discussed in the forthcoming sections.

As challenges to legacy business models grow, so too will the need for regulators and policy makers to take an active role in progressive reform and policy development to support the transition to an energy environment which looks vastly different than that of today.

This paper considers the concept of 'transactive energy' and a range of supporting regulatory policies as a possible future framework for addressing the key challenges posed by the energy transition. The concept of transactive energy extends the current transmission level optimization down to the distribution level, and considers how transactions through price enable better optimization throughout the energy system. Ultimately this shift can reduce costs, improving asset utilization and energy services for all, if it is designed with consumer value as a starting point.

Disruptive Forces Shaping the Energy Transition

Decarbonization

Climate change represents the defining global challenge of our time. In December 2015, the world's nations came together to negotiate the Paris Agreement, which commits those involved to limiting global average temperature increases to less than 2°C above pre-industrial levels by 2050. Almost every nation in the world is now focused on reducing greenhouse gas emissions to meet these targets, with the power sector expected to play a key role. While solar and wind power generation combined currently make up about 5 percent of the global electric supply (with notable exceptions being Spain with 21 percent, Germany 18 percent and UK 14 percent), this is changing rapidly.[5]

At the same time, demand for electricity continues to grow globally. The share of electricity in final energy consumption has doubled in the last 40 years from 11 percent in 1973 to 22 percent in 2015.[6]

With further electrification of transportation expected and increasing numbers of people gaining access to electricity in developing countries this trend will accelerate. With 1 billion people still without access to electricity, meeting these growing needs will require electric capacity to more than double by mid-century on a global scale.[7]

While progress on decarbonization is gathering momentum, the challenge is daunting. The Intergovernmental Panel on Climate Change (IPCC) report commissioned as part of the 2015 Paris climate agreement illustrates the sheer scale of the decarbonization challenge. It suggests that 70 to 85 percent of electricity will need to be provided by renewables by 2050 to avert the most dangerous impacts of climate change. That will require USD 2.4 trillion to be invested in all forms of renewable electricity every year from now until 2035.[8]

Fortunately, the costs of solar and wind power are continuing to decline and speeding up the transition. The cost trajectories of solar and wind mean they are already cheaper than building new large-scale coal and gas plants anywhere in the world.[9]

5 International Energy Agency (IEA), "Key World Energy Statistics" 2018, pp 10-11
6 International Energy Agency (IEA), "Key World Energy Statistics" 2017, pp 34-35
7 International Energy Agency (IEA) "Technology Perspectives 2016, Towards Sustainable Urban Energy Systems", June 1, 2016 http://www.iea.org/etp/
8 Accessed at http://www.ipcc.ch/report/sr15/
9 Bloomberg New Energy Finance (BNEF), "New Energy Outlook" 2018, June 2018, https://about.bnef.com/new-energy-outlook/

Decentralization

The falling costs of rooftop solar and battery storage is turning previously passive customers into 'prosumers,' who produce, store and consume their electricity. The cost of solar panels has fallen 70 percent since 2010 with a further 71 percent cost reduction expected by 2050, and battery costs have fallen by 80 percent since 2010 and are expected to fall a further 66 percent by 2030.[10]

Ernst and Young (E&Y) predict that once cost and performance reaches parity with grid supplied electricity this will profoundly change energy markets - making them far more decentralized than they are now.

E&Y additionally predicts that due to a wealth of solar and wind resources and the comparatively high cost of grid-sourced electricity, Australia will be the first tipping point reached by 2021. The EU will follow in 2022, by which point it is expected grid consumption will be lowered by 45 TWh per year, placing $11 billion of utility revenues at risk annually. California, with nearly 40 million people, may follow soon after. That state has recently made it mandatory that all newly constructed homes be built with rooftop solar. This is expected to bring the cost of residential solar down to the point where it will compete with larger utility scale solar, because mandatory requirements create positive spin-offs that reduce the 'soft costs' of residential solar, such as those associated with permitting, financing, installation and the cost of customer acquisition.[11]

These tipping points are anticipated to drive a profound transformation of energy markets, making them far more decentralized than they are today. For example, by 2050 BNEF expects that at least 45 percent of Australia's overall power generation capacity will be located on the rooftops of residential consumers and businesses. Japan is expected to become the second most decentralized market in the world with a third of its generation capacity expected to be located behind the meter. The EU will follow with a third of its generation capacity behind the meter by 2050.[12]

Critical Tipping Points	< 3 years	< 7 years	< 20 years
	Off-grid energy will reach cost and performance parity with grid-delivered energy	Electric vehicles will reach cost and performance parity with combustion engine vehicles	The cost of distributing energy will exceed the cost of generating and storing it locally

Source: https://www.nrel.gov/analysis/electrification-futures.html, http://www.ey.com/gl/en/industries/power---utilities/ey-will-blockchain-technology-be-adopted-in-a-distributed-energy-world

10 Bloomberg New Energy Finance (BNEF), New Energy Outlook 2018, June 2018, https://about.bnef.com/new-energy-outlook/
11 https://pv-magazine-usa.com/2018/05/14/california-residential-solar-power-headed-to-1-12-w-2-5%C2%A2-kwh/
12 Bloomberg New Energy Finance (BNEF), "New Energy Outlook" 2018, June 2018

Digitalization and the Internet of Things

Advances in digital technologies are disrupting business models in every industry they touch. Communications are increasingly possible between sensor-embedded digital devices, appliances and databases, creating a vast virtual machine known as the Internet of Things (IoT).

The potential for new business models underpinned by digital capabilities to disrupt industries is famously demonstrated by Amazon disrupting physical shops, or Uber-style 'sharing economy' platforms. It took Airbnb just four years to have available the same number of rooms for rent as it took hotel company Hilton 90 years to build.[13]

Energy is no exception. Investment in digital energy infrastructure and software, such as intelligent home systems, 'smart' meters, thermostats, lighting and sensors is growing at 20 percent per annum with billions of devices expected to be connected to electricity markets through the internet in coming decades.[14]

A range of digitally enabled smart devices now exist on the market. Nest Labs offers Wi-Fi-enabled thermostats that use self-learning algorithms and sensors to improve heating, cooling and hot water management in households.[15] Alliander, a Dutch distribution system operator (DSO)[16], has installed smart sensors on street lamps, which allows them to respond to wholesale market price signals using specialized software and communications technologies. It has rolled out its technology to streetlights in 800,000 streets across 14 municipalities in The Netherlands.[17]

There is a growing global market for home energy management systems (HEMS), which use digital technologies to monitor and control smart appliances for managing energy and water use in homes.[18] For example, a Swedish property management company has installed sensors for HVAC and hot water systems in 10,000 apartments and connected these to a cloud-based energy management platform developed by Microsoft. This allows for optimal use of these systems for saving on energy and water costs by heating water at off-peak times when energy costs are low and reducing air conditioning loads by small amounts at peak times, while maintaining the overall level of comfort. The technology also includes a smartphone app that shows energy consumption and publishes alerts and reports to customers.[19]

Digital technologies are opening up the opportunity for millions of customers and prosumers to implement innovative ways to reduce their energy bills, engage in wholesale energy markets and provide valuable services to the grid, by allowing for the connection, monitoring, aggregation and control of their batteries, solar panels and devices.

13 Peers, Inc by Robin Chase, 2016
14 International Energy Agency (IEA) "Digitalisation and Energy", November 2017, p 25, http://www.iea.org/digital/
15 Ibid p 45
16 The DSO operates and owns the distribution networks
17 https://www.smart-energy.com/regional-news/europe-uk/alliander-introduces-internet-of-things-platform-for-dutch-municipalities/
18 https://www.utilitydive.com/news/how-the-home-energy-management-market-is-reinventing-itself/357216/
19 https://blogs.microsoft.com/iot/2017/02/21/swedish-apartments-transform-into-smart-buildings-with-iot-makeover/

The Data Revolution

Another consequence of growth in smart technologies, such as smart meters, IoT-connected devices and appliances and sensors, is the vast amounts of granular data they create. And we are only just beginning. 98 percent of the world's data has been produced in the last 2 years, according to IBM.[20]

Developments in AI, big data and analytics and the growth of blockchain technology are being harnessed by a new wave of technology companies to capture this data and turn it into useable information and value-added products and services for customers.[21] For example, AI and machine learning techniques could allow smart devices to collect energy data and use this data to predict future behavior patterns and potential energy savings based on past experience.[22]

Blockchain now makes it possible to capture and store energy data transactions in a highly secure yet decentralized fashion. Access to data stored in a blockchain is controlled through a process of encryption and 'permissioning' which requires users to have a digital key (like a password) for 'unlocking' access to the encrypted data.

This creates a framework for managing large volumes of data and guaranteeing its integrity and privacy. A key strength of blockchains are that they transform information into an asset that cannot be copied or duplicated. As such, it allows data to be bought, sold and shared with others in a quick and seamless fashion. Blockchains are explained in more detail in Box 1 on the following page.

20 https://www.iea.org/publications/freepublications/publication/DigitalizationandEnergy3.pdf
21 World Economic Forum, "Here's how AI fits into the future of energy" https://www.weforum.org/agenda/2018/05/how-ai-can-help-meet-global-energy-demand
22 NEED CITATION

Distributed ledger technologies – *also known as blockchains*

A blockchain is a form of database or ledger that is distributed across a network of participants – creating multiple identical copies. A blockchain is used to digitally represent a particular resource and record the history of all transactions ever made of that resource – it could be anything from digital currency to bunches of bananas.

Due to the mathematical and cryptographical techniques used, as well as the fact that multiple copies of the data are held and stored by different users (nodes) at any given time, it is almost impossible to fake new entries or tamper with a blockchain. This makes it possible to transact even between parties that do not trust one another.

Blockchains have recently gained popular attention. The blockchain that allows computers to create a secure cryptocurrency called ‘bitcoin’ is probably the most famous application of the technology. The other most utilized blockchain is Ethereum, which has gained traction because it allows software developers to write so-called ‘smart’ contracts, or self-executing code that can transact digital assets or data. Based on this technology, and other blockchains like them, companies are beginning to develop ‘dapps’ (distributed applications) where no one central decision-maker is required to execute the application.

Bitcoin and Ethereum run on ‘permissionless’ blockchains, allowing any node to participate as long as it plays by the rules of the contracts and code. These blockchains are also publicly accessible and verifiable, meaning that anyone with sufficient computing power can audit the history of transactions. Other blockchains are ‘permissioned’ which means only certain parties have access (e.g. a financial institution might run a blockchain that is only accessible by its customers). Transactions (or bundles of transactions) are recorded on the nodes, which all hold copies of the same information, with each transaction linked to the next using cryptographic techniques.

This results in a highly secure yet decentralized database. It also comes at a cost, because with no human in the loop it requires computer hardware, processing power and energy to process the transactions (generally energy consumption is in line with the difficulty of the cryptography, though that relationship is rapidly evolving). With these high costs come many potential benefits, including resiliency to cyber-attacks. Since it is impossible to tamper with data at one node as the information is duplicated across many nodes and no one node can override the data on others.

— Digitalization and Energy, International Energy Agency, 2017

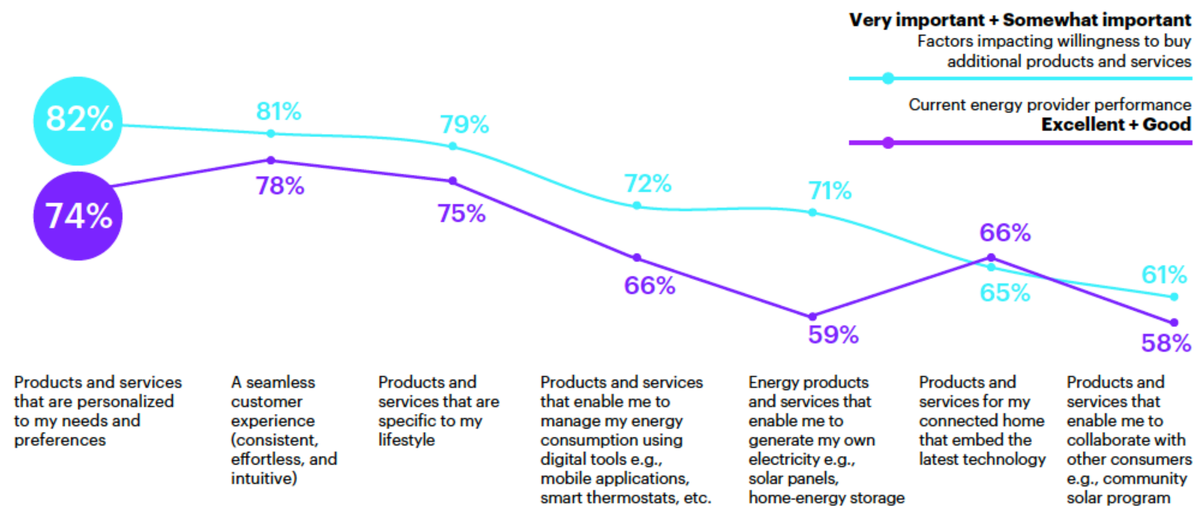
The New Energy Customer

Traditionally energy markets are based on consumers as passive customers of energy only thinking about electricity when there is an outage. This is changing, in part due to the imperative to address climate change. A recent US-wide survey found that 70 percent of customers support a move toward 100 percent renewable energy and 51 percent are willing to pay 30 percent more for it.[23] Digitalization is also changing the relationship between consumers and energy. According to a global Accenture survey, in 2017 more than 70 percent of consumers in 19 countries want more innovative and personalized energy services, including greater choice for using and managing energy, while 61 percent would like products and services that would allow them to collaborate with others, such as peer-to-peer energy trading or community solar.[24]

The Personalization Gap

One of the key consequences of advances in digitalization is that service providers will have the tools and data to improve service quality and improve customer relationships. At the same time, customers will have increased access to data and information allowing them to become more empowered and sophisticated in their engagement in energy markets (even in automated ways through setting preferences in their 'apps' or with their utilities). In addition, distributed energy resources such as rooftop solar, battery storage, smart appliances and devices are expanding the choice set for customers.

WHAT WOULD MAKE YOU WILLING TO BUY ADDITIONAL PRODUCTS AND SERVICES FROM YOUR ENERGY PROVIDER? BASED ON YOUR EXPERIENCE OVER THE PAST 12 MONTHS, HOW WOULD YOU RATE YOUR ENERGY PROVIDER'S PERFORMANCE ON PROVIDING YOU EACH OF THE FOLLOWING?



Base: All respondents.

Source: The New Energy Consumer research program, 2017 consumer survey.

23 https://www.vox.com/energy-and-environment/2018/9/14/17853884/utilities-renewable-energy-100-percent-public-opinion
24 Accenture, The New Energy Customer Research Program, 2017 customers survey, https://www.accenture.com/us-en/insight-utilities-new-energy-customer-2017

Energy Market Transition: Key Challenges

The disruptive forces shaping energy transition are creating a number of important challenges for power systems around the world. These will need to be addressed if decarbonization goals are to be achieved at acceptable costs to society and future energy markets are fit for purpose in meeting the needs and preferences of customers.

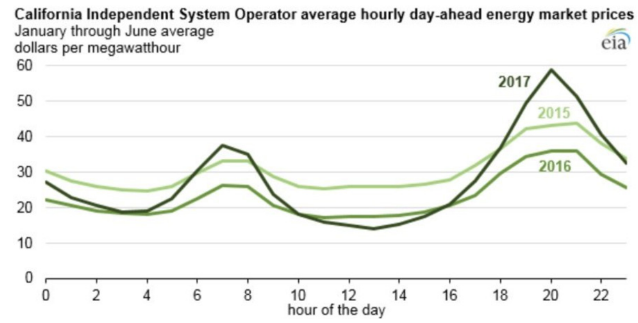
Value Deflation

The sheer scale of the investment task to avert the most serious impacts of climate change is enormous, with USD 36 trillion in investment in renewable power required by 2035. But the most popular and cost-effective solutions, solar and wind power, both have characteristics that could make the investment task impossible to achieve.

First, solar and wind power are 'non-dispatchable,' which means the power output cannot be controlled by the system operator or the owner of the generator – they generate when the sun shines or the wind blows. The second important feature is that the cost of producing an additional unit of electricity from renewable sources – its variable cost – is zero. For this reason, renewable power is typically at the bottom of the "merit order" curve and dispatched first.

The consequence of these two features is that as solar and wind power starts to dominate the daytime production of electricity in wholesale power markets, their collective dispatch will become so great it will exceed demand. This has the effect of depressing the wholesale price of electricity, even making it go negative for periods. When the price goes negative this means system operators are trying to find ways to pay generators or interconnectors to remove power from the system.

Some markets around the world, such as South Australia, UK, Germany, California and Chile, are already experiencing these effects – often referred to as the 'duck curve.' The duck curve refers to the impacts of a penetration of renewable power on the overall shape of the demand curve for grid-supplied energy. During the day, we see the curve hollowing out due to the oversupply, and peaking in the mornings and evenings when demand is greatest.



Source: US Energy Information Administration

An example of the duck curve for California is illustrated in Figure 1 above.

Figure 1 shows that the minimum daily load in California has been falling significantly in recent years, with daytime wholesale prices falling in tandem with increasing levels of daytime solar production.

Currently this might only happen a few days per year, but with higher penetrations of wind and solar this could happen so frequently it could significantly reduce future revenues for solar and wind power in wholesale markets. Such 'value deflation' risks potentially capping investment in large scale renewables well below the levels required to achieve ambitious climate policy goals.[25]

While wholesale markets vary in structure around the world, the long-term impacts are the same – if the wholesale value of renewable power declines, this will be reflected in spot markets, day-ahead markets and financial markets for daytime power.[26] The revenue model of the competitive energy industry falls, also referred to as the 'utility death spiral.'[27]

25 Sivaram Varun, Taming the Sun Innovations to Harness Solar Energy and Power the Planet (MIT Press Cambridge MA 2018) p 72
26 Ibid p 72
27 https://www.greentechmedia.com/articles/read/this-is-what-the-utility-death-spiral-looks-like#gs.sTERY98

Intermittency

Another key challenge facing the renewable investment task is the variability - or intermittency - of solar and wind power. Seasonal variations in solar due to the changing position of the sun and wind due to long-term weather systems, can cause fluctuations in output. This combined with time of day, and more often changes in wind speeds and solar radiation (e.g. due to cloud cover can cause abrupt and potentially large swings in the amount of electricity generated) have two important consequences for power systems.

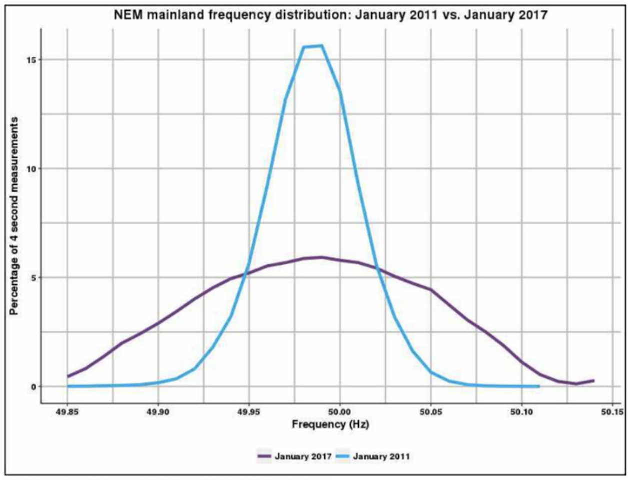
First is reliability. Solar and wind power have relatively low capacity factors reflecting that they only produce power when the right environmental conditions prevail - high solar radiation or wind speeds. Solar power is most reliable during the day and the reliability of wind power can vary depending upon location, it often does not coincide with peak electricity demand, which occurs in the mornings and evenings. This means that at those times when wind and solar power are not generating, customers will need to rely on other sources of supply to meet their demand requirements.

Second, the variability of renewable power also creates issues for the security of the power system. Large and rapid swings in output due to fluctuating environmental conditions can interfere with the delicate frequency bands power systems must operate within continuously to avoid blackouts. Frequency is determined by the balance of supply and demand in the system at any point in time and must not move outside of a narrow band of 50 or 60 Hz (depending on the power system). For example, a large amount of supply coming off line requires immediate restoration of frequency by reducing demand or rapidly increasing supply from other sources. This typically requires the system operator to call on expensive fast start gas-fired or diesel-fueled generation to quickly inject more energy into the system to restore frequency levels.

The risks of frequency deviations to the power system will increasingly become an issue as large fossil fuel generators (such as coal-fired generation) exit the market over time, as such generators are an important source of inertia which is provided by means of their large spinning turbines. Inertia makes power systems stronger by preventing the frequency deviation in the first place. Figure 2 illustrates analysis done in the Australian electricity market by the Australian Energy Market Commission, which shows a power system operating more often at frequencies at the edges of the normal operating frequency band (50Hz). Some of the consequences of deteriorating frequency performance include an increase cost of ancillary services and a reduction in system resilience to disturbances.[28]

continued...

Figure 2: Frequency profile of the Australian Electricity Market in January 2011 versus January 2017



Source: AEMC analysis of 4 second frequency data provided by AEMO.

To date, the variability has been managed by making sure sufficient fossil fuel generation is available for the provision of system inertia and fast start backup. However, keeping large amounts of fossil fuel capacity in the power system for backup and system security is expensive, since much of the capacity is used infrequently, and is inconsistent with achieving ambitious emissions reductions targets. For instance, capacity market contracts in the UK went predominantly to fossil fuel generation (74%).[29]

28 AEMC, Frequency Control Frameworks, Final Report, 26 July 2018, p 28- 29
29 https://blog.tempusenergy.com/blog/2018/11/16/we-have-just-removed-56-billion-worth-of-state-aid-from-the-capacity-markets-where-was-this-money-going

Impacts of Distributed Generation on Networks

As markets become more decentralized, intermittency will also become a technical challenge for distribution networks. Distributed generation creates two-way flows on networks that have typically been designed to accommodate flows only one way – from centrally located power stations to consumers. Excessive flows in the opposite direction can cause voltage fluctuations that affect the operation of appliances and devices on the networks, potentially causing physical network limits to be breached – impacting the quality of the electric supply customers receive.[30] In addition, many of the rooftop solar panels that have been installed to around the world are 'passive' since they were installed without smart inverters. This means they are invisible to system operators and unable to be managed in ways that could deliver a greater impact on the network.

Traditional strategies for managing distributed generation include limiting its ability to export or building more network to accommodate increasing use. These approaches however increase infrastructure costs and conflict with the preferences of prosumers, who would typically prefer to increase the value of their distributed generation by exporting more of their surplus generation into the network, rather than being forced to export less.

Access to Energy-Related Data

Digitalization is unlocking vast amounts of data. This data will be fundamental to unlocking new business models and supporting innovative new products and services for customers. However, in many energy markets around the world it has been difficult to capture energy data in ways that are useful and meaningful for customers and third parties. Much of this data is complex and difficult to access, typically locked away and controlled by utilities, who have little incentive to share this data with others.[31]

The value of data to third parties is expected to increase significantly as customers become more engaged in energy markets and it will need to be protected from market capture, exploitation and cyber threats. Establishing clear frameworks for accessing and managing data will be fundamental to empowering customers in a data rich environment and supporting innovative new products and energy services. Even as new regulation begins addressing data governance regardless of sector, voluntary governance and data management processes are important complementary activities required to build consumer trust. The recent scandals surrounding large tech companies and misuse of data provide cautionary examples.[32]

30 Australian Energy Market Operator (AEMO) and Energy Networks Australia (ENA), "Open Energy Networks, Consultation Paper" 2018, p 4
31 See for example: https://www.greentechmedia.com/articles/read/california-utilities-on-data-sharing-yes-no-and-lets-talk-about-it#gs.cP_Gw9s
32 https://www.marketwatch.com/story/facebook-google-privacy-settings-trick-consumers-into-giving-up-data-consumer-groups-allege-2018-06-28

Transactive Energy:

A New Approach for Future Power Systems

The disruptive forces transforming energy markets are creating challenges for power systems but also new opportunities for addressing those challenges. Intermittency and value deflation of renewable resources, in particular, will need to be addressed if ambitious climate change goals are to be achieved at reasonable cost to society.

Fortunately, advances in smart technologies and digitalization is now making it possible to address these issues. For example, batteries can store excess energy and also release energy at a later time. Smart inverters (which connect solar PV to the grid) can now be installed that allow the flow of electricity from rooftop solar panels to be turned on or off to smooth their impacts on the grid. Advances in ICT and software now allow distributed energy technologies, smart appliances and devices (such as smart thermostats) to respond to price or control signals in real time to balance supply and demand.

However, for the potential value of DERs to be realized in this way it will require a coordination mechanism that can ensure efficient trade-offs can be made between the different services DERs can provide to the system as well as to their owners. Markets are the best means for allowing those tradeoffs to be made, with prices guiding DER services to their most valued uses. A market-based approach to realizing the value of DERs has been referred to as "transactive energy," defined by GridWise Architecture Council[33] as:

> *"A system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter"*

The concept of 'value' referred to in the definition is the market price, which has three key components:

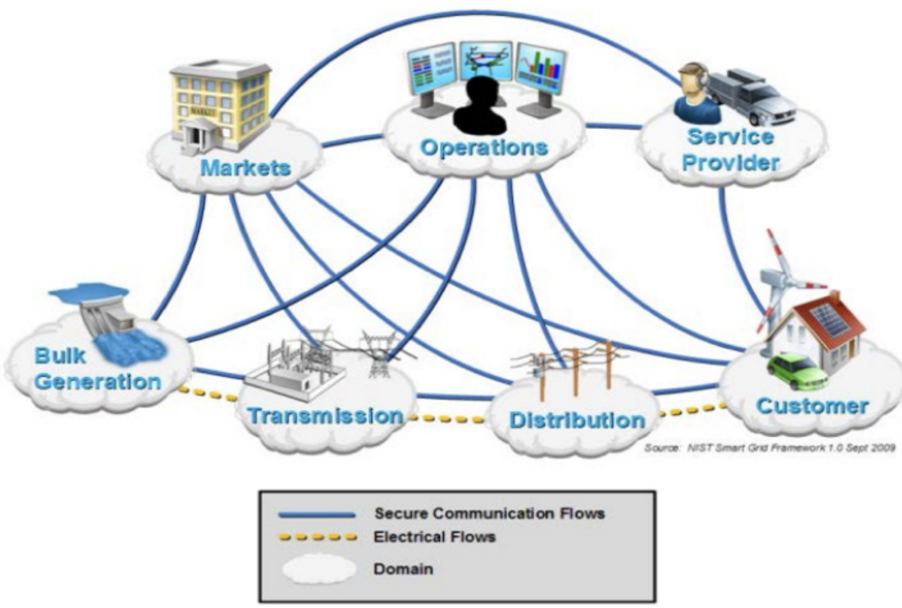
- It reflects the short-term marginal value of energy and the cost of transportation to each customer connection point;
- It is transparent to all producers and end users; and
- All supply and demand decisions within the power system are based on those price signals.

Transactive energy is not a new concept; wholesale markets already operate to encourage balancing of supply and demand through price signals (more expensive times usually correspond to times when the grid requires more resource to manage). What is new, however, is the extension of this concept to distribution networks, or to the 'grid edge.' Under a transactive energy approach, customers – by means of their DERs or smart appliances – participate directly in energy markets through exposure to market-based time and locational-varying price signals.

The concept of a transactive market is illustrated in Figure 3 *(next page)*, where customers with DERs can participate directly in energy markets alongside other market participants such as large generators and retailers, as well as still having the choice to do so through energy service providers.

33 GridWIse Architecture Council (GWAC), "GridWise Transactive Energy Framework. Version 1, January 2015, p 11- 12

Figure 3: Conceptual model of Transactive Energy Market



Source: Distributed Generation and its implications for the Utility Industry" Academic Press, San Diego, Published Elservier 2014, p 197

Transactive energy markets comprise a number of key components:[34]

- Equipment and devices that can be activated either automatically via a local computer responding to external data inputs or remotely via a communications network. These can include thermostats, commercial building control systems, appliances, electric vehicle chargers, solar panel inverters, and grid storage systems;
- Technologies for measuring power flows, voltage, and other grid characteristics at intervals from every few seconds to once an hour. Examples include line sensors, outage sensors, and smart meters;
- Communications technologies for relaying information between devices or systems. This includes the Internet and utility-owned or privately controlled networks that allow smart meters to communicate wirelessly with utilities;
- External data inputs from systems outside of the transmission and distribution smart grid – the key component being price signals from the wholesale power market which need to apply at all connection points within the distribution network; and
- Software for coordinating and managing controllers, sensors, devices, communications networks and the applications that process the data and deliver outputs (such as turning devices on and off).

34 These requirements are reproduced from Chris King, "Transactive Energy: Linking Supply and Demand Through Price Signals" p 189 in "Distributed Generation and its implications for the Utility Industry" Academic Press, San Diego, Published Elsevier 2014

Transactive Price Signals for Efficient Grid Utilization

The core objective of a transactive energy framework is to use price signals to incentivize efficient production and consumption decisions all the way out to the grid edge, the areas physically closest to customers, while taking into account the limitations of the grid. Transactive price signals will reflect two types of costs.

First, the cost of supplying electricity to a particular customer will vary with the timing of when that consumption takes place. In the evenings coincident demand on the network tends to be highest as customers come home from work and turn on their appliances, which means the overall cost of supply is also higher since the additional capacity called on to meet demand comes from more expensive generation because the cheaper options have already been used.

Second, the costs of supplying customers is dependent upon where those customers are physically located within the network. This is because the capacity of the network varies by location, which limits the amount of energy that can flow to different parts of the network. Consequently, in order to ensure that demand can continue to be met, the system operator will need to check that the supply options available can meet that demand without breaching network limits. If the demand cannot be met, the system operator will typically require those generators to reduce their production and ask others to increase their level of production to be able to meet that demand. This typically increases market prices because generators in the latter group are asked to produce more than their preferred level and will therefore need to be paid more by the system operator for doing so.

This type of decision making by the system operator is normally automated through mathematical optimization algorithms that compute resulting prices at high frequency (e.g. a 5-minute by 5-minute basis) although actual supply and demand balancing must occur on a second-by-second basis. Consequently, the cost of supplying electricity varies by timing and location.

However, energy markets also vary in terms of how they calculate and communicate these costs to market participants. In energy markets with locational marginal pricing (LMP) at the transmission level (most US markets), market prices reflect these costs and therefore vary every 5 minutes at each transmission connection point. The locational marginal price represents the lowest cost combination of generation required to meet an additional increment in demand at a connection point, taking into account network limits (i.e. congestion) and losses.

In many other markets (referred to as 'zonal markets'), such pricing is only included in optimization models for the purposes of managing dispatch of generation within network limits, but not communicated to market participants. In zonal markets, prices are usually determined based on a merit order dispatch (with the most expensive bid usually setting the market clearing price) and assumes there are no constraints within the system.[35]

35 In markets based on self-dispatch and balancing markets this approach applies in the balancing market only (i.e. the market price reflects balancing actions only)

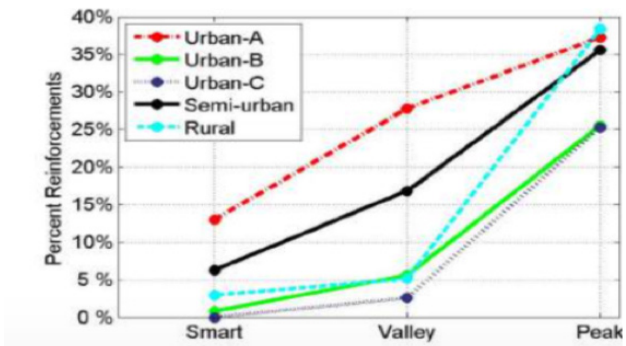
36 While prices could potentially vary every 5 minutes for customers retailers may prefer to manage the risk on behalf of customers

Transactive energy prices would transmit the above cost signals directly to end users at the distribution level, so that each consumer faces the marginal value of electricity supply at their connection points. This would have several desirable properties for encouraging efficient utilization of the grid. For example, high transactive energy prices in a particular part of the distribution network would signal to customers that supply is scarce (and only more expensive generation capacity is available to meet demand), which should therefore discourage consumption at these times or locations, or alternatively put greater value on self-consumption or dispatching DERs.[36] Conversely when transactive prices are low in a particular part of the network this would signal that there is plenty of spare network capacity available (or more than enough supply to meet demand) in that part of the network at that particular time. This should encourage consumption in these locations and/or times.

Therefore, customers and their devices would face real time and locationally-variant prices that would tell them exactly how much they would be paid for reducing or increasing their production in different parts of the network. This would not need real-time or frequent manual intervention by customers. Customers could simply pre-program their solar inverters or batteries to undertake certain actions as different price thresholds are reached, or delegate the decisions to trusted third parties. This would allow supply and demand to be met in real time at each connection point in the system and signal where and when customers' DERs can deliver the most value to the power system. The potential value of locationally and temporally varying price signals for DERs is illustrated in a case study explored by the Massachusetts Institute of Technology (MIT)[37] summarized in Box 2 *(next page)*.

37 MIT, "Utility of the Future: An MIT Energy Initiative response to an industry in transition" 2016

Transactive price signals and EV charging



BNEF estimates that by 2040 some 33 percent of the global car fleet will be EVs, with annual sales reaching 30 million vehicles by 2030 . This suggest that EV charging could contribute a significant increase in electricity demand. Enabling smart charging of EVs is therefore key to reducing the impact of this new class of demand on power system costs. One recent model demonstrates the impact of different charging strategies on costs within five large-scale distribution networks in Spain.

EVs are modeled under three different charging strategies (smart, valley, and peak). The "smart charging" strategy is responsive to price signals or dispatch signals that reflect local distribution network constraints. The "valley charging" strategy charges vehicles on a schedule that considers only wholesale energy prices, without accounting for distribution network constraints. Under the "peak strategy," EV owners start charging their vehicles whenever they arrive home without regard to marginal energy prices or distribution network constraints. Three scenarios were modeled, a low, medium and high EV uptake scenario. The diagram below illustrates the distribution network reinforcement costs (as percentage of initial network cost) in five representative distribution networks out to 2035 under a high EV uptake scenario (EVs reach 20 percent of the overall light-duty vehicle fleet).

A peak charging strategy wherein EV owners plug in their vehicles whenever they arrive home would entail a 25 - 40 percent increases in distribution network costs (as well as additional impacts on generation and transmission network costs).

A valley charging strategy that is responsive to wholesale energy prices reduces the impact on distribution networks somewhat. Yet EV charging may still drive network reinforcements under this strategy on circuits that experience local coincident demand peaks that do not align with system-wide demand peaks. By contrast, a smart charging strategy that reflects local network limits requires the lowest distribution network reinforcement costs, adding less than 14 percent to existing network costs in an urban context. This illustrates the importance of pricing electricity services to reflect the cost of distribution network constraints to avoid unnecessary network reinforcements.

Source: "Utility of the Future: An MIT Energy Initiative response to an industry in transition"

38 BNEF, Electric Vehicle Outlook: 2018

39 Mateo, C., T. Gomez, A. Sánchez-Miralles, J. Peco, and A. Candela. 2011. "A Reference Network Model for Large- Scale Distribution Planning with Automatic Street Map Generation." IEEE Transactions on Power Systems 26 (1): 190–97.

Role of Transactive Energy in Addressing Intermittency and Value Deflation

Transactive energy provides a framework within which DERs can address the problems of intermittency and value deflation. In relation to intermittency, batteries or connected devices can participate in demand response, instantaneously responding to dynamic price signals produced by supply and demand imbalances (as reflected in balancing or real time markets) and quickly restoring system frequency. A greater reliance on grid-edge resources should lower overall power system costs because the energy that is required to keep the system secure and reliable can come from these grid-edge resources rather than from 'backup' or 'spinning reserve' fossil fuel.

For example, if the transactive energy price moves above a certain threshold due to a rapid fall in renewable electricity supply (caused by a drop in wind speed or solar radiation) this could activate demand response either by triggering appliances or smart devices to be turned down, or by triggering those customers with battery storage to dispatch their electricity into wholesale markets. Conversely, if the local price moves below a certain threshold (e.g. due to overproduction during the day) this could trigger those solar installations with smart inverters to turn off their electricity flow or signal those residential battery storage or EVs with the appropriate communications technologies to begin absorbing electricity from the grid, limiting overproduction and subsequent impacts on wholesale prices. This could address the issue of value deflation. In this way transactive control technologies and price signals would assist in keeping markets balanced and the consequences of intermittency and value deflation under control. The potential role for transactive price signals in facilitating demand response is illustrated in a study outlined in Box 3 (next page).

Demand centers, price signals and demand response

Energy management of large and distributed data centers is becoming a more common feature of energy markets around the world. With the fast development of cloud computing services, it is now common for a cloud provider (e.g., Google, Microsoft, or Amazon) to build multiple, large, and geographically dispersed data centers across continents. Each data center may include hundreds of thousands of servers, massive storage equipment, cooling facilities, and power transformers. The energy consumption and cost of data centers can be significant. For example, Google reported in 2011 that its data centers continuously draw almost 260 MW of power across the US. That's more power than is used in all of Salt Lake City.[40]

A recent study examined the potential for owners of data centers to shift energy consumption between different data center locations based on price signals. iCloud service users sent computing requests via the Internet to the cloud provider. They allocated this request to any connected data center, as illustrated in the diagram below:

The study applied a tiered approach to pricing, with higher prices applied at locations or times where demand was high and lower prices at locations where demand for cloud services was lower. The model then minimized the total energy cost of the data centers by assigning users' requests to different data centers depending on the hourly price at each location.

The results showed that data centers could reduce their total energy cost by an average of 28 percent over 24 hours by taking advantage of dynamic prices to reallocate their workload. At the same time, they were able to reduce pressure on the grid at peak times.

Source: Hao Wang, Jianwei Huang, and Xiaojun Lin, and Hamed Mohsenian-Rad, "Proactive Demand Response for Demand Centres: a Win Win Solution", IEEE transactions on a Smart Grid 7, No 3, May 2016: 1584-1596

40 https://www.environmentalleader.com/2011/09/google-reveals-electricity-use-breaking-its-silence/

The Potential of Transactive Energy to Promote New Business Models

Transactive energy markets will provide opportunities for innovative new business models to flourish. These will arise from exposing customers to efficient price signals, which provide a clear and transparent compensation mechanism for DERs. Clear and transparent price signals will increase the value of digitalization and encourage consumers to adopt smart technologies as a way to lower their own energy costs while providing value to the power system. This will spur growth of non-traditional energy companies to enter energy markets and technology companies such as Amazon, Google and Apple could participate as well.

Transactive energy principles are already beginning to be implemented through innovative new business models. For example, some retailers and technology companies are developing software platforms that can connect customers directly to wholesale markets. Currently this occurs primarily through the creation of virtual power plants (VPP) in which large numbers of individual DERs (such as rooftop solar with smart inverters, batteries or appliances) are aggregated to collectively look like larger resources and then connected to the market system operators.[41] Many countries are in the process of changing their market rules to make it easier for such aggregators to participate in wholesale energy and ancillary markets.[42]

However, implementation of transactive energy markets may in the long term even diminish the need for aggregators as DERs who could participate directly in energy markets by responding individually and autonomously to their location marginal price at their connection point.[43]

While it has only been applied in a limited way thus far, the potential for demand response would appear to be enormous in a future where billions of customers will be interconnected to power systems through their smart devices and the IoT. With the right price signals, this could provide a huge pool of demand-side resources for absorbing large volumes of intermittent renewable resources.[44]

An important issue that will need addressing in a transactive market environment, however, are those more vulnerable customers who may not necessarily be able to afford to install the required appliances they need to benefit from transactive price signals. Without the right tools, such customers may be disadvantaged. Strategies must be put in place to ensure those customers can benefit from transactive energy markets. Already, studies of dynamic pricing in Illinois and the UK[45] show that some of the fears may be unfounded: with an hourly pricing tariff, 99% of Com Ed's lower income customers would have saved money.[46]

> 99% of low-income customers would have saved money using Com Ed's hourly dynamic tariff.

41 For example, South Australia is developing the world's largest virtual power plant, comprising some 50,000 Tesla batteries and rooftop solar installations for dispatch into the wholesale market. The VPP will be the equivalent of a gas fired peaking plant (approximately 250 MW).
42 https://www.euractiv.com/section/electricity/news/eu-negotiators-agree-dynamic-pricing-of-electricity/ https://www.energymatters.com.au/renewable-news/new-rules-virtual-power-plants-australia/
43 This issue is explored in Massachusetts Institute of Technology (MIT), Utility of the future, "An MIT Energy Initiative response to an industry in transition", 2016, Section 6.4
44 Sivaram Varun, Taming The Sun Innovations to Harness Solar Energy and Power the Planet (MIT Press Cambridge MA 2018), p 215
45 https://octopus.energy/static/consumer/documents/agile-report.pdf
46 Com Ed's Hourly Pricing Program 2016 Annual Report, April 25, 2017

How Customers Could Benefit from Transactive Energy

These new capabilities will enable and incentivize an increased volume and diversity of transactions beyond the familiar energy retail model of dollars-for-kilowatts. Some of the elements we see changing are:

New pricing and payment systems

Instead of paying for electricity as we do today, on fixed-price, one to three year contracts using estimated rather than actual consumption (which is required for standard accumulation meters), we will be paying prices that vary dynamically with time and location using apps or tokens to do so. This is as true for markets like Africa where mobile payments are already commonplace as it is for advanced markets where we expect all our services to be costed on-demand. Optimization of settlement, which can significantly reduce utility costs, is one outcome, but new service options based on time and location can realize far more disruptive benefits, such as those highlighted below.

New customization

Local energy, green energy or self-sufficiency will be able to be priced and valued in the new marketplace. Fleet owners, commercial customers or large housing associations with significant demand can expect to be able to customize what they need for their business, such as a willingness to let their employees plug in their EVs (thereby increasing employee retention). It will be possible to create bespoke solutions for each factory in a corporate's global operations that follow a set of business preferences including, maximizing for 100 percent renewables (which more than 100 global corporations have already committed to[47]) or for cost, or ideally, both at the same time. These solutions exist today but are not yet deployed at scale.

Mobility integrated to electricity

Today we do not think of our cars as mobile electricity storage, but in the near term, we may be able to buy electricity to power our cars at different prices in different neighborhoods or be offered services to avoid parking in places that have high charging costs. Already, pilot projects allow EV owners to share their charge with their neighbors. Integrated mobility increases demand but provides better livability in cities (less pollution on site) and the advent of autonomous vehicles will change the patterns of mobility, increasing unpredictability for distribution network operators.

Convenience and reliability

New service providers will be looking for ways to engage customers in new offers, where electricity is just an enabler. Why replace a fridge once it is broken when electrical signals can warn you it is likely to fail, and order you a new one? Why not have insurance for smart appliances wrapped into your bill? Why not have your security provider turn on your heating before you get home?

47 http://there100.org/

Public health and lifestyle benefits

Companies already are exploring the potential opportunities this could offer. What if your elderly mother's kettle sent you an alert if she didn't get up one morning for her 7am cup of tea? What if we could eradicate fuel poverty by using storage heating in social housing to soak up excess onshore wind generation at night, so that tenants could wake up to free hot water? And what if we could enjoy clean air by utilizing 100% of the renewable energy that we have already generated, displacing carcinogenic emissions-producing diesel farms and coal? In addition to these benefits we would also be reducing future capital costs for new renewables projects, because the power is used, not wasted.

Local density of service

As new products and services from brands like Tesla and NEST, along with smart appliances, rooftop solar and renewable-powered microgrids penetrate the market, we will see a very different potential for energy service provision. The most obvious is buying power from a neighbor or business, but this is just the beginning of the possible benefits. Providing the grid with ways to avoid 'congestion' in demand and supply and locally balanced electricity grids will also provide value with new services providers emerging to bring these benefits to customers.

Predictive capabilities

Predictive capability is already showing the potential for improving services around us that electricity is an invisible part of. Companies are already predicting generation capacity of wind and solar from weather data, or the closing price of electricity on wholesale markets. Artificial intelligence is just beginning to be applied to energy but creates more opportunities for both efficiency and new services.

Regulatory Priorities for Transactive Energy Markets

While many of the technological ingredients for transactive markets are now available, such as low cost DERs and digital technologies, significant changes to market design and regulatory frameworks would be necessary for a full implementation of the transactive energy market model. We turn to these considerations next.

Implementing Transactive Price Signals

Transactive energy is an approach to getting prices 'right' based on implementing transactive prices that reflect supply and demand at each connection point in the power system. The more accurately prices dynamically reflect their true underlying costs, the more useful they will be for underpinning a future transactive grid. Currently, retail prices are far from their efficient ideal, typically being highly averaged with respect to both the location and timing of consumption.[48] A future grid based on transactive price signals will require significant reforms to existing tariff structures.

Current pricing structures

The retail tariffs customers currently pay are made up of several different components, including; the wholesale cost of generating the electricity; the cost of transporting the electricity over the transmission and distribution networks; the costs of running the market, and the specific costs a retailer incurs for running its retail operations. Retail tariffs will also usually include the costs of meeting government policies, such as those relating to environmental and social obligations (e.g. efficiency programs, subsidies for capacity, renewable energy, etc.)

The generation and network cost components included in the retail tariff are typically not total cost reflective, and they do not vary by location or the timing of when consumption takes place. Retail tariffs reflect a highly averaged cost structure, with most of the costs recovered through a volumetric $/kWh charge and the remainder (a much smaller proportion) recovered through a fixed $/kW charge.[49]

As a consequence, customers have little visibility over the true costs associated with their consumption decisions. This is likely to lead to overconsumption at peak times, when the true cost of consumption tends to be much higher than the tariffs customers pay (usually in the evenings, when people collectively use the most electricity), and underconsumption at off peak times, when the cost of consumption is typically much lower than the tariffs they pay.[50] It will be impossible to encourage customers to invest in the smart devices, appliances and other DERs that can help achieve efficient usage if they are not exposed to and made aware of the costs incurred by their consumption decisions and the implications of altering them.

Efficient Pricing: Concepted

An efficiently constructed retail tariff will have two components. First, to reflect the variable costs of using electricity at different times and in different places, there will be a transactive energy price. However, that will be insufficient to recover all the various sunk costs (those that do not vary by the level of consumption) a retailer incurs on the customer's behalf including the upfront costs of running a retail operation (such as billing and other systems), the costs of meeting

48 Severin Borenstein, James Bushnell, "Do two electricity pricing wrongs make a right? Cost Recovery, Externalities and Efficiency, Energy Institute at HAAS WP 294, September 2018, p 21
49 Ibid, p 21
50 Darryl Biggar, "The Transformation of the Electricity Sector in Australia: The Public Policy and Competition Policy Issue", Paper submitted for 63rd meeting of the OECD Working Party No. 2 on Competition and Regulation, 19 June 2017, p 7

policy obligations and the costs of already installed network infrastructure.[51] These costs should be removed from the volumetric ($/kWh) component of the tariff and charged in a manner that minimizes distortions of the cost-reflective pricing component. This could, for instance, be an annual lump sum conveniently distributed in the form of a monthly fixed access charge (c/kW).

Crucially, because the fixed costs of the network would no longer be recovered in volumetric rates, this would remove cross subsidies between different types of customers, such as non-solar and solar customers.

Further, as customers who own DERs would be directly involved in the energy market they would be rewarded for their investment in DERs by the opportunity to capitalize on transactive energy pricing. So there would be no need for administratively determined compensation approaches such as feed in tariffs (FITs)[52] and net metering, which are often fraught with highly complex and contentious regulatory proceedings. The price DER owners would receive for their exports would reflect the true local energy and network value of that generation at that particular point on the network, much like generators and retailers at the transmission level pay or receive only the wholesale price.

It is important to emphasize that the development of transactive price signals for customers' distribution networks does not imply they would directly pay the resulting volatile and time-varying prices. Retailers currently provide the interface between the time-varying wholesale price and the structure of tariffs that the customer chooses to pay. Inevitably some customers will be prepared to face dynamic prices; other customers may prefer to be insulated from such price volatility; but in either case, in a competitive market, retailers will have incentives to provide customers with the retail product that corresponds to the customers' risk appetite.[53]

Efficient Pricing: In Practice

An important issue to address in moving to a framework of more efficient pricing is how it can be technically implemented.

While many energy markets around the world are experimenting with more dynamic pricing approaches, such as critical peak pricing (CPP) and real-time pricing, these have rarely been implemented on a commercial level.[54] More common for those customers that have smart meters installed are Time-of-Use (TOU) tariffs (which apply different price levels to peak and off-peak times); or network components based on an individual customer's peak demand. Typically the types of tariffs are not sufficiently dynamic for signaling the actual network and energy costs in ways that will deliver real value to DERs or to the power system.

Implementing true transactive pricing signals would require prices to vary at each customer connection point in the distribution network. Already described in a previous section, a locational marginal pricing (LMP) approach

51 The cost of the existing poles and wires are sunk and cannot be avoided regardless of the level of consumption. Recovering fixed network costs through volumetric charges distorts consumption decisions. A variable network charge should signal variable costs only (essentially congestion and losses) since these costs can be avoided by changes in behavior.

52 This recognizes that benefits associated with emissions reductions are captured through other policies, such as tax credits and renewable energy certificates.

53 Darryl Biggar, "The Transformation of the Electricity Sector in Australia: The Public Policy and Competition Policy Issue", Paper submitted for 63rd meeting of the OECD Working Party No. 2 on Competition and Regulation, 19 June 2017, p 9

54 Massachusetts Institute of Technology (MIT), Utility of the future, "An MIT Energy Initiative response to an industry in transition", 2016, p 7

would require use of powerflow modeling and complex mathematical techniques to calculate the market price for electricity at each connection point on the distribution system.[55]

LMP has been employed for over a decade now at the transmission level in many North American markets and in New Zealand,[56] however it has not been employed at the distribution level, to date. This is primarily because the substantial implementation costs have not been worth the perceived benefits, given customers' historically limited ability to respond to highly variable price signals as well as the low penetration of DERs. While advances in digital technologies now provide customers with the capability to respond to such price signals, and growing penetration of DERs is increasing the importance of having well-designed economic signals at the distribution level, the complexity of implementing LMP will likely mean it remains some way off.

In the meantime, perhaps the most effective means for implementing transactive energy principles is by expanding opportunities for consumers, particularly those with DERs, to participate in distribution-level markets. Software platforms are already being developed that serve to connect customers to a range of different markets, including wholesale and ancillary markets, as well as provide the means for distribution system operators to procure relevant grid services (sometimes referred to as 'non-wires solutions' as a replacement for network augmentation, for example). As such platforms gain in sophistication they will allow DERs to be bought and sold in response to dynamic wholesale price signals and consumer preferences, with DER services flowing to those who value them the most: to the distribution system operator as a network service; to the system operator as an ancillary service; to an aggregator for dispatch into the wholesale markets, or perhaps even to a neighbor as a peer-to-peer transaction.[57] One of the more advanced examples worldwide of connecting individual customers to wholesale markets has recently been implemented in the Netherlands, which we describe in more detail in Box 4 *(next page)*.

55 Ibid, p 102
56 Ibid, p 91
57 Australian Energy Market Commission, "Distribution Market Model", Final Report, August 2017, p 26

Alliander Real time Energy Exchange (REX)

Alliander, a Dutch distribution business, partnered with CGI to develop a real-time energy exchange (REX) software platform to connect end-users with the Dutch wholesale and imbalance markets. It uses software called PowerMatcher, which is a user-friendly auction mechanism that gives customers visibility over real-time wholesale prices (providing they have a smart meter) and allows customers to make bids and offers for participating in the wholesale market.

While REX is primarily focused on providing access to the wholesale and imbalance markets for aggregators, it is also available for use by individual customers. PowerMatcher can link individual smart appliances and devices (such as a washing machine or battery) directly to the wholesale market, so energy users can respond in real time to price changes. For example, customers can program their battery to store energy when wholesale prices are low and dispatch that energy for their use when prices are high.

Source: https://exe.energy/en/home-2/

Key Points

- Enable cost-reflective pricing across the electricity system
- Ensure transparent access to refined nodal/temporal pricing at distribution level
- Aim for locational marginal pricing for marginal costs of network use
- Study new options for fixed-cost recovery not related to production and consumption, to allow all participants fair access

Extending Power System Optimization to the Grid Edge

In their purest form, transactive energy markets will require an extension of the principles, rules and processes of wholesale markets to be applied at a local level. To set efficient local prices will require the usual price formation process, based on merit order dispatch, to incorporate local dispatchable DERs (such as virtual power plants) and local network constraints. Increasing volumes of DERs connecting to distribution networks will cause technical impacts on distribution networks that will need to be managed. Typical wholesale market services such as forecasting, scheduling dispatch, curtailing resources to manage congestion and balancing and settlement will to some degree need to be applied at the distribution level, requiring strong integration and coordination between transmission and distribution level operations.[58]

Managing potentially millions of active endpoints in the distribution network will significantly increase the complexity of managing power systems - the transmission system operator (TSO)[59] currently might only have to optimize thousands of generation and load resources, not millions. The scale of settlement would be an order of magnitude larger, as this would now potentially include the microtransactions of DER resources. In addition, not only would there be a requirement to monitor and manage real-time flows and network constraints applied to the transmission system, this would also apply to the distribution infrastructure.[60]

While a range of different governance models are possible, the preferred approach may be to leverage the TSOs knowledge and skills in operating and running transmission-level wholesale markets and extending this to the distribution level. The TSO would become responsible for managing DERs, including balancing and settling the transactions of aggregators and microtransactions of individual DERs for the services they provide the system and verifying that they have provided those services.

Much like the concept of independent system operators (ISOs) which manage transmission level markets in the US, the TSO should preferably not own any network assets. This is necessary because the asset owner, the DNO, is also responsible for investing in and managing access to their networks. Integrating ownership with market operational functions would create conflicts between responsibilities for investing in and managing network access and operating distribution level transactive energy markets.[61] It is likely that even the perception of an inherent conflict could undermine growth of markets for DERs services.

To manage this complexity will likely require a different approach to optimization. Currently the power system is only optimized at the transmission level, with the TSO having no visibility over the distribution network or the DERs within it. A more efficient approach for

58 Australian Energy Market Operator (AEMO) and Energy Networks Australia (ENA), "Open Energy Networks, Consultation Paper" 2018, p 29-30
59 TSO is usually responsible for ensuring a secure and reliable network and balancing supply and demand. In the EU they often also own and operate the transmission infrastructure, in the US states they typically do not own network infrastructure and are referred to as Independent System Operators (ISO)
60 Paul De Martini & Kristov Lorenzo, "Distribution Systems in a High Distributed Energy Resources Future: Planning Market Design,Operation and Oversight", Berkeley Lab, October 2015, p 37
61 See comments of Jon Wellinghoff, Stoel Rives, llC and Katherine Hamilton and Jeffrey Cramer, 38 north solutions, llC, Proceeding on Motion of the Commission in regard to Reforming the Energy Vision, Case No 14-M-0101, p 37

transactive energy could be a nested or 'bottom up' approach to optimization, where DERs would first be optimized at the distribution level with the outcome of that optimization subsequently fed into the transmission level optimization process.[62] Aggregators, much like what occurs now, would provide bids to the TSO (for example, in the day market) representing their dispatch preferences. A key difference however is that the TSO would optimize the dispatch merit order of DER based upon those bids, but also taking into account both local network limits and transmission network limits. The TSO would provide its dispatch schedules to aggregators, who would then activate their customer's DER.[63]

Under a transactive energy market, individual DERs (or those below a certain level) would not need to be included in a centralized dispatch mechanism since it's presumed they respond autonomously to price signals to which they are exposed under a transactive market framework. This would necessitate a strong coordination between the TSO and the Distribution System Operator (DSO)[64], with DSO providing the TSO information on relevant local network constraints to feed into the centralized dispatch mechanism.

Key Points

- Optimize first at the distribution level, then at the transmission level.
- Extend responsibilities of the TSO for optimization to the grid edge
- Implement a layered approach to optimization likely for system operators to allow functions currently within their remit to be handled locally where problems occur, rather than nationally
- Create lower minimum thresholds for customer participation in wholesale markets
- Make TSOs independent operators
- Explore different approaches to address these imperatives, which will be different in each country depending on current regulatory guidelines

62 Australian Energy Market Operator (AEMO) and Energy Networks Australia (ENA), "Open Energy Networks, Consultation Paper" 2018, p 29 -30
63 Ibid, p 30
64 The DSO owns and operates the distribution network

Leveling the Playing Field for Distributed Energy Resources

The success of transactive energy markets in delivering value to DER providers and the power system more generally will depend in part on the degree to which DSOs decide to build more network relative to utilizing DER, and other factors, such as the quality and timeliness of connection processes and the ability of DER providers to obtain their desired levels of access to the network.

These factors are controlled by the DSO and, traditionally, regulatory limitations have provided them with few incentives to promote DER as a solution to network issues. For example, DSOs are generally subject to some form of rate-of-return regulation. The regulator determines future investments the distribution utility can make and figures an allowable rate of return. That is then multiplied by the distribution utility's asset base (which includes the investment allowance) to determine the revenues that can be recovered from customers over its regulatory period (usually 5 years). DSOs are therefore assured a stable future income stream from their capital investments.

In contrast, operational expenses are typically recovered by the regulated entities in the year they are incurred. As a consequence, because non-wires alternatives, such as the connection of DERs or other renewable solutions into the grid, are usually classified as an operational expense, distribution utilities derive greater value from investing in capital assets compared to non-wires alternatives, which creates an incentive for them to build more poles and wires rather than invest in DERs to address limitations on the network.[65] While distribution planning arrangements around the world now typically require DSOs to consider non-wires alternatives, this does not remove the inherent bias under existing regulatory approaches toward investing in capital expenditure, which attracts a guaranteed rate of return, versus investing in non-wires alternatives which is expensed as operational expenditure.

Further, because DERs, such as rooftop solar PV and battery storage tend to lower grid use by customers, they reduce future revenues for distribution utilities, which further limits incentives for DSOs to support DERs. As the pace of decentralization increases this trend will continue, and may increase incentives for DSOs to hinder or frustrate the connection of DERs and limit their operation or export capability thereby undermining growth in DER markets as a way to protect revenues. The inherent bias in regulatory arrangements will increase costs for customers and reduce the value available to DERs.

Alternatives to current regulatory approach regulation, such as total expenditure (TotEx) approaches, should therefore be explored to support healthy and liquid markets for DERs. TotEx would replace current assessment and establishment of separate allowances for capital and operating expenditure with a single regulatory allowance and rate of return, thus eliminating the capital bias.

65 Australian Energy Market Commission (AEMC) Economic Regulatory Framework Review, Promoting Efficient Investment in the Grid of the Future, 26 July 2018, p 15

Changes to how expenditure is assessed and remunerated will also need to be accompanied by a shift to performance-based regulation (PBR). By rewarding outcomes instead of inputs, PBR would better align the behavior and financial interests of distribution utilities with DER outcomes. The Regulatory Assistance Project, in an extensive review of PBR frameworks from around the world, shows how not only outputs but incentives (Performance Incentive Mechanisms or PIMs) to achieve those outputs can deliver diverse outcomes, including transparency, operational efficiency or lower infrastructure costs.[66]

For example, a proportion of the regulated revenues earned by distribution utilities could be made contingent on achievement of key performance metrics, such DER connection time frames, increased average grid utilization, the level of DER hosting capacity in the network, or customer satisfaction surveys etc. This type of approach has recently been legislated by the State of Hawaii for implementation for its lines businesses.[67]

Key Points

- Consider the cost savings of non-wires solutions alongside cost recovery from capital expenditure
- Explore total expenditure (TotEx) approaches to support healthy and liquid markets for DERs
- Consider performance-based regulation, where compensation is based on increased network utilization

66 https://www.raponline.org/knowledge-center/next-generation-performance-based-regulation-emphasizing-utility-performance-unleash-power-sector-innovation/

67 S.B. NO. 2039 - requiring the public utilities commission to establish performance incentives and penalty mechanisms that directly tie an electric utility revenue to that utility's achievement of performance metrics, such as the level of integration of renewable energy resources into the grid; timely interconnection processes; customers engagement and satisfaction and provision of data.

Rethinking Regulation of Retail Markets

With the right rules in place, trends toward decentralization and digitalization will create significant opportunities for new business models and new forms of competition in retail markets. Some of the issues that arise are already being looked at by regulators.

Today, all regulated participants, such as licensed electricity suppliers, are financially responsible for keeping their own 'position' managed to balance supply and demand, which in turn allows the entire power system to remain 'in balance.' What this means in practice is that, for instance, no unlicensed participant, such as two households or a local community, is able to financially transact their physical electricity, because they put the system balance at risk.

This has led to a system where even if customers have retail choice - the ability to choose different retail suppliers - that choice remains limited to a kWh commodity. To get it, the regulator typically will only allow customers to contract with one retail supplier at any point in time. This has been referred to as the 'supplier hub' principle, because the retail supplier acts as the intermediary between a retail customer and the competitive wholesale market.[68]

This prevents customers from shopping for different tariffs for different load types. A customer is not, for example, able to establish their core energy supply with one retail supplier and use a different supplier for other energy services - such as a specialized tariff and supply bundle for EV charging, specific appliances (such as pool pumps or HVAC), or peer-to-peer trading. Providers of these services can only access customers through a retail supplier.

Elexon, responsible for balancing and settlement (accounting for the difference between energy purchased by a retail supplier versus what is actually sold to the customer) in the UK, is already preparing for allowing multiple suppliers to be settled over one meter. But addressing this issue in energy markets will require more than technical changes – it will also require significant changes to different regulatory instruments. For example, it will require new rules for managing settlement in wholesale markets.[70] A customer's metered energy consumption would need to be apportioned and allocated among a range of different retail suppliers operating at each connection point. This would require changes to metering arrangements – such as subtractive or net metering – which would allow separate meter data streams to be identified and split between different suppliers.[71]

Rules for allocating network costs would also have to be redesigned to appropriately divide electricity charges among multiple retail suppliers operating at a connection point. Further, with potentially multiple retail suppliers operating at each connection point, regulation

68 See for example, Ofgem https://www.ofgem.gov.uk/publications-and-updates/ofgem-seeks-views-reforms-supplier-hub-market-arrangements
69 https://www.elexon.co.uk/wp-content/uploads/2018/04/ELEXON-White-Paper-Enabling-customers-to-buy-power-from-multiple-providers.pdf
70 Ofgem, Future supply market arrangements – call for evidence' (14 November 2017), p 5
71 See UK, NZ and AU markets are currently exploring these issues. The California PUC is exploring the value of subtractive metering in an EV pilot, see http://www.cpuc.ca.gov/general.aspx?id=5938
72 Customer protections include obligations regarding: specific content requirements for bills; hardship policies; connections and disconnections; managing life support customers etc.

would also need to detail how responsibility for specific customer protections should be allocated and shared among retailers.[72]

At a more fundamental level the whole concept of a retail supplier may also need review, an important question being whether providers of energy services such as EV charging, demand response or peer-to-peer trading should be required to have the onerous obligations that go with being a retail supplier.[73] These obligations could create a significant barrier to entry for energy service providers.

As a comparative example, this would be similar to requiring that Airbnb obtain a hotelier license or partner with a hotelier before it can promote its room-sharing platform. The key issue here is that Airbnb is not selling rooms for short stays, it is selling the transactional platform which allows customers to do it themselves. In the same way, certain services such as peer-to-peer trading, demand response or EV charging are not the same as the core services of energy supply, and therefore should be regulated differently.

One approach to addressing this issue would be to create different tiers of retailers, each having different obligations, perhaps depending on the degree to which their energy service is core to a customer's electricity needs (e.g. energy supply) or can be classified as being more of a supplementary service (e.g. demand side response, provision of network services, or sale of surplus solar PV).[74] The latter would attract fewer obligations, thus supporting the majority of new business models arising that are not specifically associated with supply of energy.

Key Points

- Further explore the 'supplier hub' model alternatives and impacts on energy transition
- Reform balancing responsibility to allow for direct generator/customer transactions
- Ensure visibility of non-electricity services for local participants to local marketplaces

73 Sandys, Laura, Jeff Hardy and Richard Green, "Reshaping regulation, Powering from the Future" October 2017 p 16
74 AER (Retail) Exempt Selling Guideline, Version 4, March 2016 p 4, available at http://www.aer.gov.au

Unlocking Access to Energy Data

Digitalization is creating vast amounts of data. However, access, privacy and cyber threats are increasingly becoming issues that need to be managed. Data governance will become as important in energy markets as the governance of the physical flows of electricity currently the purview of regulators.

A number of countries are now exploring these issues and are adopting data privacy rules that set standards on how data can be shared with third parties.[75] One such initiative is “Green Button,” developed and implemented by the US Department of Energy, which provides 60 million utility customers in the US with easy and secure access to their energy usage information.

Several other data-sharing models are under consideration across regions. Data hubs store the data with a central authority that manages access by interested parties. In Nordic countries, for example, this data hub manager can be the transmission system operator. Another model takes a decentralized approach with communication standards that allow distribution utilities to collect and distribute data to eligible partners. This model is used in Germany and elsewhere in the EU. Another interesting proposal in New York would allow utilities to sell customer data and includes security provisions to keep that data safe.

Australia is in the process of implementing a specific data right for customers in finance and energy, which will give customers a right to direct their data be shared with others they trust, so that they can benefit from its value. The data ‘right’ addresses important questions about formats in which data should be provided, how data should be transmitted, and relevant standards (such as IT security standards) to which the data processors must adhere so that data is meaningful and secure.

75 https://www.missiondata.io/

Establishing Regulatory Sandboxes for Innovation

The disruptive forces of decarbonization, decentralization and digitalization are providing new ways for customers to participate in energy markets and driving the creation of new business models. It is not necessarily clear, however, how the principles highlighted here will translate into specific regulatory changes needed to support these developments in each market.

One way governments are beginning to respond is with energy regulatory 'sandboxes' such as those found in the UK. Regulatory sandboxes allow companies to test new business models in an environment where existing rules are relaxed, providing an opportunity to develop a deeper understanding of new commercial and technical practices and the costs and benefits of different regulatory approaches. These also allow regulators to better understand what is within their remit to change to support innovative business models, and what changes will need to occur outside of energy sector regulation, such as competition policy, standards or cyber security, to make them possible. This results in valuable learnings for participants and regulators, allowing subsequent changes to market rules to be implemented more rapidly.

For new service providers and innovative new business models that face barriers to entry, regulators need to provide a way for initial trials to move into commercialization. As competition for better customer outcomes outpaces regulated monopoly approaches, those responsible for safeguarding markets from anti-competitive behavior will need to create the appropriate oversight of energy market activities so they align with the stated goals of governments to reach climate change targets and meet the economic needs of all customers. These strategies would assist new service providers in proactively identifying where new solutions are locked out, and act toward increasing competitiveness, which could include legal action or lobbying.

Key Points

- Utilize sandboxes to provide important learning about market issues
- Allow sandboxes to provide insights on how to shift from regulated profits/returns to competitive models (focus on markets and be technology agnostic)
- Develop and provide appropriate routes out of trials and into commercialization

75 https://www.missiondata.io/

Conclusions:
Taking Action Today

"Future regulatory architecture needs to facilitate change, embrace the lack of uniformity, recognize success, and allow for and learn from failure."[76]

The often quoted need to 'put consumers at the center' of our energy systems is actually very disruptive to current market designs. Transactive energy describes the technical capabilities and market vision that can turn the grid edge disruption into an opportunity for vastly increased productivity and participation.

Today we are already facing the effects of climate change. This is creating higher likelihood of a more disruptive shift that can no longer be ignored. As it stands, energy-related CO2 emissions must peak next year in 2020 and fall by 70% by 2050 if we are to have a 66 percent chance of staying within under two-degree warming.[77] A recent report from the Intergovernmental Panel on Climate Change declares that to do that requires an 'unprecedented' scale of change.

The most forward-looking businesses and communities are ready for an energy transition, and transactive energy is a response to this need. Consumers and businesses now require a regulatory response to match the demand.

This regulatory response puts consumers into the leading role as participants, both as generators and customers, supported by local networks and marketplaces solving physical problems close to the grid edge where they arise.

We have outlined a transactive energy approach that is long term and ambitious, but the benefits to consumers are worth it. Getting prices right will entail separating the system costs from the variable costs of electricity. We recommend a layered approach to managing the market that is entirely the opposite to the existing model. This would involve solving problems of frequency or imbalance as they occur at the local distribution level first, before involvement of balancing solutions at the transmission level. Retail markets as they are designed today give very little opportunity for new services such as smart appliances or EVs that are increasingly coming to market to benefit the grid (as well as customers) and will rely on persistent and secure access to energy data. Where new utility business models are challenged, and no path for transition seems clear, regulatory sandboxes have a role to play in increasing the likelihood of new models to be adopted at scale, but they must be designed to provide routes to commercialization for new business models, rather than isolated experiments.

A transition pathway will not be the same in each country or regulated market. In the transactive energy section of this paper, we have highlighted a number of use cases already required by power markets where transactive energy approaches could be utilized. The question is how to bring those approaches into the markets alongside the current approaches. Performance-based regulation

76 https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/collaborative-publications/Reshaping-Regulation-Powering-from-the-future.pdf
77 https://www.irena.org/DocumentDownloads/Publications/Perspectives_for_the_Energy_Transition_2017.pdf

is already providing a framework for allowing change to happen within the current systems, creating incentives for achieving outcomes, such as dynamic tariffs or cost-recovery based on asset optimization, allowing regulators and participants to maintain service, economic and physical stability, while also embracing disruptive change.

The opportunity is clear for a transactive energy future. Transactive markets will maximize opportunities for a large range of different innovative business models to succeed, and for the promise of a customer-centric energy system to become a reality.

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