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Fuel-price reform to achieve climate and energy policy goals in Saudi Arabia: A multiple-scenario analysis

Markus Groissböck[a], Matthias J. Pickl[b,*]

[a] University of Innsbruck, Institute for Construction and Materials Science, Innsbruck, Austria
[b] King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

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ABSTRACT

Saudi Arabia experiences annual growth of 6% in its power demand. Generation expansion has been driven by low domestic retail fuel prices leading to a power generation mix based on fossil fuels only. In light of current climate change discussions, this research assesses future generation expansion under different potential fuel-price reforms by an enhanced OSeMOSYS model. Results demonstrate that domestic retail fuel price levels > 20% [> 60%] of expected international wholesale fuel prices[1] are necessary to minimize emissions when considering emissions penalties [without pricing for emissions]. By 2030 renewables can reach 70% penetration by capacity and 30% by energy.

1. Introduction

With about one-fifth of the world's proven oil reserves, the Kingdom of Saudi Arabia (KSA) is endowed with energy resources and is the largest oil exporter in the Organization of Petroleum Exporting Countries (OPEC) (OPEC, 2016). The country also holds the world's sixth largest proven gas reserves (BP, 2014), has abundant solar (Farnoosh et al., 2014) and wind (Alyousef and Stevens, 2011) energy resource potential, and is the world's 13th largest producer and consumer of electricity (The World Factbook, 2017). As a result of low oil and gas prices over the last two years, several countries in the Middle East (including the United Arab Emirates, Oman, Bahrain, and the KSA) have increased their domestic energy prices since the beginning of 2016 (Mills, 2016). This is one of several measures taken by these countries to cope with the loss of revenues from oil and gas sales. It follows examples such as Jordan, Morocco, and Egypt that already implemented energy price adjustments in previous years.

The KSA has experienced remarkable growth in demand for power in the last decade (SEC, 2014) driven by multiple factors, including population growth, robust economic development, improvement in standards of living, harsh weather conditions, industrial development, economic policies geared toward diversification into energy-intensive industries, and low energy pricing regimes that encourage lavish consumption (Fattouh, 2013, Woertz, 2013). Peak electricity demand has grown by 6.1% per year since 2003. Peak demand reached 56.5 GW in 2014 and annual electricity demand amounted to 274.5 TWh in the same year.

To meet this increased demand, a substantial amount of power generation infrastructure has been added over the last years. Until now, almost 100% of power generation is based on the domestic fossil fuel sources of oil and gas (Farnoosh et al., 2014), apart from decentralized photovoltaic applications in Dhahran (10.5 MW and 0.035 MW), Tabuk (1 MW), Riyadh (5.3 MW and 0.2 MW), Jiddah (5.4 MW), on Farasan Island (0.5 MW) and at the King Abdullah University of Science and Technology (2 MW). The major reason for the sole utilization of fossil fuel resources lies in the domestic fuel pricing policies that keep prices well below international levels (Alyousef and Stevens, 2011, OIES, 2015). This hinders the society's awareness of energy efficiency (Gately et al., 2012), makes investment into renewables financially unattractive, and contributes to a growing cumulative carbon dioxide emissions level (Mansouri et al., 2013). At present, low prices for gas, diesel, gasoline, and power turned the world's 20th biggest economy into its 6th biggest consumer of oil (Reuters, 2013). However, growing concerns about climate change have become an important factor influencing energy policies in the Middle East and North Africa (MENA) (Griffiths, 2017) and were elevated by the COP21 Paris Agreement, which was ratified by the KSA (UNFCCC, 2016). This research examines the Kingdom's commitment to addressing climate challenges and develops a fuel-price ratio based on international fuel-price expectations.

We contribute to the research in the field of fuel-price liberalization by using actual costs for renewable and conventional generation technologies to show which price levels will trigger an energy exporting

* Corresponding author.
E-mail addresses: markus.groissboeck@student.uibk.ac.at (M. Groissböck), matthias@kfupm.edu.sa (M.J. Pickl).

[1] The international wholesale fuel price provides a proxy for future costs as well as an upper limit as it represents the highest expected fuel price for imported fuels.

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Nomenclature

CC	Combined Cycle (or Combined Cycle Gas Turbine)
CSP	Concentrated Solar Power
COP	Conference of the Parties, e.g., COP21 in Paris
CO_2	Carbon dioxide
EIA	U.S. Energy Information Administration
ELCC	Expected Load Carrying Capability
EROI	Energy Return on Energy Investment
FOM	Fixed Operational and Maintenance
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GEP	Generation Expansion Planning
GT	Gas Turbine (or Open Cycle GT)
GW	Gigawatt
HFO	Heavy Fuel Oil
IPP	Independent Power Producer
KSA	Kingdom of Saudi Arabia
kWh	kilowatts per hour
LQER	Lesser Quantity Emissions Rates
MBD	Thousand Barrels per Day
MCDA	Multi-Criteria Decision Analysis
MENA	Middle East & North Africa
MILP	Mixed Integer Linear Programming
MMBTU	Million British Thermal Units
MW	Megawatt
NO_x	Nitrogen oxides
OPEC	Organization of Petroleum Exporting Countries
OSeMOSYS	Open Source energy MOdeling SYStem
PJ	Peta Joule
$PM_{2.5}$	Fine particles with a diameter of 2.5 lm or less
PV	Photovoltaics
QELD	Quality Enhanced Life Days
RES	Renewable Energy Sources (or Renewables)
SAR	Saudi Riyal (1 SAR = US$ 3.75, 1 SAR = 100 Halala)
SEC	Saudi Electricity Company
SO_2	Sulfur dioxide
ST	Steam Turbine
SWF	Sovereign Wealth Fund
TWh	Terawatts per hour
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compounds
VOM	Variable Operation and Maintenance
VR	Vacuum Residue

country's utility sector to diversify its portfolio and reduce the role of fossil fuels.

The structure of the remainder of the paper is as follows: Section 2 offers a comprehensive literature review. Section 3 provides an extensive overview of the utility sector in the KSA. Section 4 reviews the fuel-price liberalization research. Section 5 outlines the modeling approach and describes the scenarios considered. Section 6 illustrates the results and Section 7 concludes. Finally, Section 8 presents possible future research.

2. Literature review

Research exists on power generation expansion planning all over the world (Zhang et al., 2013, Thiam et al., 2012, Fairuz et al., 2013, Walmsley et al., 2014, Habib and Chungpaibulpatana, 2014, Lienert and Lochner, 2012, Aliyu et al., 2013, Wu and Huang, 2014, Shahmohammadi et al., 2015, Chaudry et al., 2014, Becerra-Lopez and Golding, 2008, Brand and Missaoui, 2014), although the future electricity generation development in the KSA under different fuel-price scenarios has not been analyzed. Previous studies related to modeling the KSA power generation expansion planning include (Farnoosh et al., 2014, Mansouri et al., 2013, and Groissböck and Pickl, 2016). The studies of Farnoosh et al. focus on cost optimization in an assumed international wholesale fuel price context (Farnoosh et al., 2014), while Mansouri et al. (2013) deal with CO_2 emissions savings where carbon capture and storage and solar photovoltaic are considered. Groissböck and Pickl (2016) model the KSA's power market retrospectively under both cost and environment considerations for the period 2003 to 2013. The Open Source energy MOdeling SYStem (OSeMOSYS) model framework, developed by renowned KTH Royal Institute of Technology in Stockholm, represents a flexible and comprehensive Mixed Integer Linear Programming (MILP) framework for long-term energy planning that is available on an open source basis (Bazilian et al., 2012). MILP is a commonly used method to assess medium and long-term impacts within power systems of economies of varying sizes and stages of development (Howells et al., 2011, Welsch et al., 2012, Welsch et al., 2014). In its base form, OSeMOSYS provides a test-bed for new energy model developments and system model applications, especially in developing countries. More advanced forms include added functionalities for prioritization of demand types, shifting demand, and storage options (Welsch et al., 2012), as well as reserve requirements and dispatching features (Welsch et al., 2014). Groissböck and Pickl (2016) made model improvements to OSeMOSYS including multi-objective functions (adjustable weights on costs and emissions). OSeMOSYS has been used by other researchers to model the long-term electricity mix in Tunisia (Dhakouani et al., 2017), to assess overall energy security questions (Augutis et al., 2015), to hedge the risk of increased emissions in long-term energy planning (Niet et al., 2017), to model the British Columbia and Alberta electricity systems (English et al., 2017), to address the energy, economy and land use nexus when exploiting bioenergy in developing countries (Gonzales-Salazar et al., 2016), and to estimate the cost of energy access in Timor Leste (Nerini et al., 2015).

The topic of future electricity capacity expansion in the KSA under different price reform scenarios, including the choice of fossil fuel generation versus renewable generation, deserves detailed study since it is of broader policy, industry, and geopolitical interest, not least because of the major role the KSA plays in world oil markets. At times of low oil prices, fuel-price reforms are a major topic of consideration in many countries as budgets of oil-producing nations face increased stress. Indeed, energy subsidies have recently been at the center of research in academia (Griffiths, 2017, Moshiri, 2015, Guillaume and Zytek, 2010, Dartanto, 2013, Krane and Hung, 2016, Fattouh and Sen, 2016, Benes et al., 2015, Lahn, 2016) as well as by the International Monetary Fund (IMF, 2008, 2013, 2015, 2014), the World Bank (World Bank, 2010), and the International Energy Agency (IEA, 2010, 2011). This study: (i) provides a brief overview of the KSA power market with the latest data; (ii) analyzes the impacts of different price-reform scenarios on the future electricity market expansion in terms of renewable penetration and CO_2 reduction to comply with COP21 (and upcoming COP's) agreements; and (iii) improves the OSeMOSYS model framework by implementing a multiple-scenario analysis as well as by including the possibility to allow plant retirements, as today's KSA power plant fleet consists of more than 40% inefficient gas turbines (GT). Temperature correction is incorporated into the model to allow performance and generation output adjustments based on ambient air temperatures (Groissböck and Pickl, 2016).

Specifically, this research investigates the evolving of the power market and the renewable energy penetration in the KSA over the period 2015 to 2030 under different fuel-price reform scenarios in light of recent COP discussions with the goal to reduce CO_2 emissions: i) no price reform; ii) intermediate price reform (annual change by increasing the domestic retail fuel price by 10%–100% (in 10%