UCL-CIRED Workshop [Absract] POPPER: Strategic Energy Analysis Under Deep Uncertainty

This proposed report will describe a project examining strategic alternatives available to Israel to make greater use of domestic and imported sources of natural gas in the future. We explored both natural gas utilization and supply infrastructure strategies in an environment characterized by extreme uncertainty and potentially large consequences. The goal was to demonstrate applications of new computer-based methodologies to assess how different energy strategies might enhance the robustness of Israel's energy posture despite the prevailing uncertainties. This resulted in an expandable modeling and analytical framework for energy analysis used to examine factors among the many unknowns which could have the greatest effect and therefore the largest influence over policy choices. Despite being conducted before the most recent major gas developments off-shore, both the recommendations and directions of this work have stood the test of time. The project led directly to a subsequent government decision to completely redo the nation's energy master plan on the basis of the principles demonstrated in this study.

We conducted the analysis in two steps. In the first, we used computer modeling to search across thousands of scenarios to discover and improve strategies for the utilization of natural gas in Israel. We sought those strategies that to the year 2030 would be low in total cost, low in total emissions of greenhouse gases, and would have low land use requirements. We sought strategies that were robust enough to achieve set threshold values for these criteria across 1,400 alternative plausible future states of the world. We then applied the same process to the discovery of robust supply infrastructure strategies for natural gas. In this instance we searched for those strategies that would achieve low cost, avoid excessive depletion of domestic natural gas reserves, and have low susceptibility to unmet demand in case of unintended supply cutoffs. We tested these strategies for their ability to achieve similar threshold values across a set of 5,000 different scenarios. From this analysis we were able to draw inferences about policy choices that would tend to enhance the robustness of natural gas utilization and supply infrastructure strategies.

The logic of the analytical approach was that it is not sufficient to optimize strategy for one assumed set of conditions in the presence of the deep uncertainty that surrounds long-term planning and analysis. Rather, the goal should be to seek those strategies that might not be optimal in any given future but are likely to prove robust. As we systematically vary assumptions about factors whose future values are presently unknowable, we generate an ensemble of alternative futures purposefully constructed so as to act as a test bed for helping select among policy alternatives. In effect, we are now asking which uncertainties would affect our decisions today and how certain values of these presently uncertain factors might affect our choice among actions. In our analysis, we systematically examined the factors shown in Table 1 divided into four classes for convenient exposition.

The first two classes are external uncertainties, the "X" factors outside the control of the planner or decisionmaker, in contrast to the those"Levers" controlled by different government bodies. The third is the class of different measures used to determine how closely the outcomes produced by candidate strategies under particular assumptions about future conditions come to meeting policy goals and criteria for goodness. The final group shows the relationships that tie the first three together. These represent either formal or informal models of cause-and-effect that determine how different actions taken in varying circumstances will lead to the outcomes they do.

The analytical environment integrated three different simulation models to analyze Israel's energy system: the Model for Analysis of Energy Demand (MAED), the Long-range Energy Alternatives Planning (LEAP) system for which we built a detailed model of Israel's energy economy, and the Wien Automatic System Planning (WASP) package. The Computer Assisted Reasoning system (CARs) facilitated the simulations.[1]

Table 1. Uncertain and variable factors explored in this analysis arranged by "XLRM" factor type

E"**X**"ogenous Factors Outside of Control	"**L**"evers Under Control
- Price path for coal - Price path for natural gas - Cost of CO2 emissions - Cost of fossil fuel technology - Cost of non-fossil fuel technology - Availability of non-fossil fuel technology - Demand for electricity - Cost of efficiency improvements - Administrative limits on GHG emissions - Cost of capital - - - - Supply from foreign pipelines - Discovery of new domestic reserves - Fixed cost of LNG installation - Variable cost of LNG supply - Fixed cost of new domestic natural gas - Variable cost of new domestic natural gas - Cost of storage capacity - Cost of capital	- New plant type and primary fuel - National infrastructure construction - Level of reserve generation capacity (policy) - Share of generation capacity from coal and non-fossil fuel (policy) - Dispatch order of electricity generation - Administrative control on GHG emission levels - Administrative control of land use - Imposition of price on carbon emissions - Adoption of non-fossil fuel technology and capacity - Energy efficiency enhancement - - - - Target level of reserve capacity - Rate of domestic reserve depletion - Level and timing of LNG capacity - Fuel storage types - Fuel storage levels
"**R**"elationship Among Factors	"**M**"easures Used to Gauge Success
- WASP model - MAED model - LEAP model - - - - RAND natural gas supply model	- Total system costs - Total fuel costs - Balance of cost sharing over generations - Annual natural gas supply requirement - GHG emissions - Land use requirements - Level of reserve generation capacity (actual) - Share of generation capacity from coal and non-fossil fuel (actual) - - - - Depletion of domestic reserves (actual) - Cost of providing level of supply insurance - Cost of implementing supply insurance - Potential unmet demand for electricity

We formed candidate use strategies and examined outcomes produced when applied to each future in our test set. Strategies whose results were completely dominated by the results of others were dropped from the set while others were modified and reiterated. Rather than predict futures, we used robustness criteria to render strategies successively less vulnerable to uncertainties. We followed the same procedure with supply strategies. We used data mining techniques to understand generally what properties enhance robustness as well as to determine for each strategy which scenarios were the most challenging. To demonstrate how such scenarios may be examined in detail, we also studied behavior of a complete supply cut off from Israel's then current only source of foreign supply.

As an independent research effort, we sought to develop analytical tools which could be easily amplified by further input from those formally charged with the task of planning. In exercising these tools we explored what measures would be to the nation's greatest advantage in achieving a future profile for natural gas use that reduces its people's exposure to vulnerabilities and risks.

[1] The Computer Assisted Reasoning® system (CARs™) software was developed by Evolving Logic who provided access to it for this study.