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POLICY EDITORIAL

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Sustainable Energy Transition: Intermittency Policy Based on Digital Mirror Actions

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Abstract

The transition to renewable energy requires organizations and governments to formulate and enact new energy policies. This emerging energy era is characterized by higher levels of supply and demand intermittency, which requires information systems to manage the electricity grid. We propose key policy elements for managing intermittency based on information systems to implement digital mirror actions for managing the production, consumption, and transfer of electricity and market mechanisms for maintaining grid equilibrium. This article discusses these and their energy policy implications.

Keywords: Information Systems, Energy Policy, Intermittency, Digital Mirror Actions

John Leslie King was the accepting senior editor. This policy editorial was submitted on November 1, 2021 and underwent four revisions.

1 The Need

Energy consumption underlies production (Landes, 1999). When a lower-cost source of energy emerges, it takes about half a century to shift the global energy supply system from the old energy model to the new (Smil, 2014). We have reached a critical juncture where renewables, mainly solar and wind, are driving a global energy transition (Gielen et al., 2019). By 2020, renewables had achieved the lowest and most rapidly declining levelized costs of electricity generation (Figure 1).[1]

Renewables bring several benefits, which, among other things, include lower electricity prices, reduced greenhouse gas emissions, decreased healthcare costs because of higher air quality (Buonocore et al., 2016), and economic stimulus. The International Monetary Fund (IMF) projects that green investment over the next 15 years will raise global GDP by 0.7% and create around 12 million jobs.[2] According to the International Energy Agency,[3] achieving these gains means that "a surge in well-designed energy policies is needed to put the world on track for a resilient energy system that can meet climate goals."

A policy reformulation of the electricity management system must embrace renewables and increase energy efficiency. Organizations and governments need guidance on establishing such policy (Hoppe & Miedema, 2020). Given that grid management is an information-intensive problem (Fridgen et al., 2016) (Ketter et al., 2016), information systems (IS) scholars are well-positioned to contribute to the development of such policy.

[1] Levelized costs of electricity are a measurement of total cost divided by electricity generated by an asset over its lifetime. https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/

[2] https://www.imf.org/en/News/Articles/2021/04/15/sp041521-securing-a-green-recovery

[3] https://www.iea.org/reports/world-energy-outlook-2020

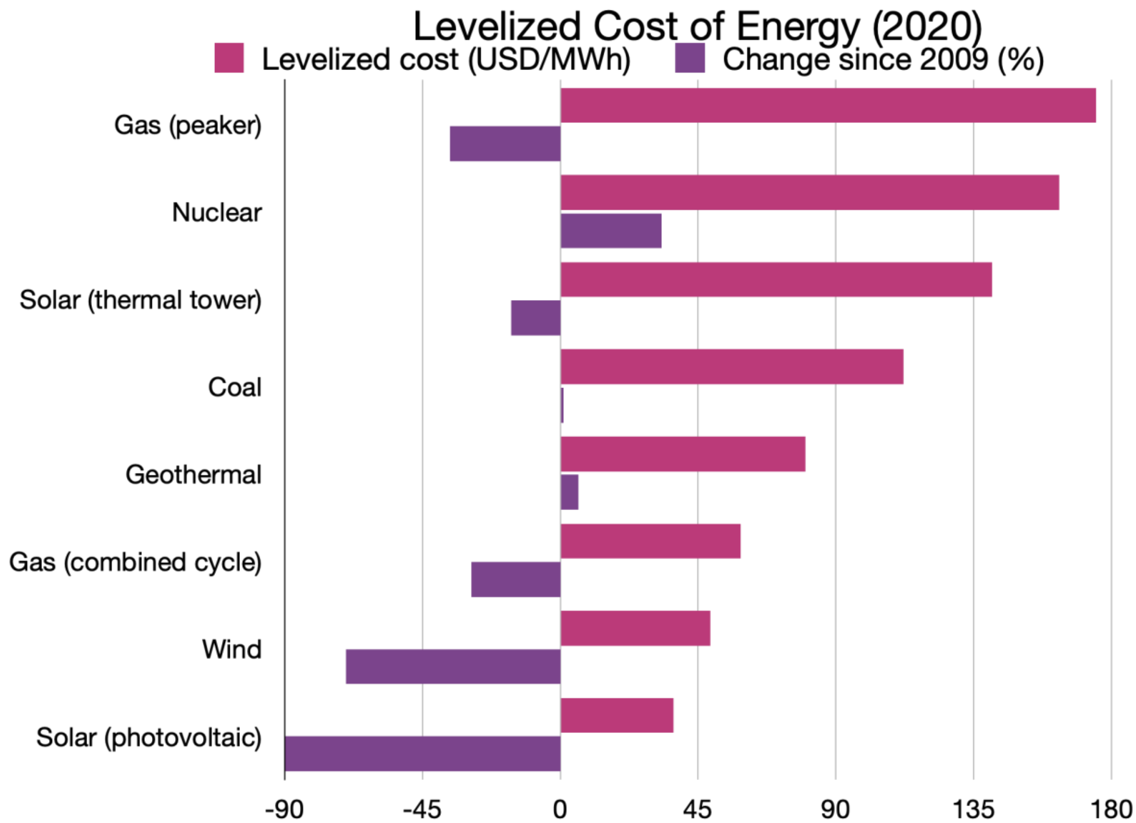

Figure 1. Levelized Costs of Electricity (Lazard, 2020)

IS scholarship has historically had a limited impact on international, national, or even regional policy. This situation is now changing: There is an opportunity for IS scholars to influence important policy decisions. Indeed, two of the co-authors on this paper have worked directly with policy makers. The purpose of this article is to stimulate the engagement of IS Scholars in energy policy formulation.[4] Compromise is usually unavoidable. The best is the enemy of the good (cf. Voltaire, *La Bégueule*, 1772).

2 Digitally Informed Policy

Policy planners rely on a multilayered system to make and enact policies, and these layers inevitably involve information systems. For example, the Internet of Things (IoT) (Yang et al., 2021) facilitates new policy-relevant services based on a technology stack that allows entities to (1) collect data about electricity supply and demand at an unprecedented speed, scale, and granularity; (2) analyze data to predict electricity supply and demand; and (3) manage and control an electricity grid.

This technology stack plays a dual role in policy making. First, policy makers must consider the emergent technology stack and its implications because the arrangement of decision rights and accountabilities can impact the design of those layers. Second, they can leverage the various integrated layers to make data-informed decisions about new policies and to ensure their efficient execution.

Policy development and enactment are often supported by frameworks and associated principles (King & Kraemer, 2019). We provide a generic model (Table 1) to discuss the potential role of IS in informing policy. The top layer, policy, informs and impacts three lower levels (e.g., decisions about standards impact the data communication layer). Second, policymaking and enactment can capitalize on the data-informed insights and predictions generated by lower levels.

The lower three layers require digital interventions that IS scholars could co-design and test with business and public administrators, such as new cyberphysical infrastructure, standards for data exchange (Watson et al. 2010), AI-powered models for decision-making (Ketter, 2021), or experiments for assessing new decision rules for electricity trading (Ketter et al., 2016).

[4] The authors will send this article to national, state, and provincial energy agencies.

Table 1. Design Layers, Issues, and Considerations

Layer	Design issues	Key considerations
Policy	Design of a stable, resilient, and secure grid that promotes market efficiency and innovation	Managing the transition from fossil fuels to renewables and the long-term operation of a grid based primarily on renewables Using analytics to achieve policy objectives
Management and control	The control and management of a grid and electricity market under varying circumstances	Managing a grid during envisaged and emergent situations Designing an efficient electricity market
Analytics	Techniques for dynamic identification of model parameters to support real-time operational decisions and long-term planning	Dynamic data mining of digital data streams to make operational decisions within milliseconds and to continually recalibrate a grid's digital twin to reflect changing demand and supply patterns
Data and communications	Capturing data for analysis at the appropriate level of granularity and frequency to enable the transmission of control commands at the necessary volume and speed for effective systems management	Creating standards that enable grids that operate relatively independently to also interconnect to support major perturbations

From a policy-setting perspective, the goal is to determine the short- and long-term effects of prospective interventions (King & Kraemer, 2019). From a policy enactment standpoint, the aim is to determine the measurable effects of policies. Thus, complementary actions for IS are to anticipate and analyze the effects of policies.

The transition from burning fossil fuels to technology-based and weather-dependent renewable energy generation requires the increased use of digital technology to facilitate policy innovations, such as revamping business models based on last century's measurement technology and fossil fuel sources. With the widespread adoption of wireless digital smart metering, new policies can aim to stimulate business model and grid management systems innovations.

3 A Policy Proposal: Managing Intermittency through Mirror Actions

A policy overhaul is necessary to galvanize what is arguably the major digital transformation of the next decade. This redesign must address a key challenge—intermittency (Wee et al. 2012)—because the major renewable sources for electricity, in particular wind and solar, are subject to the vagaries of the weather and diurnal rhythms. Intermittency is more than an electricity production problem: demand-side intermittency (Dong, 2017) is influenced by factors such as the weather, day of the week, holidays, sporting events, and pandemics.

Intermittency is a policy challenge because renewables increase the complexity of managing over- and undersupply, the mirrors of under- and overdemand. While energy storage, such as chemical batteries, can balance the mismatch between electricity supply and demand, the roundtrip efficiency for a charge/discharge cycle over 15 years with one cycle per day is 85% (Cole & Frazier, 2019). Thus, to reduce storage costs and losses, the preferred mitigation strategy would be to manage the electricity demand so that it is consumed, as much as feasible, when generated. Enacting this suggestion, however, would require processing millions of transactions in real time to achieve stability by dynamically balancing demand and supply (Figure 2).

Dynamically handling intermittency requires extensive computer-based control systems for implementing digitally enabled mirror actions to manage the production, consumption, and transfer of electricity and market mechanisms. Some of the possibilities—i.e., mirror actions—to tackle oversupply and underdemand (as well as the mirrors of undersupply and overdemand) are detailed in Table 2 and depicted in Figure 2.

These mirror actions are information intensive and thus critically dependent on digital technology. Managing intermittency requires mass scale dynamic mirror actions to maintain grid equilibrium. While massive investment in energy storage capacity could keep a grid stable, an investment in information systems to manage grid equilibrium by dynamically applying the suggested mirror actions might be less costly because it would reduce the need for energy storage and its charge/discharge inefficiencies. This mix of batteries and information systems can be modeled to determine the right formula for various renewable, commercial, industrial, and residential environments.

Table 2. Operational Mirror Actions for Managing Grid Equilibrium

	Oversupply /underdemand	Undersupply /overdemand	Key elements
Managing deferrables	Activate devices (e.g., hot water heaters), whose current operation is not critical, can be time-shifted so usage is deferred	Deactivate devices whose current operation is not critical	Connected devices, energy storage, electricity networks
Managing rights markets	Purchase electricity production rights	Purchase electricity consumption rights	Market participants: electricity producers and consumers
Managing dynamic pricing	Lower electricity prices	Increase electricity prices	Market participants: electricity producers and consumers
Managing energy storage	Charge energy storage (e.g., chemical batteries)	Discharge energy storage	Energy storage, devices, electricity networks

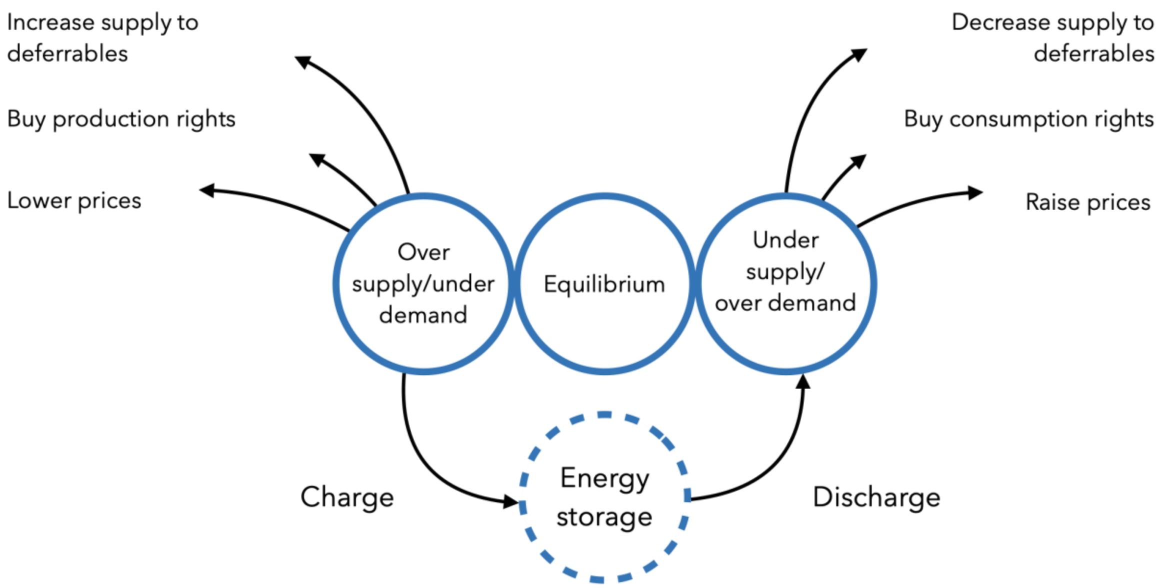

Figure 1. Operation Mirror Actions for Managing Grid Equilibrium

We now highlight how the four identified mirror actions can be digitally enabled and how each requires decisions at the data communications, data analytics, and management and control levels. We also discuss how the actions and involved layers are subject to and can inform policy making and enactment.

4 A Key Policy Elements: Digitally Enabled Mirror Actions

4.1 Managing Deferrable Devices

Digitalized and connected commercial and household devices whose operations can be deferred provide an opportunity to match supply and demand. Dishwashers, for example, might be loaded in the evening and activated overnight so dishes are clean in the morning. We need three conditions to enable deferrables management: (1) the device operator must be able to state their requirement (e.g., dishes washed by 7 a.m.); (2) the device must be remotely controllable; and (3) the energy required to meet requirements (e.g., fully charging an electric vehicle) must be determinable by querying the device.

Requirements: Digital mirror actions for deferrables require collecting and analyzing data (data and communications layer) on the current state of electricity producing or consuming objects and changing their status dynamically as necessary. All deferrable devices need to be individually addressable, remotely controllable, and capable of reporting their current status and future energy needs (management and control layer) (Watson et al., 2010). These data also can be used for consumption predictions (analytics layer).

Policy Implications: Deviations between anticipated and actual electricity supply and demand can be measured, and insights about their origins and sources (e.g., corporate, public) made available at different levels of granularity (e.g., devices, communities). Consequently, policies can set incentives or regulations that provide the basis for deferrables management, such as requiring certain devices to be remotely controllable. Because supply and demand can be monitored at different levels of granularity, the impact of policies is observable and can be tuned appropriately.

4.2 Managing Rights Markets

When an entity signs up with an electricity supplier, it effectively buys a right to consume. This right could be tradeable, so that during periods of excess demand some consumers could be paid to curtail consumption, as is the case with irrigation water rights (Thobanl, 1997). Rights trading would enable some entities, typically large-scale organizations, to monetize their flexibility. Similarly, production rights should be tradeable. When faced with excess supply, electricity distributors could have among their options the ability to buy production rights to limit generation. Rights trading would require the establishment of a platform that satisfies the conditions for an efficient market (Roth, 2008).

Consider the rights market implemented by OhmConnect, which provides consumers with a free smart thermostat in return for the right to remotely control its setting. When a grid is near overload, OhmConnect adjusts these thermostats and sells the aggregated electricity savings at peak market prices to utilities. The savings are shared with consumers who have signed on with OhmConnect.[5]

Requirements: An electronic market and appropriate rules and regulations could be established for a grid. Electricity demand and supply forecasting (analytics layer) require large-scale collection and analysis of digital data streams from producers and consumers, fine-grained weather forecasting, and data on local short-term anomalies, such as a major sporting event (data and communications layer).

Policy Implications: Policy makers would design the regulatory framework for markets and related grids in terms of roles and their associated rights and obligations. This would involve the implementation of mechanisms to avoid market failures, such as limiting information asymmetry or control loss. Information is needed to enable policy makers to understand the effects of policy decisions related to rights trading.

4.3 Managing Dynamic Pricing

Most householders pay electricity prices that reflect little if any information about the current wholesale price of electricity (Pérez-Arriaga et al., 2017). They typically pay a flat rate that might vary slightly by season but not by current demand. Hence, many utilities operate expensive and inefficient demand response systems to handle peak wholesale prices (Sioshansi, 2006). Real-time electricity prices could be set to balance supply and demand. However, electricity is a continuous flow rather than a set of interspersed transactions (Moriarty & Honnery, 2016), so pricing would likely need to be somewhat constant (e.g., the next hour), with some forewarning of large changes, rather than truly dynamic.

Requirements: Smart grids provide the components for managing intermittency. Dynamic pricing requires (1) real-time reporting of electricity use to enable consumers to manage dynamically their costs (data and communications layer); (2) procedures that accurately reflect electricity scarcity to motivate consumers to change their behavior to minimize usage (analytics layer) and motivate producers to manage their generation capacity (management and control layer).

Policy Implications: A framework is needed to support the dynamic setting of electricity prices that reflect current conditions in the local grid and its associated market. As pricing is politically sensitive, analysis of supply and demand (data and communications layer, analytics layer) can help policy makers understand the ramifications of policy before its implementation. IS scholars could conduct experiments on consumers' reactions to policy possibilities to assist policy makers.

4.4 Managing Energy Storage

Large-scale renewables suppliers use various forms of energy storage to capture an oversupply of electricity and release it when demand rises. Similarly, solar households use batteries to reduce their grid dependency by storing excess electricity. An electricity distributor faces dual decisions. Long term, it must determine where to place batteries within its portion of the grid. Short-term, it must decide when to add to or draw from the various forms of energy storage.

Requirements: Using energy storage options to balance energy supply and demand requires software that allows

[5] https://www.economist.com/business/2021/06/24/can-american-utilities-avoid-summer-blackouts

(1) the storage operator to enter characteristics of its need; (2) remote control; and (3) storage capacity querying. Similar to deferrables, batteries also must be individually addressable, remotely controllable, and capable of reporting their current status (data and communications layer). We foresee including intelligent deferrable devices with built-in batteries in the management schema (analytics layer). Finally, it will be necessary to implement digital controls to create a network of batteries for maintaining grid equilibrium (management and control layer).

Policy Implications: Measuring the impact of the energy storage capacity of a distributed and decentralized system can help policy makers decide on standards and protocols for creating a reliable network. The increasing number of electric vehicles highlights how this energy storage capacity could be distributed among stakeholders representing different institutional orders, including private households, corporations, and the state.

5 Conclusion

The transition towards renewables requires organizational and government policy makers to establish a framework to guide the use of digital mirror actions that support grid equilibrium. Because the proposed mirror actions are digitally enabled, data analytics can generate insights to shape policy. Managing intermittency requires the continuous, dynamic search for an optimal or near-optimal solution to a problem containing multiple, deeply interwoven decisions (Kahlen et al., 2018): which deferrables to prefer or defer, which consumption or production rights to trade and at what price, how to price electricity, or how much electricity to store in or extract from energy storage.

The multidimensionality of the intermittency problem rules out mathematical optimization. Discovery platforms (Ketter et al., 2013) or digital twins can be used to model and explore the consequences of various strategies. The lessons learned must be translated into sociotechnical interventions, such as consumer incentives and algorithms, which need to be complemented by relevant policy and institutional changes as well as control and supervision. Several of these changes have been implemented, and a digital infrastructure is often in place. IS scholars, more than ever, can engage in organizational decision-making at multiple levels and inform policy to facilitate this critical digital transformation.

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