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King Abdullah Petroleum Studies and Research Center

Workshop Policy Brief

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Energy Systems Modeling to Support Policy Making

Summary for policymakers

In October 2013, KAPSARC convened a workshop in Washington, DC attended by some 30 international energy economic modeling and policy experts. Discussions addressed the need to match evolving policy imperatives with new and improved modeling approaches.

The main needs of energy system models over the past three decades trace a journey from an era in which concerns about security and sufficiency of supply were the dominant themes (1970s and 1980s), through a swing towards liberalizing markets, particularly North American natural gas and electric power (1980s and 1990s), to a growing concern about climate change and greenhouse gas emissions (2000s). In addition, there are now numerous countries with quickly developing economies under central economic controls. Perhaps the future will require models that optimize the energy economies of such countries, developing under a centralized state capitalism model and administered prices.

As policy imperatives evolved over time, so did the various models and their types, changing their techniques and evolving their data sources. As a result, there is now a plethora of different models that cater to the evolving needs of policy makers, including optimization, equilibrium, and macro-econometric models.

Successful models to support policy interventions distinguish between:

- the policy objectives or needs for the degree of intervention necessary,
- the measures and targets used to influence the decision making environment in the sector or economy, and
- the actions which address the policy objectives and meet the targets.

As valuable as these models are in describing various scenarios, policy makers can, nonetheless, benefit from remembering that model outputs are not forecasts so much as descriptions of what would happen if the representation of reality they describe were to play out. Models are always simplifications of reality and there will always be exogenous factors that lead to a difference between "forecasts" and the actual outturn.

About KAPSARC

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

Legal notice

Background to the workshop

The workshop was hosted in collaboration with The George Washington University and Johns Hopkins University. Its three primary goals were:

– to identify how changing energy, economic and environmental policy imperatives created demand for new model forms,

– to characterize the evolution of existing models, and

– to describe the KAPSARC Energy Model (KEM) and present it for external review.

The first and second objectives were achieved by considering historical perspectives on the National Energy Modeling System (NEMS), the Market Allocation Model (MARKAL) and its successor The Integrated MARKAL EFOM Systems (TIMES), the Gas Pipeline Competition Model (GPCM). These and other approaches have achieved widespread adoption for analyzing policy challenges, including those employed by commercial enterprises. The KAPSARC Energy Model (KEM) is a multi-sector model that seeks to optimize energy systems under administered pricing economies. Appendix A to this brief contains a more detailed description of the drivers of KEM and its application in countries that rely on administered prices to balance economic efficiency with social goals.

Discussions among participants revealed several key insights in relation to the evolving needs of energy system models over the past three decades. Policy priorities have moved from an era in which concerns about security and sufficiency of supply were the dominant themes (1970s), through a swing towards liberalizing markets, particularly North American natural gas (1980s and 1990s), to a growing concern about climate change and greenhouse gas emissions (2000s). New challenges will drive the modeling agenda in the future.

Characteristics of successful policy models

Models are useful to explore directional changes that would result from implementing different policies and testing them under varying economic scenarios. However, model outputs are not forecasts so much as descriptions of what would happen if the representation of reality described in the model were to play out. Moreover, models are always simplifications of reality and there will always be exogenous factors that lead to a difference between "forecasts" and the actual outturn. As the first Administrator of the Energy Information Administration (EIA), Lincoln Moses, reminded Congress during testimony: *"There are no facts about the future."*

It can be helpful to distinguish between three characteristics in policy models. These are:

– the *policy objectives* or needs for the degree of intervention necessary,

– the *measures and targets* used to influence the decision making environment in the sector or economy, and

– the *actions* which address the policy objectives and meet the targets.

"There are no facts about the future."
– Lincoln Moses, First Administrator of the EIA

Advances in computational power have increased the breadth and depth of policy makers' desire for quantitative analysis as they seek evaluations from energy policy modelers and their tools. To meet these increased demands, larger and more complicated models ensued that require a clear design architecture that permits flexibility and the decentralization or modularity of components to meet these new and changing demands. This raises

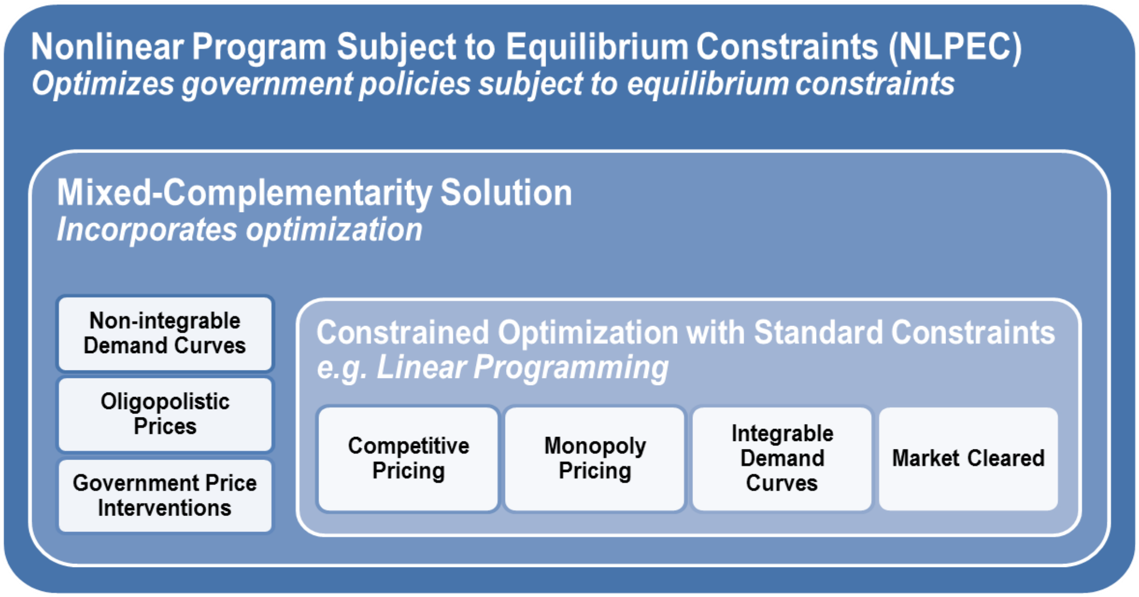

Figure 1: Layers of modeling capabilities.

an issue of scale regarding the appropriate level of detail, or "Bigness" in models. The quantity and quality of data required to support the effort can be problematic and a hard constraint. Moreover, increasing the level of disaggregation and detail can be counterproductive if the quality of data is poor or even non-existent.

"The plural of anecdotes is not data!"

Almost independent of the size issue are two important tradeoffs that are critical individually and jointly. First, all models require simplification. They are only representations of markets, sectors, and the economy which need to be realistic. Second, models need to incorporate and be clear on how technological innovation and adoption are treated. These two issues are the basis for much debate in any policy discussion, particularly when there are gaps in the actual data used for the models.

Better outcomes are achieved when the modeling methodology and solution are appropriate for the environment in which they are used. Once again, there are tradeoffs in the value and appropriateness across alternative model solving methodologies and techniques, see Figure 1. These include linear programming / optimization, general equilibrium, mixed complementarity, and hybrid models.

Optimization models are best suited to situations where decisions and allocations are based roughly on marginal costs and benefits. Mixed complementarity models meet the need of economies where administered prices drive the perception and mindset of public and private industry and households. Hybrid models can have a combination of optimization, mixed complementarity, energy econometric, and technology simulation procedures. They attempt to take the best from each methodology to address policy issues, but possibly at the expense of model complexity and granularity.

Additionally, there are important non-technical factors that affect the success of models. They are more likely to be successful if well documented, have champions, and to a degree are publicly available. A clearly written description of a model, explaining how it works and how to interpret the equations, the variables, and their sources, are critical for the model to be maintained and updated in the future. Replication of the model, or the belief in the ability to do so, instills confidence in outsiders and is essential for model users.

Model documentation is an essential investment for model building rather than an afterthought, as some modelers treat it. Once a model has been built, there need to be internal and external experts who believe the model or representations and tasks for which it is used are credible. Those champions have an understanding of the strengths and weaknesses of the model, can say where it fits in the analytical and policy debate, and provide historical or institutional memory about the model. When models are made publicly available and can be run by outside users, credibility and value are strengthened. Also users provide feedback about the model and can become champions of the model over time as their confidence in it builds up.

Models for changing policy imperatives

New types of models emerge over time to cater to the changing policy imperatives. Examples of energy models that have successfully evolved over time are NEMS and TIMES, mentioned here earlier. The underlying architecture in both cases relies on competitive markets and price clearing as the method of allocating resources.

NEMS was originally developed by the EIA in 1992 as a regional energy-economy model. It produces annual projections for the medium term to 25 years. NEMS reports provide a reference case (absent policy changes) and scenarios on energy consumption and production by fuel, sector, relative prices, imports, and exports. The scenarios are based on feedback with technology adoption and economic trends. Environmental policy indicators, such as carbon dioxide emissions, are produced with the energy values.

TIMES, an outgrowth of the IEA's MARKAL model, is a technology-rich model combined with an economic optimization model for national, multi-regional energy, and global systems. It uses a bottom -up framework to incorporate richness in technology and the economy for estimating the development of the energy system over a long-term time horizon. There is a large database containing the structure and attributes of the energy system being modeled. Rational expectations with full information and perfect foresight are assumed by economic agents, who are cost minimizers.

Many of the emerging economies rely on administered prices and some regulatory oversight to allocate resources in the economy in order to meet desired social goals. These goals may be to provide energy at low cost (whether above or below the marginal cost of domestic production) compared to globally traded prices. They may also be market reflective prices but regulated to dampen volatility and thus social upheaval resulting from price fluctuations. Such systems are now very common worldwide and need special kinds of models that can naturally accommodate their constraints. The KAPSARC Energy Model (KEM) was developed to provide a tool for such economies to capture as much of the economic efficiency that market based prices can provide without requiring full price deregulation. The cost of the goal of retaining social stability can thus be assessed against a theoretical deregulation case. Appendix A describes the objectives and functioning of KEM in greater detail, and a working paper provides a complete description of the current implementation for Saudi Arabia.

Other examples of changing model needs in the face of evolving policy imperatives involve natural gas markets, the global oil market, and water and land use issues. The GPCM was developed in the wake of North American gas deregulation and the unbundling of production, transportation, and distribution along with the demise of long-term take-or-pay contracts between producers and utilities. These policy and market changes required updating of existing models and developing new models to understand how prices of gas at different nodes in the transportation network might equilibrate in the face of changing patterns of supply and demand. It has become a widely used model in North America.

However, globally, the picture has been less dynamic because natural gas markets remain dominated by regional factors and long-term contracts tied to oil prices or prices of alternative fuels. Increasing supplies from new discoveries off-shore, shale gas, tight gas, and expanding pipeline and LNG receiving infrastructure are adding to flexibility in the market and changing international trade flows. As a result, the indexation of natural gas prices to oil prices in contracts is becoming less rigid. This and the globalization and spreading deregulation of natural gas markets through the growth of global LNG trade (and particularly the emergence of routine LNG spot trades) has led to a need for more sophisticated modeling. Such models trace trade and tanker flows and calculate market prices in equilibrium. They account for demand, production capacity constraints, pipeline and terminal infrastructure, and tanker availability, for both spot as well as contract deliveries of LNG and their interaction with regional markets that are now linked through this global trade.

Another example of changing policy concerns is the incorporation of Peak Oil (and the work of M. K. Hubbert) into long-term oil price forecasting models. Such modeling became more prevalent as oil prices ballooned in the 2000s, leading to fears about the ability of supply to keep pace with demand growth. However, in light of unconventional oil development and growth in deep water exploration and crude oil substitutes (responding to these high prices), concerns on this front have abated in policy circles.

"The value of a model is not necessarily in the accuracy of its predictions but in the extent to which it helps us understand the problem."

A working version of a partial equilibrium model that incorporates and reconciles economic / technological and geological factors at a global level to explain oil production and prices was discussed in the workshop. This was an example of a small (econometric) model, appropriate for analytical and policy purposes – the intuition and dynamics can be much clearer than in large-scale models. The model examined the demand and supply sides of the oil market with the latter grounded in geological resource constraints (based on a Hubbert curve framework with modifications to the curves as additional resources cause originally forecasted depletion to be deferred). The model did not incorporate the effect of expected real oil price growth on investment in production and the response to incentives for oil substitutes. However, it provided a useful case study to illustrate the tradeoffs modelers face when deciding how "Big" or disaggregated to make a model. In addition, it suggested a possible path for learning, improving, and model evolution.

A final example of evolving policy imperatives and the modelers' response can be found in the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). It is a global optimization model for resource use and international trade. It combines general and partial equilibrium modeling for global food, energy, and water issues – with water providing geographical and biophysical constraints. IMPACT can be used for examining the outcomes of different policies and regulatory behavior, including resource use by region, trade in food and fuel, and the marginal or shadow value of binding resource constraints.

IMPACT is a large model that disaggregates into 32 agricultural commodities and 281 global regional/ spatial units. Trade is governed by domestic policies and international agreements. The size of the aggregate model means that data limitations prevent estimation and the construction of confidence intervals. Rather, numerous policy simulations and scenarios are used to examine the robustness of projections.

However, in an increasingly interconnected world, both geographically and sectorally, the nexus of food, energy, and water looms large. These integrated multi-sector models may represent the next stage in the evolution of policy models more generally and require best practices in model architecture, integration, and management.

Conclusions

KAPSARC's Workshop on Energy Systems Modeling brought together some 30 energy experts from the private sector, public sector statistical services, regulatory bodies, international institutions, academia, and research think tanks. They represented both producers and consumers of energy policy models with backgrounds in economics, systems engineering, operations research, finance, and environmental science.

The workshop participants' collective experience provided breadth and depth to a discussion about changes in evolving policy issue imperatives and the technical issues in developing new model forms and upgrading existing models. Important questions were raised about the role of models in policy analysis and policy making, the design and development criteria for models to address current and future policy issues, modeling techniques, and the credibility of models in the eyes of professionals and policy makers.

The Workshop generated candid discussion by model builders, policy decision makers, and model users across the table in an environment where a diverse collection of models was presented and discussion was encouraged.

Appendix A: Introduction to the KAPSARC Energy Model for Saudi Arabia

The initial implementation of the KAPSARC Energy Model (KEM), an energy systems mixed complementary model, looks at a multi-sector formulation for Saudi Arabia. This model has to address similar issues in energy economics and the environment, but in a different context. Most of the popular energy economy and environmental models to date have been built around the experience of western OECD countries, whose energy policy either directly or indirectly emphasizes the greenhouse gas perspective, given the level of existing development and incomes in those countries.

Some of the novel features of KEM, include the following:

- It is the first integrated, equilibrium energy model of Saudi Arabia. Moreover, it is generally applicable to other economies, in the sense that the methodological approach it utilizes captures government interventions that permeate numerous economies outside the OECD. In order to handle these interventions properly, the model adopts a mixed complementarity formulation rather than use conventional optimization methods such as linear programming

– The model design and component organization uses an architecture that allows it to solve critical model-management issues that have been part of building energy-systems models from the very beginning. Such models have tended to be complicated and unwieldy, creating management and convergence issues.

Model need

Historical policies and social institutions in Saudi Arabia have created an economic structure with its particular issues, in common with many emerging and developing countries whether resource rich or not. The social objectives and policies of these economies have focused on rapid economic growth while providing energy, other commodities, and, to the extent possible, health care and education at low cost, in order to maximize wealth sharing or minimize hardship among the population. Administered pricing and even free provision have been used to meet such objectives.

Can Saudi Arabia implement a set of transfer prices among energy sectors that induce greater efficiencies and lower energy consumption while preserving current consumer prices?

Despite the long-term goal of more market-based incentives, during the transition to that goal, the perspectives and approach taken by firms and households for resource allocation are not based strictly on market criteria. They are, instead, based on the institutional framework in which they live and operate. Economic efficiency argues these countries will eventually transition toward market institutions to meet their objectives, but the speed and path each takes depends on their circumstances. The

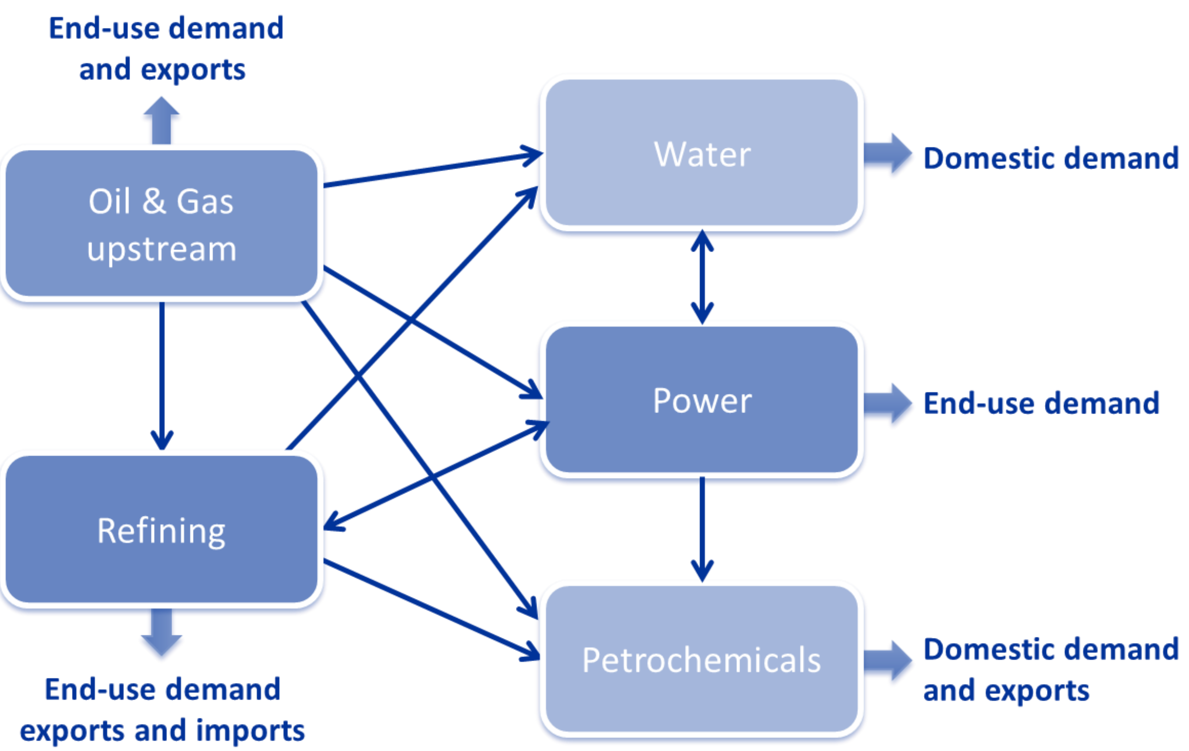

Figure 2: Sector relationships in the KAPSARC Energy Model.

KAPSARC model has been built to examine these circumstances consistently for energy production, investment, and consumption in such countries

This alternative pricing approach can be a first step toward using market prices for decentralizing decision-making (instrumentalist approach)

KEM takes an integrated view of the energy issues faced by Saudi Arabia and similar countries that have administered energy pricing schemes. It is a mixed-complementarity model that captures the non-market features resulting in prices that are different from marginal costs. It represents the major fuels, (crude oil and natural gas), energy-transformation technologies, (oil refining and electricity generation), two major fuel-consuming industries, (petrochemicals and water desalination), and other end-use consumption. KEM is representative of large-scale energy process and natural resource economic models.

Saudi Arabia faces a complex set of energy issues that result from growing domestic energy demand that can impact the country's ability to export oil, constrained supplies of natural gas that affects its use of gas as an economic development tool, and a growing domestic energy economy. Energy prices are set by the government and not markets, whereby domestic oil and gas prices are administered because low local production costs mean prices can be kept low without incurring accounting losses. These prices are passed through to domestic end consumers of power, water, and transportation fuels and they observe or pay low administered prices. Thus, the model serves as a tool for estimating the consequences of alternative policies that shape energy production and use within the country.

Saudi Arabia is making large investment decisions in the energy and water sectors to meet rapid demand growth that is driven by the growing population and real income. Changes in economic decision making and institutional relationships are necessary to make the economy more competitive and energy efficient while minimizing any negative effects on the society's welfare during the transition. However, making investment decisions using administered prices leads to economically inefficient outcomes because marginal costs are different from prices. Furthermore, there is the question of how to alter administered prices while maintaining the current levels of consumer welfare. KEM is designed to address these and other energy issues.

Implementation

The design of KEM enables countries that rely on administered prices to transition at relatively low social cost to competitive pricing and markets in most goods, by finding second-best strategies that increase economic efficiency while maintaining existing social policies.

Fiscal policy can be used in lieu of deregulated markets to achieve near-market allocations; for example KEM allows policy makers to provide tax incentives to energy producers to invest in higher energy efficiency embodied capital stock. Producers can charge "market prices" among themselves without changing consumer prices therefore at a small overall social welfare cost. Several such policies were illustrated for Saudi Arabia. However, the architecture, methodology, and technology of KEM have been designed to be sufficiently general in order to conduct further studies on other countries.

About the workshop

The workshop, held in October 2013 with some 30 international experts, was held under the Chatham House rules of capturing the discussion in a non-attribution basis. Participants included:

AbdulAziz Ahmed – Research Associate, KAPSARC

Anthony Andrews – Energy Policy Specialist, Congressional Research Services

Robert Brooks – President, RBAC Inc.

Ximing Cai – Professor, University of Illinois at Urbana-Champaign

John Conti – Assistant Administrator, Office of Energy Analysis, EIA

Andreas Ehrenmann – Chief Analyst, GDF Suez, Center of Expertise in Economic Modeling and Studies

Frank Felder – Director, Center for Energy, Economic & Environmental Policy

Mark Finley – General Manager, Global Energy Markets & U.S. Economics, BP

Lessly Goudarzi – CEO and Managing, Director, OnLocation Inc.

Howard Gruenspecht – Deputy Administrator, EIA

Susan Holte – Director of Office of Integrated Analysis and Forecasting, EIA (former)

Benjamin Hobbs – Professor of Geography and Environmental Engineering, Johns Hopkins University

David Hobbs – Head of Research, KAPSARC

Hill Huntington – Executive Director of Energy Modeling Forum, Stanford University

Fred Joutz – Senior Research Fellow, KAPSARC

Amit Kanudia – Energy Modeling Researcher and Consultant, KanORS

Steven Kimbrough – Professor, Wharton School, University of Pennsylvania

Michael Kumhof – Deputy Division Chief, Modeling Division, International Monetary Fund

Daniel Mabrey – Assistant Professor, University of New Haven

Walid Matar – Senior Research Analyst, KAPSARC

Fred Murphy – Senior Visiting Fellow, KAPSARC (and Prof. Emeritus, Temple University)

Richard O'Neill – Chief Economic Advisor, Federal Energy Regulatory Commission

Dalia Patino-Echeverri – Assistant Professor of Energy Systems and Public Policy, Duke University

Anthony Paul – Fellow, Resources for the Future

Axel Pierru – Research Fellow, KAPSARC

Stephen Rattien – Senior Research Advisor, KAPSARC (and former Director, RAND S&T)

Bertrand Rioux – Senior Research Analyst, KAPSARC

Muhammad Saggaf – President, KAPSARC

Maria Scheller – Senior Economist and Manager, ICF International

Benjamin Schlesinger – President, Benjamin Schlesinger and Associates, LLC

James Smith – Professor, Edwin L. Cox School of Business, Southern Methodist University

Govinda Timilsina – Senior Economist, Environment & Energy, World Bank

Sonia Yeh – Research Scientist, Institute of Transportation Studies

Acknowledgement

We would like to thank the Office of Academic Technologies at George Washington University for the logistical support that contributed so much to the workshop's success.

About the Energy Modeling team

Walid Matar is a Senior Research Analyst developing energy systems models. Prior to joining the Center in August 2011, he obtained a B.Sc. degree in mechanical engineering from the University of South Carolina. He then received a graduate degree in the same field from North Carolina State University. On his return to Saudi Arabia, he worked at King Abdullah University of Science and Technology (KAUST) in the area of business incubation.

Frederic Murphy is a Senior Visiting Fellow collaborating with the energy systems modeling work at KAPSARC. He is also Professor Emeritus, Marketing and Supply Chain Management (MSCM) at the Fox School of Business at Temple University. Prior to Temple University, he worked at the Energy Information Administration (EIA) of the U.S. Department of Energy, forecasting and analyzing policy impacts on energy markets. Prof. Murphy worked on all the energy forecasting models for the EIA, including a pioneering role in developing the National Energy Modeling System (NEMS) model.

Axel Pierru is a Research Fellow, leading KAPSARC's energy systems modeling work. He joined KAPSARC after 15 years at IFP Energies Nouvelles. He led research, consulting, and training projects as well as teaching graduate courses at IFP School (supervising three Ph.D. students). Axel received his Ph.D. in economics from Pantheon-Sorbonne University (Paris) and has published numerous research papers in academic journals, mainly in the fields of energy economics and modeling, corporate finance, and the price of oil.

Bertrand Williams-Rioux is a Senior Research Analyst developing energy systems models. He graduated from King Abdullah University of Science and Technology (KAUST) after completing a Master's thesis in Computational Fluid Dynamics. He also has a Bachelor's degree in Atmospheric Physics and Chemistry from McGill University, in Montreal, Canada in 2008. He previously spent an eight month internship as a research assistant at the Canadian Space Agency.