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MIT Energy Initiative

UTILITY OF THE FUTURE
EXECUTIVE SUMMARY

An MIT Energy Initiative response to an industry in transition

In collaboration with IIT-Comillas

Universidad Pontificia ICAI ICADE Comillas Madrid
Instituto de Investigación Tecnológica

MIT

Full report can be found at: energy.mit.edu/uof

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Study Participants

Principal Investigators

IGNACIO PÉREZ-ARRIAGA
Professor, Electrical Engineering, Institute for Research in Technology, Comillas Pontifical University
Visiting Professor, MIT Energy Initiative

CHRISTOPHER KNITTEL
George P. Shultz Professor of Applied Economics, Sloan School of Management, MIT
Director, Center for Energy and Environmental Policy Research, MIT

Project Directors

RAANAN MILLER
Executive Director, Utility of the Future Study, MIT Energy Initiative

RICHARD TABORS
Visiting Scholar, MIT Energy Initiative

Research Team

ASHWINI BHARATKUMAR
PhD Student, Institute for Data, Systems, and Society, MIT

MICHAEL BIRK
SM, Technology and Policy Program ('16), MIT

SCOTT BURGER
PhD Student, Institute for Data, Systems, and Society, MIT

JOSÉ PABLO CHAVES
Research Scientist, Institute for Research in Technology, Comillas Pontifical University

PABLO DUENAS-MARTINEZ
Postdoctoral Associate, MIT Energy Initiative

IGNACIO HERRERO
Research Assistant, Institute for Research in Technology, Comillas Pontifical University

SAM HUNTINGTON
SM, Technology and Policy Program ('16), MIT

JESSE JENKINS
PhD Candidate, Institute for Data, Systems and Society, MIT

MAX LUKE
SM, Technology and Policy Program ('16), MIT

RAANAN MILLER
Executive Director, Utility of the Future Study, MIT Energy Initiative

PABLO RODILLA
Research Scientist, Institute for Research in Technology, Comillas Pontifical University

RICHARD TABORS
Visiting Scholar, MIT Energy Initiative

KAREN TAPIA-AHUMADA
Research Scientist, MIT Energy Initiative

CLAUDIO VERGARA
Postdoctoral Associate, MIT Energy Initiative

NORA XU
SM, Technology and Policy Program ('16), MIT

Faculty Committee

ROBERT ARMSTRONG
Director, MIT Energy Initiative

CARLOS BATLLE
Research Scholar, MIT Energy Initiative
Professor, Institute for Research in Technology, Comillas Pontifical University

MICHAEL CARAMANIS
Professor of Mechanical Engineering and Systems Engineering, College of Engineering, Boston University

JOHN DEUTCH
Institute Professor, Department of Chemistry, MIT

TOMÁS GÓMEZ
Professor, Institute for Research in Technology, Comillas Pontifical University

WILLIAM HOGAN
Raymond Plank Professor of Global Energy Policy, John F. Kennedy School of Government, Harvard University

STEVEN LEEB
Professor, Electrical Engineering & Computer Science and Mechanical Engineering, MIT

RICHARD LESTER
Associate Provost and Japan Steel Industry Professor of Nuclear Science and Engineering, Office of the Provost, MIT

LESLIE NORFORD
Professor, Department of Architecture, MIT

JOHN PARSONS
Senior Lecturer, Sloan School of Management, MIT

RICHARD SCHMALENSEE
Howard W. Johnson Professor of Economics and Management, Emeritus
Dean, Emeritus, Sloan School of Management, MIT

Research and Project Advisors

LOUIS CARRANZA
Associate Director, MIT Energy Initiative

STEPHEN CONNORS
Director, Analysis Group for Regional Energy Alternatives, MIT Energy Initiative

CYRIL DRAFFIN
Project Advisor, MIT Energy Initiative

PAUL MCMANUS
Master Lecturer, Questrom School of Business, Boston University

ÁLVARO SÁNCHEZ MIRALLES
Senior Associate Professor, Institute for Research in Technology, Comillas Pontifical University

FRANCIS O'SULLIVAN
Research Director, MIT Energy Initiative

ROBERT STONER
Deputy Director for Science and Technology, MIT Energy Initiative

Advisory Committee

PHILIP SHARP
Utility of the Future Advisory Committee Chair and Retired President, Resources for the Future

RICHARD O'NEILL
Utility of the Future Advisory Committee Vice Chair
Chief Economic Advisor, Federal Energy Regulatory Commission

M. MASOOD AHMAD
Division Head, Power Systems Planning Department, Saudi Aramco

JANET GAIL BESSER
Executive Vice President, Northeast Clean Energy Council

ALAIN BURTIN
Director, Energy Management, EDF R&D*

PAUL CENTOLELLA
President, Paul Centolella & Associates LLC
Senior Consultant, Tabors Caramanis Rudkevich

MARTIN CROUCH
Head of Profession for Economists and Senior Partner, Improving Regulation, Ofgem

ELIZABETH ENDLER
Research Program Manager, Shell International Exploration & Production (US) Inc.

PHIL GIUDICE
Chief Executive Officer, President and Board Member, Ambri Inc.

TIMOTHY HEALY
Chief Executive Officer, Chairman and Co-Founder, EnerNOC

MARIANA HEINRICH
Manager, Climate & Energy, World Business Council for Sustainable Development

PAUL JOSKOW
President, Alfred P. Sloan Foundation
Elizabeth and James Killian Professor of Economics, Emeritus, MIT

MELANIE KENDERDINE
Director of the Office of Energy Policy and Systems Analysis and Energy Counselor to the Secretary, U.S. Department of Energy

CHRISTIANA LA MARCA
Head of Innovation, Global Thermal Generation, Enel

ALEX LASKEY
President & Founder, Opower*

ANDREW LEVITT
Sr. Market Strategist, PJM Interconnection*

BLANCA LOSADA MARTIN
Chief Executive Officer, Gas Natural Fenosa Engineering.
Chief Technology Officer, Gas Natural Fenosa

LUCA LO SCHIAVO
Deputy Director, Infrastructure Regulation, AEEGSI — Italian Regulatory Authority for Electricity, Gas, and Water

GARY RAHL
Executive Vice President, Booz Allen Hamilton

MARK RUTH
Principal Project Lead, Strategic Energy Analysis Center, National Renewable Energy Laboratory

MIGUEL SÁNCHEZ-FORNIE
Director, Global Smart Grids, Iberdrola

MANUEL SÁNCHEZ-JIMÉNEZ, PHD
Team Leader Smart Grids, European Commission

LAURENT YANA
Director Advisor of Global BUs, Group Strategy Division, Engie

AUDREY ZIBELMAN
Chair, New York State Public Service Commission

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REGINE BELHOMME (EDF)

SUSAN COVINO (PJM)

JIM KAPSIS (Opower)

Contents

Full report and related working papers are available at: ***energy.mit.edu/uof***

Foreword and Acknowledgments

An important evolution in the provision and consumption of electricity services is now under way, driven to a significant degree by a confluence of factors affecting the distribution side of the power system. A range of more distributed technologies — including flexible demand, distributed generation, energy storage, and advanced power electronics and control devices — is creating new options for the provision and consumption of electricity services. In many cases, these novel resources are enabled by increasingly affordable and ubiquitous information and communication technologies and by the growing digitalization of power systems. In light of these developments, the MIT Energy Initiative's *Utility of the Future* study examines how the provision and consumption of electricity services is likely to evolve over the next 10 to 15 years in different parts of the world and under diverse regulatory regimes, with a focus on the United States and Europe.

The Utility of the Future study is the first of a new series of reports that is being produced by the MIT Energy Initiative (MITEI) to serve as balanced, fact-based, and analysis-driven guides to key topic areas in energy for a wide range of decision makers in government and industry. This study specifically aims to serve as a guide for policy makers, regulators, utilities, existing and startup energy companies, and other power-sector stakeholders to better understand the factors that are currently driving change in power systems worldwide. The report distills results and findings from more than two years of primary research, a review of the state of the art, and quantitative modeling and analysis.

This study does not attempt to predict the future. We follow the dictum of poet and author Antoine de Saint Éxupéry: "As for the future, your task is not to foresee, but to enable it." We identify key barriers and skewed incentives that presently impede the efficient evolution of the power sector and offer a framework for regulatory and market reform, based on a comprehensive system of efficient economic signals, that will enable an efficient outcome, regardless of how technologies or policy objectives develop in the future.

MITEI's Utility of the Future study was supported by a consortium of 23 diverse organizations from across the energy sector, and it is complemented by [a] distinguished Advisory Committee and Faculty Committee. We gratefully acknowledge the support of the following consortium members at the Sponsor level: Booz Allen Hamilton, EDF, Enel, Engie, Gas Natural Fenosa, General Electric Corporation, Iberdrola, National Renewable Energy Laboratory, PJM, Saudi Aramco, Shell, US Department of Energy, and World Business Council for Sustainable Development. At the Participant level we wish to thank: The Charles Stark Draper Laboratory, Duke Energy, Enzen, Eversource, Lockheed Martin, NEC Corporation, PSE&G, Siemens, and Statoil. At the Observer level we wish to thank Paul and Matthew Mashikian. In addition to providing financial support, a number of our sponsors provided data that were helpful for our modeling activities. We are very grateful for this assistance.

Our Advisory Committee members dedicated a significant amount of their time to participate in meetings and to comment on our preliminary analysis, findings, and recommendations. We would especially like to acknowledge the efficient conduct of Advisory Committee meetings under the able and experienced direction of Chairman Philip R. Sharp and Vice Chairman Richard O'Neill.

This study was initiated and performed within MITEI. Professor Robert Armstrong has supported this study in his role as director of MITEI and as an active participant in the faculty committee. Louis Carranza, associate director of MITEI, structured the commercial model and worked closely with study executive director Raanan Miller in assembling the consortium members. MITEI staff provided administrative and financial management assistance to this project; we would particularly like to thank Emily Dahl, Debra Kedian, Francesca McCaffrey, Chelsey Meyer, Jennifer Schlick, Jessica Smith, and Kelley Travers for communications and event support. Finally, we would like to thank Kathryn O'Neill and Marika Tatsutani for editing this document with great skill and patience, and Opus Design for layout and figure design.

This report represents the opinions and views of the researchers who are solely responsible for its content, including any errors. The Advisory Committee and the Study Consortium Members are not responsible for, and do not necessarily endorse, the findings and recommendations it contains.

This report is dedicated to the memory of our friend and colleague Stephen Connors.

Executive Summary

Important changes in the provision and consumption of electricity services are now underway, driven to a significant degree by a confluence of factors affecting the distribution side of power systems. A variety of emerging distributed technologies — including flexible demand, distributed generation, energy storage, and advanced power electronics and control devices — are creating new options for the provision and consumption of electricity services. At the same time, information and communications technologies are rapidly decreasing in cost and becoming ubiquitous, enabling more flexible and efficient consumption of electricity, improved visibility of network use, and enhanced control of power systems.

These technologies are being deployed amidst several broad drivers of change in power systems, including growth in the use of variable renewable energy sources such as wind and solar energy; efforts to decarbonize the energy system as part of global climate change mitigation efforts; and the increasing interconnectedness of electricity grids and other critical infrastructure, such as communications, transportation, and natural gas networks.

The MIT Energy Initiative's *Utility of the Future* study presents a framework for proactive regulatory, policy, and market reforms designed to enable the efficient evolution of power systems over the next decade and beyond. The goal is to facilitate the integration of all resources, be they distributed or centralized, that contribute to the efficient provision of electricity services and other public objectives. This framework includes a comprehensive and efficient system of market-determined prices and regulated charges for electricity services that reflect, as accurately as possible, the marginal or incremental cost of providing these services; improved incentives for distribution utilities that reward cost savings, performance improvements, and long-term innovation; reevaluation of the power sector's structure to minimize conflicts of interest; and recommendations for the improvement of wholesale electricity markets. This study also offers a set of insights about the roles of distributed energy resources, the value of the services these resources deliver, and the factors most likely to determine the portfolio of cost-effective resources, both centralized and distributed, in different power systems. We consider a diverse set of contexts and regulatory regimes, but focus mainly on North America and Europe.

This study does not try to forecast the future or predict which technologies will prevail. Instead, it identifies unnecessary barriers and distortionary incentives that presently impede the efficient evolution of the power sector and provides a framework that will enable an efficient outcome regardless of how technologies or policy objectives develop in the future. In addition, we recognize that regulatory and policy reform often proceeds incrementally and that each jurisdiction faces unique challenges and contexts. As such, we offer this framework along with guidance on the key trade-offs regulators and policy makers confront as they pursue opportunities for progressive improvements.

The measures identified in this study could produce significant cost savings. Low-cost information and communications technologies and advanced metering enable more cost-reflective prices and charges for electricity services that can finally animate the "demand side" of the power system and align myriad decisions with the optimization of net social welfare. Efficient prices and charges will unlock flexibility in electricity consumption and appropriately value the services that distributed energy resources provide. To date, power systems have been designed to meet infrequent peaks in demand and to comply with engineering safety margins established in an era when electricity customers were largely inflexible and blind to the true costs and potential benefits of their electricity consumption or production decisions. In many cases, this has resulted in costly and significantly underutilized infrastructure. Smarter consumption of electricity and, where cost-effective, the deployment of distributed energy resources, could deliver billions of dollars in savings by improving the utilization of electricity infrastructure.

At the same time, the need for proactive reform is clear. Customers now face unprecedented choice regarding how they get their power and how they manage their electricity consumption — regardless of whether they are aware of those choices or are acting on them today. New opportunities include the ability to invest in distributed generation, smart appliances, and energy efficiency improvements. At present, the vast majority of power systems lack a comprehensive system of efficient prices and regulated charges for electricity services. As a result, some customers are making inefficient investments and are overcompensated for the services that they provide to the power system. At the same time, many more opportunities that could deliver greater value are being left untapped because of inadequate compensation. For example, the combination of simple volumetric tariffs and net metering policies has contributed to the rapid adoption of rooftop solar photovoltaics (PV) in several jurisdictions, while exposing several flaws in current ratemaking. The rapid uptake of solar PV also demonstrates how quickly customers can react to economic signals — whether well or poorly designed — and the importance of proactive, rather than reactive, policy-making and regulation. In multiple jurisdictions, challenges that once seemed insignificant have quickly become overwhelming, and failure to act can catch policy makers and regulators flat-footed.

The framework proposed in this study is designed to establish a level playing field for the provision and consumption of electricity services, whether via centralized or distributed resources. The goal is to remove inefficient barriers to the integration of cost-effective new sources of electricity services, rethink ill-designed incentives for certain resources, and present a system of prices and charges that can animate efficient decisions. With this framework in place, all customers and producers of electricity services can make efficient choices based on accurate incentives that reflect the economic value of these services and their own diverse personal preferences.

This study highlights several core findings:

The only way to put all resources on a level playing field and achieve efficient operation and planning in the power system is to dramatically improve prices and regulated charges (i.e., tariffs or rates) for electricity services.

- To establish a level playing field for all resources, cost-reflective electricity prices and regulated charges should be based only on what is metered at the point of connection to the power system — that is, the profile of injections and withdrawals of electric power at a given time and place, rather than the specific devices behind the meter. In addition, cost-reflective prices and regulated charges should be symmetrical, with injection at a given time and place compensated at the same rate that is charged for withdrawal at the same time and place.
- Increasingly affordable information and communications technologies (e.g., advanced meters or interval meters) enable detailed monitoring of electricity withdrawals and injections and therefore facilitate more efficient prices and charges. Without more accurate consumption and injection data from all customers, it is impossible to capture the full value of electricity services.

- Flat, volumetric tariffs are no longer adequate for today's power systems and are already responsible for inefficient investment, consumption, and operational decisions.

- Peak-coincident capacity charges that reflect users' contributions to incremental network costs incurred to meet peak demand and injection, as well as scarcity-coincident generating capacity charges, can unlock flexible demand and distributed resources and enable significant cost savings.

- Granularity matters. The value or cost of electricity services can vary significantly at different times and at different locations in electricity networks. Progressively improving the temporal and locational granularity of prices and charges for these services can deliver increased social welfare. However, these benefits must be balanced against the costs, complexity, and potential equity concerns of implementation.

- Care must be taken to minimize distortions from charges that are designed to collect taxes, recover the costs of public policies (such as efficiency programs, heating assistance, subsidies for renewable energy, cross-subsidies between different categories of customers, etc.), and recover residual network costs (i.e., those network costs that are not recovered via cost-reflective charges).

- Policy makers and regulators must be wary of the possibility of societally inefficient "grid defection" if residual network costs and policy charges become too high. This may suggest an upper limit on the portion of these costs that can be collected in electricity tariffs rather than through broader taxes or other means.

The regulation of distribution utilities must be improved to enable the development of more efficient distribution utility business models.

- Forward-looking, multi-year revenue trajectories with profit-sharing mechanisms can reward distribution utilities for cost-saving investments and operations, aligning utilities' business incentives with the continual pursuit of novel solutions.

- Several "state of the art" regulatory tools, including an incentive-compatible menu of contracts, an engineering-based reference network model, and automatic adjustment factors to account for forecast errors, can better equip regulators for an evolving and uncertain electricity landscape.

- Equalizing financial incentives related to capital and operational expenditures can free utilities to pursue cost-effective combinations of conventional investments and novel operational expenditures (including payments to distributed resources).

- Outcome-based performance incentives can reward utilities for improvements in quality of service, such as enhanced resiliency, reduced distribution losses, and improved interconnection times.

- Incentives for longer-term innovation are needed to accelerate investment in applied R&D and demonstration projects and learning about the capabilities of novel technologies and practices that may have higher risk or longer-term payback periods.

The structure of the electricity industry should be carefully reevaluated to minimize potential conflicts of interest.

- Network providers, system operators, and market platforms constitute the critical functions that sit at the center of all transactions in electricity markets. Properly assigning responsibilities for these core functions is thus critical to an efficient, well-functioning electricity sector. It is also critical to establish a level playing field for the competitive provision of electricity services by traditional generators, network providers, and distributed energy resources.

- As experience with restructuring in the bulk power system has demonstrated, structural reform that establishes financial independence between distribution system operation and planning functions and competitive market activities would be preferable from the perspective of economic efficiency and would facilitate more light-handed regulation.

- If financial independence is not established, several additional measures are critical to prevent conflicts of interest and abuses of market power. These include: stricter regulatory oversight of distribution network planning and operation; legal unbundling and functional restrictions on information exchange and coordination between distribution system operators and competitive subsidiaries; and transparent mechanisms for the provision of distribution system services (such as public tenders or auctions).

- Maintaining a data hub or data exchange may constitute a fourth critical function. Such a hub or exchange would serve several purposes: securely storing metered data on customer usage, telemetry data on network operation and constraints, and other relevant information; allowing non-discriminatory access to this data to registered market participants; and providing end customers with timely and useful access to data on their own usage of electricity services. Responsibility for this function should also be carefully assigned, with priority given to data security and customer privacy considerations.

Wholesale market design should be improved to better integrate distributed resources, reward greater flexibility, and create a level playing field for all technologies.

- Wholesale markets should enable transactions to be made closer to real time to reward flexible resources and to enable better forecasting and control of variable renewable resources and electricity demand.
- Wholesale market rules such as bidding formats should be updated to reflect the operational constraints of novel resources such as demand response and energy storage, as well as new patterns of operation of conventional power plants.
- More efficient pricing of reserves can help wholesale markets function better, improve price signals for energy and operating reserves, and strengthen the link between these two services.

Widespread connection of distributed energy resources and smart appliances and development of more complex electricity markets increase the importance of cybersecurity and heighten privacy concerns.

- Robust regulatory standards for cybersecurity and privacy are needed for all components of an interconnected electricity network.
- To keep pace with rapidly evolving cybersecurity threats against large and complex electric power systems, electric utilities, vendors, law enforcement authorities, and governments should share current cyber threat information and solutions quickly and effectively.

Better utilization of existing assets and smarter energy consumption hold great potential for cost savings. At the same time, economies of scale still matter, and the distributed deployment of solar PV or energy storage is not cost-effective in all contexts and locations.

- The value of some electricity services can differ substantially depending on where within the power system that service is provided or consumed. This variation in "locational value" underscores the importance of locationally granular prices and charges and makes it impractical to define a single value for any distributed resource.
- Distributed energy resources can be sited and operated to provide services in those areas of the power system where their services are most valuable. Understanding the specific services that have locational value is thus critical to understanding how distributed resources can create value in power systems.
- Unlocking the contribution of resources that already exist — such as flexible demand, electric vehicles, power electronics, or distributed generation that is already deployed — can be an efficient alternative to investing in electricity generation and network capacity.
- Economies of scale still matter, even for distributed energy resources. For resources that can be deployed at multiple scales, such as solar PV and battery energy storage, incremental costs associated with failing to exhaust economies of unit scale can outweigh locational value. This can result in a "distributed opportunity cost," making distributed deployment of these resources inefficient. Trade-offs between the incremental costs and additional locational value associated with deploying distributed resources on a smaller scale must be considered in each context.
- For resources that exhibit significantly higher unit costs at smaller scales, such as solar PV and battery energy storage, distributed deployment is likely to be inefficient in many locations. Exceptions may include areas that have heavily congested networks or that are experiencing rapid growth in electricity demand. In these areas, locational value may be significant.
- New innovations may transform economies of unit scale for solar energy or storage technologies, enabling more ubiquitous distributed deployment of these resources.

MAILING ADDRESS

MIT Energy Initiative
77 Massachusetts Avenue, E319-307
Cambridge, MA 02139

energy.mit.edu