

## **ABSTRACT**

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Title: Management of Energy Supply Chains under Uncertainty

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Energy sources, including natural gas and electricity, have played and will continue to play a very important role in the development of human society. For instance, natural gas, which is currently produced from shale formations in U.S., is used to generate electricity, for heating in residential and commercial sectors, and as raw material in the industrial sector. Indeed, driven in part by the shale gas development in U.S., natural gas production is growing faster than any other fossil fuel. However, among other issues, high water utilization as well as the potential for degradation of underground and surface water sources constitute critical environmental challenges for the exploitation of shale gas resources. Moreover, electricity, which is the most flexible and manageable energy form, is currently used in a variety of activities and applications. For instance, electricity is used for heating, cooling, lighting, and for operating electronic appliances and electric vehicles. Nowadays, given the rapid development and commercialization of technologies and devices that rely on electricity, electricity demand is increasing faster than overall primary energy supply. Nevertheless, the reduction of CO<sub>2</sub> emissions and climate change adaptation are important challenges that need to be addressed by the power sector. Consequently, the design and planning of energy supply chains is becoming a progressively more important issue in order to provide affordable, reliable and sustainable energy sources, not only in developed countries but particularly in developing economies where energy demand is increasing even faster. However, the management of energy supply chains is a challenging issue, where, in addition to the complexity of the system, decision makers face a significant level of uncertainty in factors such as pricing and availability of energy resources as well as in the forecasting of energy demand.

This research develops deterministic and stochastic optimization frameworks for the management of energy supply chains under uncertainty. Specifically, this study addresses the

development of deterministic and stochastic optimization models for the design and planning of integrated shale gas and water supply chains as well as the integration of power generation and transmission expansion in power systems. First, this research addresses the development of a deterministic decision-support optimization framework for the strategic design and tactical planning of shale gas supply chains integrated with water management as well as with the selection of well-pad layouts. The proposed deterministic framework includes a methodology for the simulation and preliminary evaluation of different well-pads layouts as well as constraints concerning water quality issues and environmental constraints for the exploitation of shale gas resources. Moreover, this study also deals with the development of a deterministic optimization framework for the integrated planning of power generation and transmission expansion in interconnected power systems. The novelty of this framework stems from the integration of power generation and transmission planning along with spinning and non-spinning reserve constraints as well as CO<sub>2</sub> emission constraints and mitigation options. Concerning CO<sub>2</sub> emission mitigation options, the penetration of renewable energies, the integration of Carbon Capture and Sequestration (CCS) technologies, and the implementation of Demand Side Management (DSM) strategies are considered. This framework is used to address some revealing applications including “business as usual” and “CO<sub>2</sub> mitigation policy” scenarios.

Finally, this research also addresses the characterization and modeling of the uncertainties inherent to the design and planning of the aforementioned energy systems as well as the development of the corresponding stochastic optimization models. Specifically, Global Sensitivity Analysis (GSA) is carried out in order to identify the most impactful uncertainties in each deterministic model. Then, based on the outcomes of the GSA, key uncertain parameters are identified and two-stage stochastic optimization models are developed. These stochastic optimization frameworks are then used to address some applications in both shale gas and power systems domains, including design and planning of integrated shale gas and water supply chains with constant gas composition as well as design and planning of power systems for climate change adaptation.