March 2014
KS-1404-WB02A

A Framework for Fuel and Technology Transitions in Energy: Evaluating Policy Effectiveness

Summary for policy makers

In November 2013 KAPSARC organized a workshop in Riyadh, Saudi Arabia, to discuss a framework that adds to existing approaches for evaluating energy transitions and policy. The framework that KAPSARC is developing aims to provide a tool for assessing the effectiveness of policy instruments in delivering rapid transitions in the energy mix. However, together with pace, policymakers aspire to support transitions that are both affordable and supportive of local economies, thereby maximizing societal gain relative to cost.

Efforts to transform the energy technology and fuel mix over condensed time frames across several national economies were discussed. These initiatives are motivated by resource conservation and environmental concerns, together with aspirations to develop green economies. This has brought to surface the challenge of expediting the transition processes within the capital-intensive energy industry—historically a decades-long undertaking.

The policy instruments for accelerating transitions to more diversified fuel and technology mixes were discussed. In the power sector, these include a combination of renewable energy obligations, multi-pollutant emission reduction targets, and financial incentives for developing and deploying new technologies.

Experiences from Europe and North America highlight the inherent challenges in balancing the objectives of speed, cost effectiveness, and promotion of local industries. Ensuring the continuous reliable operation of the power system adds another layer of complexity. Furthermore, the likely unrelenting competitive responses from incumbent technologies and supply chain capacity of the new entrants can significantly impact the pace and path of the transition. These complex dynamics suggest that a more comprehensive framework is valuable for informing energy transition policy.

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

Figure 1 : Today's planning for technology and fuel transitions in energy is motivated by multiple factors and utilizes a variety of drivers. Unintended outcomes could result given the incumbent competitive dynamics and system costs.

Background to the workshop

KAPSARC's November 2013 workshop was attended by approximately 30 global energy experts from industry, governments, and academia. The objective of the workshop was to discuss a framework to add to current approaches for evaluating the effectiveness of policy instruments in delivering rapid transitions that meet their intended objectives.

Fuel and technology transitions in the capital-intensive energy industry have historically taken decades, if not centuries, to materialize organically in response to market forces. Innovation-driven cost improvements in energy technologies have typically had to grapple with infrastructure constraints and access to capital. The evolution of energy technology mixes has also been largely influenced by the structure and economics of technology supply chains.

Engineered fuel and technology transitions in the energy sector were first attempted in the 1970s to address concerns over energy security and environmental quality. Today, as illustrated in Figure 1, resource conservation, environmental concerns and socioeconomic goals are motivating plans to transform the energy mix over highly condensed time frames.

Understanding the tradeoffs among transition objectives is helpful in evaluating the effectiveness of policy and incentives. Chief among these is the tradeoff between the pace of the transition and its impact on the local economy. In several markets across North America and Europe, for example, solar energy incentives have been used to mobilize the investment required to meet renewable energy and emission reduction targets. However, the combination of generous financial incentives and short timeframes for compliance made these markets highly attractive to solar technology supply industries in general—particularly in China and other parts of Asia. These international suppliers could mobilize faster or achieve lower selling prices than domestic suppliers, thus limiting the prospects for development of local solar industry sectors. Moreover, the taxes, tariffs, and incentives resulted in additional burden to society, with associated increases in electricity cost to consumers that exceed the growth in their income.

Evaluating the effectiveness of transition policy and incentives requires an understanding of the key dynamics that determine the pace and path of transitions. This workshop, and subsequent sessions, will seek to provide policymakers with a framework for assessing the implications of policy instruments on achieving the intended objectives of their energy transition plans.

Prioritizing transition policy objectives to address tradeoffs

Increasingly, research organizations are attempting to capture the complexity of the tradeoffs among transition policy objectives. The World Economic Forum's (WEF) "energy triangle" and the Transition Pathway Consortium's "energy policy objectives trilemma" both underscore the growing pressure to balance industrial competitiveness and environmental goals with energy security, access, and affordability.

Prioritizing transition policy objectives is key to identifying desirable transition pathways and supportive policy tools. In China, for example, pollution issues, including local air and water quality, have gained primacy in deliberations over transitions to a more diversified energy mix. This is different from the stronger emphasis on greenhouse gas (GHG) emissions reduction in the European Union (EU). In the United States much greater emphasis is placed on the economic cost of compliance and the desire to maintain a strong competitive position within the global energy industry.

In Saudi Arabia, plans to diversify the generation mix combine with a desire to develop competitive renewable and nuclear energy sectors. Transition planning is, thus, partly motivated by the Saudi social and economic development priorities, including human capital development and creating employment opportunities.

The perfect storm of enablers defines or redefines transitions

Past transitions may have been driven by multiple objectives, just as today's are supported by a diverse set of drivers. But this may be a necessary, rather than sufficient, condition. A variety of enablers also have to come together for energy transitions to occur. Participants discussed the role of aligned economic, technological, and social enablers in facilitating energy transitions—a pre-condition for the Industrial Revolution that began in the UK in the eighteenth century, or the nineteenth century transition from whale oil to petroleum. These examples reinforce the benefits of understanding historical transitions and their lessons as to the role of non-policy enablers.

> **"Technology is an important factor but it is not the only one. There is an ecosystem of enabling pillars that must come together… these also include policy, market structure, and human capital."**

Today, the US electricity sector's ongoing transition from coal to natural gas is being enabled by declining gas prices precipitated by the shale gas revolution. The latter was made possible by hydraulic fracturing technology in combination with support from multi-pollutant emission reduction policy, a natural gas industry characterized by a

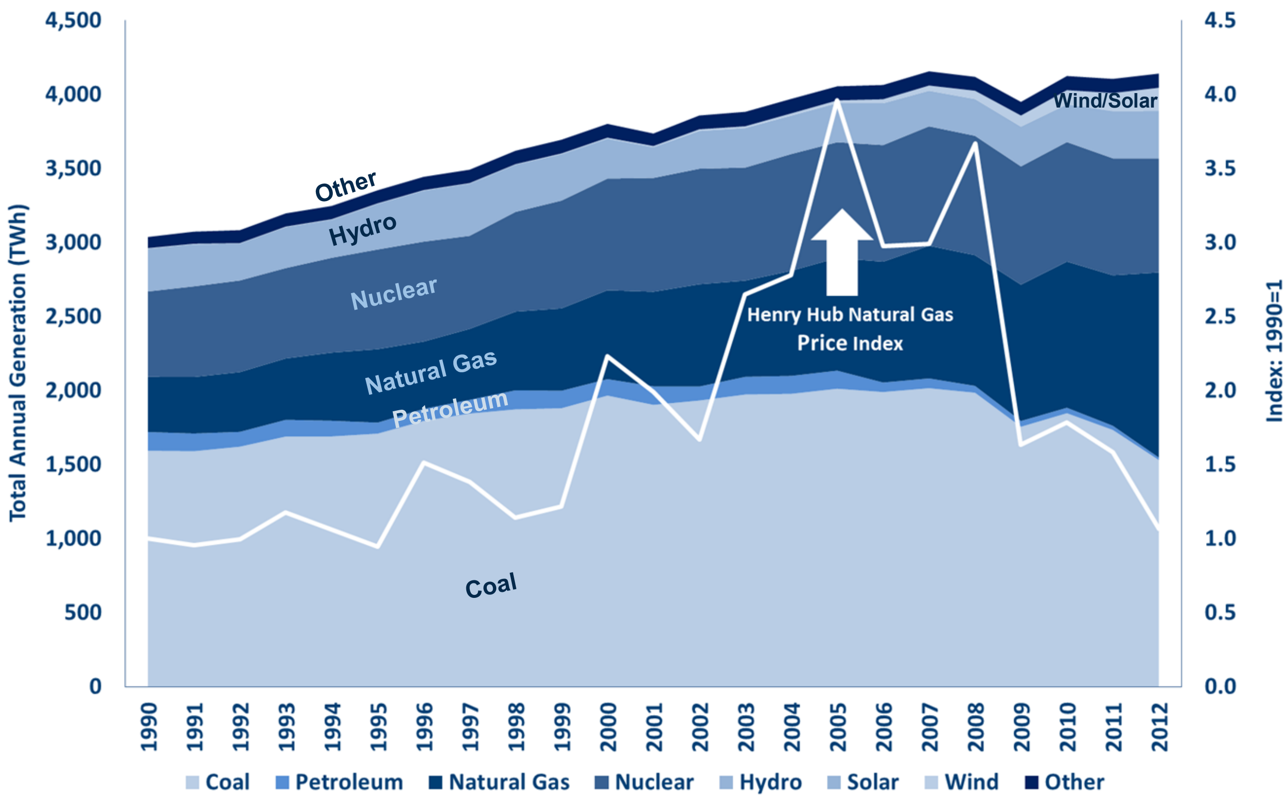

Figure 2: US The abundance of shale gas supplies and the resultant decline in gas prices resulted in significant coal-to-gas switching in the US amidst efforts to support transition to renewable energy. Data sources: EIA, EPA, DSIRE.

large number of small independent producers, and a sophisticated oil and gas workforce. Figure 2 shows the steep fall in natural gas prices since 2008.

> **"General purpose technologies led to the sustained technical progress and growth of past industrial revolutions."**

The coal to gas switching has, in turn, freed up cheap US coal supplies. These, combined with low carbon prices and the retirement of nuclear generation facilities in Germany post Fukushima, have resulted in a switch from natural gas to coal in several EU countries. The low carbon pricing resulted from changes to energy mix profiles in compliance with targets for renewable energy, energy efficiency and emissions reduction.

The unintended consequence of switching to coal in the EU has been the result of overlapping transition policies. Also, the transition between fossil fuels in the US underscores the value of understanding the implications of the very likely competitive pressure from the incumbent technology or fuel on transition planning. These experiences demonstrate the need for a deeper understanding of the transition enablers, and, more importantly, their interactions, in evaluating the effectiveness of policy instruments.

Stakeholder misalignment inhibits technological innovation

Technological innovation is generally accepted as a key enabler of transitions. But, workshop participants reinforced the need to recognize that stakeholder misalignment can be a major inhibitor. For example, it was pointed out by some participants that innovation in road transport technology in recent decades was driven by environmental targets, fuel supply concerns and industrial competitiveness goals. However, a long-term transition to electric powertrains and biofuels is currently being hindered by the limited alignment and conservative behavior of the key actors involved, in particular the oil and automotive industries and their customers.

This is true of the electric power sector, with multiple actors, including fuel producers, manufacturers and service providers across generation technology supply chains, utilities and other power producers, regulators, and consumers. Therefore, successful transition planning may benefit from technological options and transition paths that align stakeholder priorities. The redirection of R&D budgets from carbon capture and storage to carbon capture and reuse technologies illustrates this quest for alignment.

Energy trade position and the pace of transitions

The geographic distribution of energy resources and related industry supply chains is a key determinant of the pace of transitions. More specifically, participants discussed the significance of the role that local supply chains play. Strong reliance by the incumbent technology on local fuel and/or technology supply sectors could significantly extend the duration of the transition process. In the UK, for example, major social disruptions and strikes accompanied the transition from coal to natural gas in the power sector as whole communities were faced with closures of the coal mines that supported their local economy.

Japan, by contrast, has experienced three energy transitions during the past 50 years: from coal to oil in the 1960s; from oil to LNG, coal, and nuclear in the 1970s after the oil embargo; and finally the transition to low carbon technologies in the late 1990s after the Kyoto Protocol. These transitions generally occurred at a much faster pace than transitions elsewhere. Japan imports virtually all (over 90%) of the fuels it consumes. This minimal reliance on local fuel supply industries has combined with deliberate and integrated policy to deliver faster transitions. However, in general efforts to transition away from well-established national resource-based energy mixes often face significant political and economic challenges.

Who bears the brunt of transitions?

While engineered transitions aim to achieve societal benefits ranging from economic and social development to environmental goals, minimizing societal costs can be particularly challenging. One of the most immediately visible manifestations of these costs is electricity retail rate increases. Renewable energy is characterized by zero to very low marginal cost of generation. Its penetration may cause wholesale prices to fall much lower than the levels required for full cost recovery, thereby reducing the appetite to invest in renewable energy. A typical response is to raise retail rates to compensate utilities for the high investment costs and cover the direct costs of feed-in tariffs (FITs) and similar incentives.

In Germany, the associated renewable energy costs have thus far represented no more than 15% of the residential retail rates. Still, the palatability of further increases in retail rates to finance a continued uptake of renewable energy seems limited among multiple stakeholders. This is especially problematic in a country where residential retail rates are already much higher than the regional average (Figure 3).

The high investment costs of renewable generation are not the only issue when it comes to the cost of energy transitions. Additional costs result from the unique operating and locational characteristics of

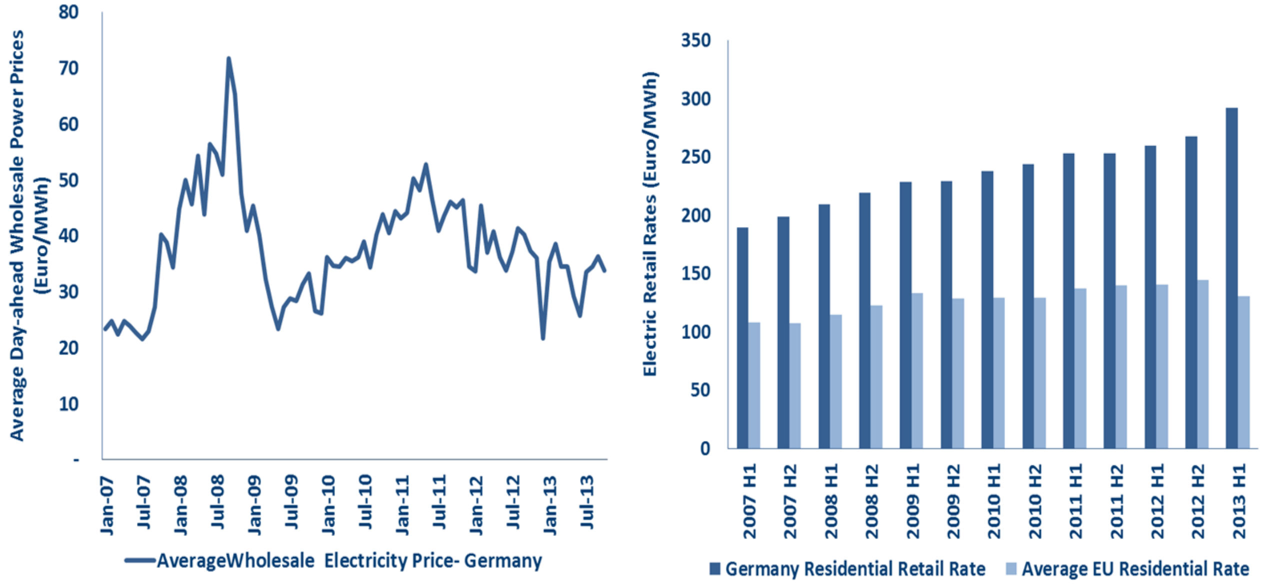

Figure 3: Historical wholesale and retail electricity prices in Germany. Data sources: European Power Exchange extracted using Thomson Reuters Datastream, Eurostat

solar and wind technologies. The entry of a large number of intermittent solar and wind facilities creates the need for compensating conventional technologies for more flexible operation. Potentially a more dramatic addition to the system costs is the cost of investing in transmission infrastructure to integrate renewable energy, since the location of a solar or wind facility is determined by the geographic distribution of renewable energy potential rather than proximity to load centers.

Informing policy: conceptualizing transitions through technology competitive dynamics

Fuel and technology transitions can be conceptualized through the competitive dynamics between the incumbent and new technologies. Expectations about generation technology competitiveness are a key driver of investment decisions within the electric utility industry. In particular, the levelized cost of energy (LCOE) has been widely used for establishing a common understanding of renewable energy economics. The levelized cost of energy is the cost at which electricity is generated from a specific technology ensuring full cost recovery over the lifetime of the project. LCOE incorporates the costs of: initial investment, fuel, operation and maintenance, emission allowances, and other variable and fixed costs.

The transition process initiates when the LCOE of the new technology declines as a result of technological breakthroughs, economies of scale, and learning effects (Figure 4). Concurrently, the LCOE of the incumbent technology might be expected to rise as a result of increasing fuel prices. However, this initial phase of convergence in LCOEs is often followed by divergence as a result of:

- The growing demand for the new technology tightens its supply/demand balance, thereby placing upward pressure on its LCOE.
- At the same time, the lower demand for the incumbent technology and fuel relaxes its supply/ demand balance, causing its LCOE to decline.

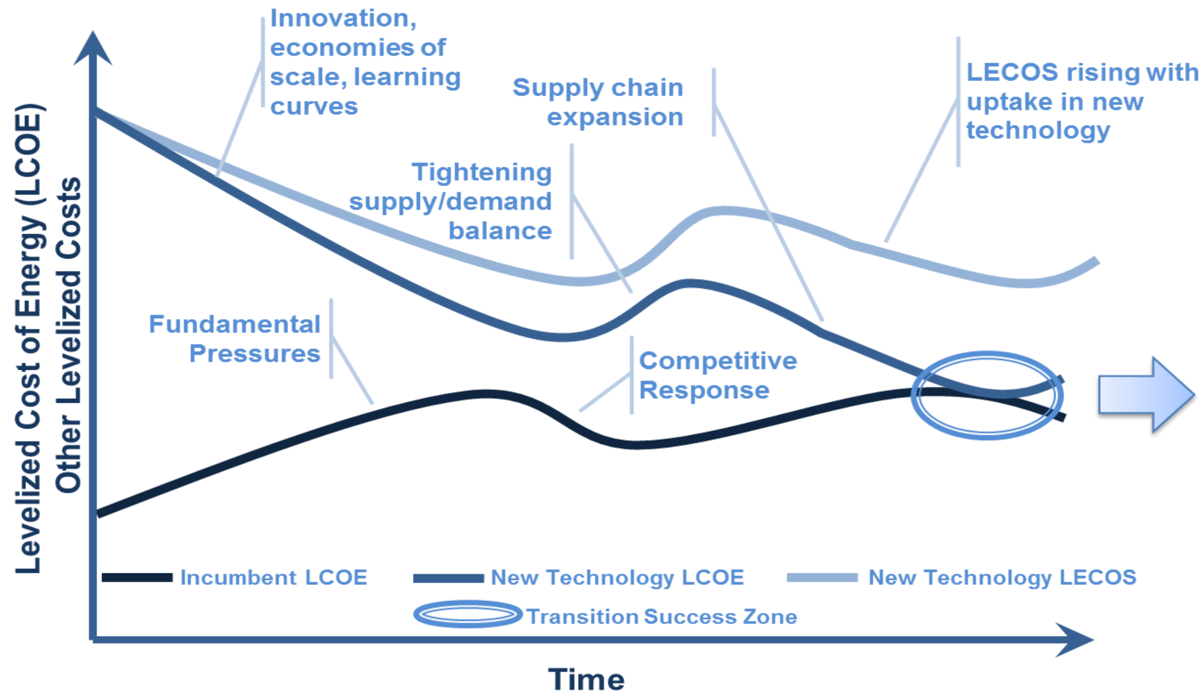

Figure 4: Conceptual framework of power technology transitions, incorporating the levelized cost of energy and overall system operational and Integration costs into the levelized effective cost of system. Source: KAPSARC.

– Consequently, incumbent supply chains experience contraction in overall capacity while the new entrant builds new supply capacity.

– These deflationary pressures on the incumbent stimulate a competitive response, reducing its LCOE.

After this divergence, a new phase of convergence will begin. The new technology benefits from more technological learning, economies of scale, and supply chain expansion, while the incumbent gradually loses momentum. These convergence/ divergence cycles may repeat several times until the LCOE of the new technology falls below that of the incumbent, thereby facilitating the transition.

In more mature economies with limited energy growth potential, transitions typically occur at a slower pace because the LCOE of the new technology (i.e. the *full cycle* cost) may have to decrease below the *marginal* cost of generation of the incumbent. This would allow the new technology to displace the incumbent only by pushing existing facilities into early retirement. In faster growing economies, the need to invest in new assets to meet load growth in developing economies may allow transitions to occur at a faster rate because it is the full cycle costs of both technologies that are competing against each other.

The need of the new entrant to out-compete the marginal cost of the incumbent explains the slow pace and unpredictable outcomes of naturally occurring energy transitions. If policymakers wish to engineer transitions over condensed time frames, they will typically reinforce their plans through the deployment of policy instruments. These include financial incentives such as tax breaks or feed-in tariffs in exchange for investment in or production from renewable technologies. Incentives would effectively reduce new technology LCOEs thereby expediting the LCOE convergence and motivating investment in the new technology.

As discussed earlier, the high costs associated with integrating and supporting new forms of generation can significantly influence the pace of the transition. These include the costs of investing in new transmission infrastructure and compensating conventional technologies for new modes of operation. The levelized *effective cost of service* (LECOS) may be a useful concept that combines the system integration costs of renewable energy with LCOEs. These additional costs tend to be geography and market specific—potentially losing some of the general applicability of LCOE—and they rise with the increasing uptake of new technologies, hence further delaying the competitive dynamics and the overall transition process (Figure 4).

Next Steps

The workshop discussions highlighted the complexity of the dynamics determining the effectiveness of transition policy. Those identified dynamics suggest areas for future research:

– The effectiveness of the transition path and the economic efficiency of the associated instruments benefit from the prioritization of policy objectives.

– The alignment of regulatory, technological, economic, and societal enablers has been an important ingredient for naturally occurring and engineered transitions alike. Conversely, misalignment among the different stakeholder sectors can significantly derail progress in new technology adoption.

– Another force that could slow down transitions is the reliance of the incumbent technology on well-established local fuel and technology supply chains.

– The pace of energy techonology transitions is also influenced by changes in relative societal costs and consumer/taxpayer appetite through time. These include new technology installation costs and infrastructure integration and operational costs.

– Energy transitions can be conceptualized by representing the cost competitiveness between the incumbent and the new technologies. This conceptualization underscores the significance of technology supply chain evolution on the pace and path of transitions.

Therefore, understanding how transition policy can best support its main objectives requires gaining more insight into key relationships. These relationships explain linkages among the various industry sectors, decision makers, and other actors. In particular, discussions during the workshop highlighted important gaps in knowledge in the following areas:

– The direct and indirect effect of policy intervention on the development of new technology supply chains, including both the manufacturing and service sectors.

– The impact of the structure and scale of the supply chains on the cost competitiveness of both the new and the incumbent technologies.

In the coming months we will be conducting research in these two areas using a combination of methods. The results of this research will be fed into KAPSARC's dynamic simulation modeling framework (see Appendix). The modeling framework will capitalize on an improved understanding of the key areas outlined above. This will allow us to create a test bed to capture and compare the impact of different policy instruments on the overall rate of transition and on the development of local supply chains. An important foundation to the framework is the competitive dynamic between the incumbent and new technologies discussed earlier in this brief.

Appendix 1: KAPSARC's Analytical Energy Transitions Framework

Energy technology and fuel transitions are impacted by a large number of actors and forces. This results in resistance to policy intervention and other potential unintended consequences. Also, energy transition policy aims to achieve multiple objectives: expediting the transition to desired portfolios in a cost-effective manner while stimulating national industries. Due to this complexity, KAPSARC is developing an analytical framework for assessing the effectiveness of transition policy instruments in achieving the overall policy objectives.

Existing literature on energy transitions includes several empirical analyses of historical transitions, theories of innovation and technological transition, and some recent modeling efforts. Drawing on this, we have mapped the transition problem in the particular case of power generation sector as represented in Figure 5. This mapping reflects the complexity of decision making in the power sector, the resultant competitive dynamics, and the wide variety of stakeholders involved.

In particular, we have identified supply chains for power generation technologies as a key element of the transition process. Developing local power generation technology manufacturing and services sectors is one of the transition policy priorities in many countries. National industry development is being supported using a range of direct and indirect policy measures. The scale and structure of the supply chain significantly impacts the cost competitiveness of the relevant technology. This means that a positive feedback loop exists between the development of the supply chain and the rate of uptake of the technology. However, developing local supply chains involves certain lead times, indicating a tradeoff between this policy objective and the pace of the desired transition.

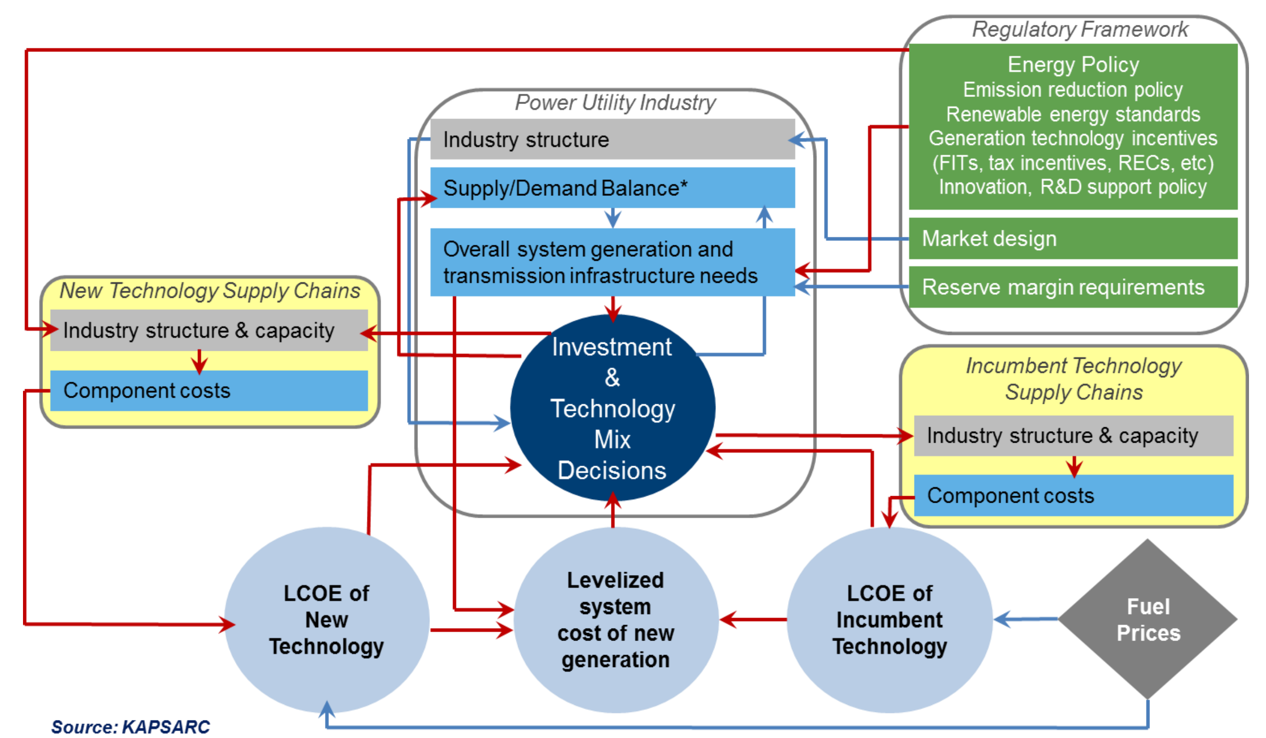

Figure 5: Schematic Illustration of the Transition Process in the Power Generation Sector

About the workshop

KAPSARC convened a workshop in November 2013 with some 30 international experts to facilitate a dialogue on the components and dynamics to be incorporated in a framework we are developing at KAPSARC for understanding fuel and technology transitions. The workshop was held under the Chatham House rules of capturing the discussion in a non-attribution basis. Participants included:

Najeeb Aljamea – Former Director of Energy Department, Economic Affairs, GCC

Ibrahim Babelli – Chief Strategist, King Abdullah City for Atomic and Renewable Energy (K.A.CARE)

Roberto Bocca – Senior Director, Head of Energy Industries, World Economic Forum

Guy Caruso – Senior Advisor, Center for Strategic and International Studies (CSIS)

Marcello Contestabile – Research Fellow, KAPSARC

Amro Elshurafa – Research Associate, KAPSARC

Hind Farag – Research Fellow, KAPSARC

Fatma Al-Hakmani – Director of Energy Department, Economic Affairs, Gulf Cooperation Council (GCC)

Shahid Hasan – Research Fellow, KAPSARC

Zack Henry – Director, Energy Dialogue, International Energy Forum (IEF)

David Hobbs – Head of Research, KAPSARC

Abdallah S. Jum'ah – Former President & CEO, Saudi Aramco, Kingdom of Saudi Arabia

C.S. Kiang – Chairman, Sustainable Development Technology Foundation, China

Timm Lau – Assistant Professor, King Fahd University of Petroleum and Minerals (KFUPM)

Coby van der Linde – Director, Clingendael International Energy Programme (CIEP)

Marwan Masri – President Emeritus, Canadian Energy Research Institute (CERI)

Harro Meijer – Director, Energy and Sustainability Research Institute Groningen

Majid Al-Moneef – Secretary General, Supreme Economic Council, Kingdom of Saudi Arabia

Nora Nezamuddin – Research Analyst, KAPSARC

Peter Pearson – Professor, Cardiff University

Christof Ruhl – Group Chief Economist & Vice President, BP plc

Muhammad Saggaf – President, KAPSARC

Hamad S. Al-Sayari – Former Governor, Saudi Arabian Monetary Agency (SAMA)

Ton Schoot Uiterkamp – Honorary Professor, University of Groningen

Adnan Shihab-Eldin – Director General, Kuwait Foundation for the Advancement of Sciences (KFAS), Kuwait

Daniel Sperling – Director, Institute of Transportation Studies, University of California Davis

Abdullah Sultan – Director, Center of Petroleum and Minerals, King Fahd University of Petroleum and Minerals (KFUPM)

Mohammed I. Al-Suwaiyel – President, King Abdulaziz City for Science and Technology (KACST)

Masakazu Toyoda – Chairman & CEO, Institute of Energy Economics, Japan (IEEJ)

Sonia Yeh – Research Scientist, Institute of Transportation Studies, University of California Davis

Daniel Yergin – Chairman, IHS-Cambridge Energy Research Associates (IHS-CERA)

About the Energy Transitions Team

Marcello Contestabile is a Research Fellow, leading KAPSARC's transitions modeling efforts. He is an expert on low-carbon vehicle technologies, particularly hydrogen fuel cells, batteries and related infrastructure. Marcello joined KAPSARC from the Centre for Environmental Policy, Imperial College, London, from where he received a PhD in Energy Policy and Technology and a MSc in Environmental Technology. He also received a MSc in Chemistry from the University of Rome La Sapienza.

Amro Elshurafa is a Research Associate working on technology assessments and the implications of generating technology competitiveness on the deployment of renewable energy. He joined KAPSARC after four years as a Research Fellow at KAUST, focusing on the development of passive devices for wireless communication, inertial sensors, and energy storage. Amro holds a PhD in Electrical Engineering in the area of micro- and nanosystems from Dalhousie University in Halifax, Nova Scotia.

Hind Farag is a Research Fellow, leading KAPSARC's energy transitions research. Previously at Wood Mackenzie, Hind was Head of North America Gas and Power Research. She led and delivered consulting and research offerings related to power market assessments, fundamentals forecasts, asset valuations and long-term planning studies, renewable energy development, and energy policy assessments. Hind holds a Bachelor of Business Administration and a MBA from the American University of Cairo, Egypt.

Nora Nezamuddin is a Research Analyst focusing on the interplay of transition policy and technology supply chain development. She joined KAPSARC from the US-Saudi Arabian Business Council in Washington, D.C., where she provided business recommendations and solutions for the 200+ Council members and non-members. Nora received a dual degree in Business Administration and International Studies, with specializations in Finance and International Business from the American University in Washington, D.C.

Tamim Zamrik is a Research Associate developing a modeling framework to evaluate the implications of policy instruments on the pace and effectiveness of energy transitions policies. Tamim is a mathematical finance expert, with extensive work on novel and efficient numerical algorithms in option pricing and stochastic optimal control. His education includes degrees from Damascus University, Lancaster University, and City University, culminating in a PhD in Quantitative Finance from Imperial College, London.