A MARKAL-based analysis to assess the role of natural gas in electricity sector emission reductions for future energy scenarios

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Overview

Historically low prices of natural gas over the past decade and regulations controlling hazardous air pollutant emissions from electricity generating units (EGUs) have increased the competitiveness of natural-gas-fired electric power plants compared to coal-fired units. Direct CO_2 and criteria pollutant air emissions from natural gas combined cycle units are relatively lower than the emissions of those pollutants from the use of coal. However, there has been a debate on the impact of upstream methane emissions from extraction, production, and distribution of natural gas. Some researchers have reported that the leakage may range from 1%-11.7% and may offset benefits from lower emissions from natural gas-fired EGUs [1].While this range helps quantify the uncertainty around impacts of methane leakage from natural gas, the overall impact of leakage rate over a given time horizon depends upon the projected changes in the future of the overall energy system operations and infrastructure. Recent research on air quality studies indicates that social paradigms and technological advancements are two primary drivers of change, especially in the energy system [2] [3]. This paper explores the extent of the impact of uncertainties in upstream methane emissions from natural gas on the emission profile from the overall US energy system (consisting of the electric power, transportation, oil and gas, industrial, residential, and commercial sectors of the energy system) by drawing upon alternative future scenarios with different trajectories of energy infrastructure development and system operations, and varying social paradigms.

Methods

Four distinct energy futures are simulated using EPA's MARKet ALlocation (MARKAL) database [4]. Impact of uncertainties around methane leakage rate from natural gas are propagated by performing parametric sensitivity simulations over varying methane leakage rates, for each future scenario. The MARKAL energy system model is a partial-equilibrium cost-minimization model for the US Energy Sector. The modeling horizon is between years 2005 to 2055, where 2005-2010 are calibration years. The time resolution is five years. Time slices with different demand time series are represented in the database to capture seasonal and diurnal variability. Major environmental regulations on the books are represented in the database.

In this study, we utilize the scenario planning technique to capture the extent of variability in impacts of methane leakage due to natural gas production across a set of four US energy future scenarios documented in [2]. The scenarios outline plausible social priorities and technological advancements that may occur in the future. It should be noted that scenario planning is not a forecasting tool. Scenario planning enables interested parties to use an integrated approach to model complex issues and facilitate collaboration between impact assessment, adaptation and vulnerability studies [3]. To interpret the results, it is important to provide an overview of the pre-defined energy futures [2] that are explored as part of this analysis: (1) The Conservation case defines a future where society is committed to minimizing environmental impacts of energy generation and use. However, technological advances are limited to energy efficiency improvements and conservation measures due to economic constraints and the slow pace of innovations in new technology; (2) The iSustainability case defines a future where society is committed to minimizing the environmental impacts of the energy sector operation, and rapid technological innovations provide pathways to reduce environmental impacts of the energy sector; (3) The Go Our Own Way case defines a future where the social paradigms are indifferent to environmental quality but technology advances rapidly due to other drivers such as the need for energy security and independence; and (4) The Muddling Through case defines a future where society does not prioritize environmental quality and technological advances are stagnant. The base case corresponds to the reference case in EPA's 2014 MARKAL Database [4].

Results and Conclusions

Preliminary results indicate that both increased social awareness/acceptance of technologies to improve environmental quality and technological advances in cleaner energy production result in considerable reduction in cumulative system-wide CO_2 equivalent (CO_2e) emissions (Figure 1). The iSustainability future shows the most improvement: 39% -23% decrease in cumulative system wide CO_2e emissions by 2050. However, the improvements achieved may be substantially lower if the effects of upstream emissions from natural gas extraction and production are ignored. The simulation results for the Muddling Through scenario show the highest range of variations (15% to 41% increase in cumulative system-wide CO_2e emissions depending upon the CH_4 leakage rates) with the lowest range of variations being demonstrated in the results from the Conservation scenario (31% to 17% decrease in cumulative system-wide CO_2e emissions depending upon the CH_4 leakage rates).

The Conservation future reflects how social priorities translate into reductions in energy demands relative to the base scenario. This reduction in end-use demand leads to reduced consumption of natural gas and subsequent reduction in total methane emissions from the energy sector. Since the volume of natural gas consumption in the Conservation future is relatively low, the total methane emissions from the energy sector in this future are less sensitive to the value of the methane leakage rate from natural gas extraction and production. All four future scenario simulations in MARKAL indicate a growing trend in shift towards the use of natural gas rather than coal in the electric power sector. Given this trend, it is important to consider the impacts of upstream methane emissions for developing comprehensive pathways to a sustainable energy system. The lower levels of impacts observed in the Go Our Own Way future relative to the other future definitions emphasize the crucial role of social acceptance and awareness in reducing air pollutants and subsequent impacts on the environment.

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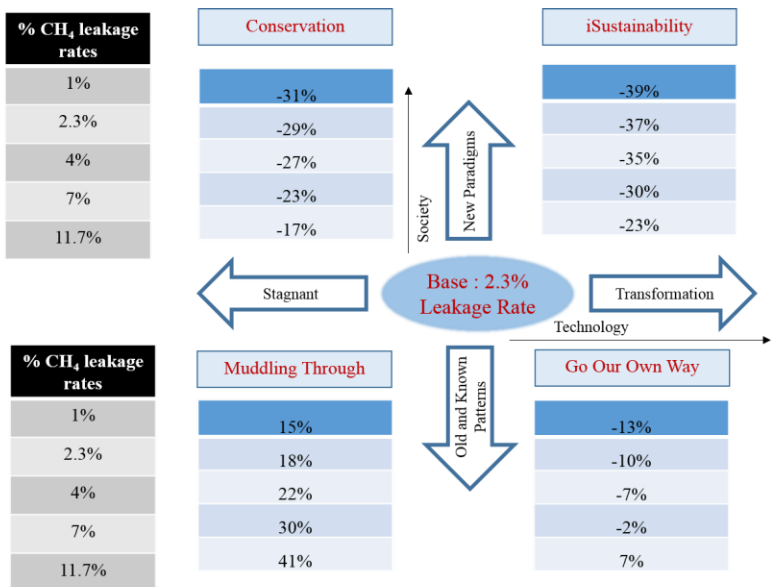

Percentage change in system wide equivalent CO_2 emissions relative to base case

Figure 1 : Percentage change in system-wide equivalent CO_2 emissions by year 2050 across different energy futures with varied assumptions of CH_4 leakage rate for extraction, production, and delivery of natural gas. The base case corresponds to the energy sector model based on EPA's 2014 MARKAL Database with a 2.3% CH_4 leakage rate for NG extraction and production

Social paradigms (that either emerge organically in the society or are induced through various policy mechanisms) and technological advancements (either innovative technology and efficiency improvements for existing technologies triggered by economic benefits or the need for energy independence) are two primary drivers of change in the quality of the environment. This is especially true for the future evolution of electric sector and infrastructure development – two major contributors to environmental degradation and subsequent socio-economic impacts. Preliminary results exploring the impacts of upstream methane emissions from natural gas-fired electricity generation indicate a wide variability of impacts depending upon social and technological trends in the future. The next step for this project consists of a detailed parametric analysis of the variations in impacts of fuel prices/availability, electrification of the transportation sector, retirement policies for nuclear/fossil-fired plants, and changes in import/export levels in the energy sector for the pre-defined energy futures.

Disclaimer

The views expressed in the abstract are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

References

[1] C. Lenox and O. Kaplan, "Role of natural gas in meeting an electric sector emissions reduction strategy and effects on greenhouse gas emissions," *Energy Economics,* vol. 60, pp. 460-468, 2016.

[2] J. Gamas, R. Dodder, D. Loughlin and C. Gage, "Role of future scenarios in understanding deep uncertainty in long-term air quality management," *Journal of the Air & Waste Management Association,* pp. 1327-1340, 2015.

[3] R. H. Moss, J. A. Edmonds, K. A. Hibbard, M. R. Manning, S. K. Rose, D. P. V. Vuuren, T. R. Carter, S. Emori, K. Mikiko, T. Kram, G. A. Meehl, J. F. Mitchell, N. Nakicenovic, K. Riahi and et.al, "The next generation of scenarios for climate change research and assessment," *Nature,* vol. 463, pp. 747-756, 2010.

[4] C. Lenox, R. Dodder, C. Gage, O. Kaplan, D. Loughlin and W. Yelverton, "EPA U.S. Nine-region MARKAL Database Documentation; EPA/600/B-13/203;," US Environmental Protection Agency, Cincinnati OH, September 2013.