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Oil Subsidies and Renewable Energy in Saudi Arabia: A General Equilibrium Approach

Jorge Blazquez, Lester C Hunt,** and Baltasar Manzano****

ABSTRACT

In 2016, the Kingdom of Saudi Arabia (KSA) announced its Vision 2030 strategic plan incorporating major changes to the economic structure of the country, including an intention to deploy 9.5 GW of renewable energy in an effort to reduce the penetration of oil in the electricity generation system. This paper assesses the macroeconomic impact of such changes in the KSA, coupled with reductions in implicit energy subsidies. Based on a dynamic general equilibrium model, our analysis suggests that if the KSA government were to deploy a relatively small quantity of renewable technology, consistent with the country's Vision 2030 plans, there would be a positive impact on the KSA's long run GDP and on households' welfare. However, we demonstrate that if the integration costs of renewable technology were high, then households' welfare would be maximized at around 30–40% renewables penetration. In addition, we show that a policy favoring renewable energy would increase the dependence of the KSA on oil, given that a larger share of GDP would be linked to oil exports and so, potentially, to oil price shocks. Finally, it is shown that exporting significantly more oil onto the international market could have a negative impact on the international oil price and thus could offset the potential gains from the renewable energy policy.

Keywords: Saudi Arabia, renewable penetration, implicit oil subsidy, oil exports, welfare costs, energy transition, general equilibrium model

https://doi.org/10.5547/01956574.38.SI1.jbla

1. INTRODUCTION

In April 2016, the Kingdom of Saudi Arabia (KSA) announced its Vision 2030 strategic plan incorporating major changes to the economic structure of the country (Vision 2030, 2016). Vision 2030 includes plans to deploy 9.5 GW of renewable energy in an effort to reduce the proportion of oil used in the electricity generation system. Some of the reasons behind this move in the KSA—and in the rest of Gulf Cooperation Council (GCC) countries—include: the growing interest in this region of the world in tackling the climate change agenda; the authorities' desire to reduce the dependence of their economies on fossil fuels; and the expected future increase in energy demand that will reduce revenues from oil exports. Renewable energy technology is therefore seen as one way to help address all these challenges.

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The economic impacts of deploying renewable energy in the KSA are arguably different to those in (almost) any other country of the world, for three reasons.[1] First, the main source of primary energy used to produce electricity in the KSA is oil (Electricity and Cogeneration Regulatory Authority, 2015), something which is less common in other parts of the world. Second, according to Matar et al. (2015, 2016) the oil used in the electricity sector is highly subsidized. Third, the KSA is an oil producer, which implies that the subsidized oil used domestically could instead be exported at international prices. Given these particular circumstances, the KSA is a particularly interesting case to study the role of renewables in such a heavily energy subsidized economy.

The approach taken to try to understand the implications of the deployment of renewables in the KSA, at a significant scale, in a country with highly subsidized fossil fuels, is based on a dynamic general equilibrium model. This approach is adopted to capture the direct and indirect impacts on households' welfare under different energy policies. Dynamic general equilibrium models are becoming increasingly popular in energy economics research. They have been used to explore the macroeconomic effects of energy price shocks (for example, Kim and Loungani, 1992 and Rotemberg and Woodford, 1996) and to evaluate the impact of energy policies on the business cycle (De Miguel and Manzano, 2006) and carbon emissions (Golosov et al. 2014). General equilibrium models have also been used to understand the impact of fossil fuel subsidies in the economy, such as Plante (2014) who analyzed the asymmetric impact of oil subsidies on oil exporting countries and oil importing countries. Other studies have considered the macroeconomic effects of removing fossil fuel subsidies, such as Lin and Li (2012) and Schwanitz et al. (2014). Nevertheless, as far as we know, this is the first attempt to combine renewable energy and energy subsidies taking a general equilibrium perspective.

Other studies have focused specifically on the KSA without using a general equilibrium approach, such as Alyousef and Stevens (2011) who discussed the costs of administered energy prices in the KSA. Matar et al. (2015) consider different policy scenarios for reducing energy consumption in the KSA without increasing administered energy prices using a multi-sector equilibrium model with a mixed-complementarity formulation and Matar et al. (2016) use a similar approach to consider the prospects for coal-fired power generation in the KSA. Two further studies took an econometric approach: Gately et al. (2012) considered the future evolution of oil consumption and its impact on oil exports in the KSA and Pierru and Matar (2014) explored the impact of volatile oil revenues on public investment.

This study therefore differs from these previous studies in considering the macroeconomic impacts of the deployment of renewable energy at a significant scale in the KSA using a general equilibrium model. The economic mechanism behind our model is straightforward; however, the implications are not. The model allows the government to deploy renewable technology that frees barrels of oil from electricity production that were sold initially at a subsidized price, but are instead exported at international prices—with the additional extra revenues being transferred to Saudi citizens. It is recognized that Saudi Arabia is an important player in the international oil market; however, this does not necessarily imply that it has the ability to control international prices in the

1. Note that some previous econometric studies have investigated whether Granger causality exists between renewable energy consumption and economic growth, such as Apergis and Payne (2010, 2011a, 2011b, and 2012) for the OECD countries, Central America, emerging market economies, and Eurasia respectively. Generally, these papers find long-run bidirectional causality between renewable energy consumption and growth; however, as far as we know, no similar econometric studies have been published that include Saudi Arabia.

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long run. That said, an unanticipated change in Saudi Arabia's production could have an impact on the oil market in the short to medium run; consequently, we also explore how a change in the international price of oil can affect the potential macroeconomic benefits of the deployment of renewable technology.

In summary, this paper uses a dynamic general equilibrium model to analyze the implications of increasing the deployment of renewable energy technologies in the KSA, an economy that at present has high implicit domestic fossil fuel subsidies due to low administered prices. The next section therefore details the model, followed by Section 3 that discusses the calibration of the model. Section 4 uses the model to assess the macroeconomic effects of renewables penetration in the KSA and presents the main results of the analysis with a summary and conclusion presented in Section 5.

2. MODEL

The KSA is represented by a dynamic general equilibrium model of a small, open economy[2] that consists of: an infinitely lived representative household; three sectors with representative firms producing electricity, energy services and final goods and services, respectively; and a government that, via the state-owned oil company, collects revenues from oil exports and selling oil, natural gas, and renewables domestically.[3] In addition, the model has been built to fit the characteristics of an oil exporting country, such as the KSA. Furthermore, the production and price of oil are assumed exogenous.

2.1 Representative household

The representative household's preferences are characterized by a utility function:

$$U(c_t, S_{H_t}) = \frac{\left([c_t^{\sigma_c} + d S_{H_t}^{\sigma_c}]^{\frac{1}{\sigma_c}} \right)^{1-\sigma}}{1-\sigma}. \tag{1}$$

The household's total consumption consists of final goods and services (c_t) and energy services (S_{H_t}), with σ_c determining the elasticity of substitution between the consumption and energy services and σ being the inverse of the intertemporal elasticity of substitution. The parameter d weights the relative utility derived from goods and services and from energy. The household maximizes the intertemporal expected discounted flow of utility, subject to the budget constraint:

$$\max_{c_t, S_{H_t}, k_{t+1}, b_{t+1}} \sum_{t=0}^{\infty} \beta^t \frac{\left([c_t^{\sigma_c} + d S_{H_t}^{\sigma_c}]^{\frac{1}{\sigma_c}} \right)^{1-\sigma}}{1-\sigma}$$

2. It is an economy where capital markets and goods markets are open to international agents. This means that savings and investments can be different. The economy is 'small' because international capital markets (the international interest rate, in particular) are not impacted by changes in Saudi savings or Saudi investments. From a practical perspective, it means that the international interest rate is set exogenously.

3. Given the structure of the KSA, it is assumed that the 'public sector' includes the state-owned oil company, Saudi Aramco, and that the all surpluses are distributed back the KSA consumers.

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subject to:

$$b_{t+1} + c_t + P_{S_t} S_{H_t} + k_{t+1} - (1-\delta)k_t + \frac{\phi}{2}\left(\frac{k_{t+1}-k_t}{k_t}\right)^2 = w_t n_t + r_t k_t + (1 + r_t^*) b_t + TR_t, \qquad (2)$$

where β is the discount factor, b_t is a one-year maturity foreign bond with a yield given by an exogenous international interest rate r_t^*. w_t are wages and n_t is labor, which is normalized to 1. k_t represents capital stock in the private sector, while r_t is the return of capital and δ is the depreciation rate. Following Mendoza (1991), we assume quadratic adjustment costs in investment to avoid excessive volatility of this variable in the model relative to actual data. $TR_t > 0$ are government transfers to households. The price of the final good is normalized to unity, thus P_{S_t} is the price of energy services relative to the final good. As a way to introduce the trade balance into the small open economy model, it is assumed that households have access to a perfectly competitive international capital market, where they can buy and sell international bonds. The first order conditions that solve the household optimization problem are presented in the appendix.

We induce stationarity in the model assuming that the interest rate of the bond depends on the level of external debt, which can be interpreted as a transitory change in the sovereign risk premium.[4] In particular, we consider that the interest rate depends on the deviations of the foreign bond from its steady state: $r_t^* = r^* + (e^{b_t - b_{ss}} - 1)$ similar to Schmitt-Grohé and Uribe (2003).

2.2 Government

The government owns the primary energy resources in this economy, that is, oil and natural gas. Oil production ($\bar{O}_t$) is an exogenous endowment that can be allocated either to the domestic market to produce electricity (O_{E_t}) and energy services (O_{S_t}), or to be exported ($\bar{O}_t - O_{E_t} - O_{S_t}$). We do not take into consideration oil depletion, although this could be a relevant issue.[5] In this model, we assume that current production is only a small fraction of the total reserves. This approach allows us to assume that the oil price is exogenously determined. Gas production ($\bar{G}_t$) is also an exogenous endowment and is only used in the domestic market to produce electricity. In the case of Saudi Arabia, natural gas is also used by the industrial sector, but given that the focus of our study is oil and renewable energy, we do not account for this consumption of natural gas.

We assume that renewable energy is produced directly using public capital, which implies that the government, via the state-owned electricity company, invests directly in this technology. Alternatively, we could assume that the government provides financial support to private investment in renewable technologies.[6] The main difference is that in our case there are no private profits, thus simplifying the analysis. Therefore, in the model, renewable energy is produced according to:

$$\bar{R}_t = \frac{A}{1 + \psi(\bar{R}_t / E_t)} k_{g_t}, \qquad (3)$$

4. Several methods have been proposed to make dynamic, small, open economy models stationary, such as endogenous discount factors, convex portfolio adjustment costs, complete asset markets, and debt elastic interest rate premiums.

5. The potential problem of oil depletion is not an issue, at least in the case of Saudi Arabia for the foreseeable future. Proven reserves in the KSA, according to BP (2015), are 267 billion barrels, which represents 73 years of production.

6. The model used here would allow for the inclusion of different types of public infrastructure, but given that the focus of the analysis in this paper is to understand better the impact of the deployment of renewable energy in the Saudi economy, these are not considered here.

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Where $\dfrac{A}{1+\psi(\bar{R}_t/E_t)}$ represents the productivity of a unit of public capital invested in renewables, or conversely, the cost of one unit of renewable energy. Note the productivity of renewables depends negatively on renewable penetration in electricity generation, reflecting integration costs on the electric system.

Domestic prices for oil ($\bar{P}_{O_t}$), natural gas ($\bar{P}_{G_t}$) and renewable energy ($\bar{P}_{R_t}$) are administered by policymakers,[7] while oil exports are priced at the international market price (P_{O_t}).

The accumulation rule of public capital is standard and is the following:

$$i_{g_t} = k_{g_{t+1}} - (1-\mu)k_{g_t}, \tag{4}$$

where μ is the depreciation share of public capital and i_{g_t} is public investment, which is a policy decision that determines the size of renewable technology.

As indicated above, the government collects revenues from oil exports and from selling oil, natural gas and renewable energy domestically via the state-owned oil company, while government spending consist of transfers to households and public investment. The budget constraint is therefore given by:

$$P_{O_t}(\bar{O}_t - O_{E_t} - O_{S_t}) + \bar{P}_{O_t}(O_{E_t} + O_{S_t}) + \bar{P}_{R_t}\bar{R}_t + \bar{P}_{G_t}\bar{G}_t = i_{g_t} + TR_t, \tag{5}$$

where transfers are chosen to balance the government budget.

2.3 Representative firms

We consider three different sectors producing different goods—electricity, energy services, and a final good.

2.3.1 Electricity sector

The firm that produces electricity is a public company, as is the case in Saudi Arabia. Oil, natural gas, and renewables are used to produce electricity (E_t) using a linear technology given by:

$$E_t = \alpha O_{E_t} + \beta \bar{G}_t + \bar{R}_t, \tag{6}$$

with all the primary energy inputs expressed in energy units and parameters α and β measuring the technical efficiency of oil and natural gas power plants.

As $\bar{G}_t$ and $\bar{R}_t$ are exogenous variables, the electricity firm only has to choose the optimal level of O_{E_t} given the prices of the primary energy inputs and the price of electricity (P_{E_t}). We assume that the electricity firm is a price-taker and maximizes profits. From the profit maximization problem, we obtain that the marginal productivity of oil has to equal relative input prices: $\alpha = \bar{P}_{O_t}/P_{E_t}$. Given the particular characteristics of this production function that could lead to a corner solution, we impose the condition that in equilibrium the marginal productivity of natural gas, oil and renewables are identical. This guarantees that there are no extraordinary profits in the public

7. For convenience, we will assume later that domestic prices for natural gas and renewable energy will be equal to natural gas and renewable energy marginal productivities respectively.

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company. In addition, we impose that all the natural gas produced in the country is consumed by the electricity company and that all renewable energy is used to produce electricity—thus avoiding the potential problem of indeterminacy. In other words, we assume that the government set the prices for $\bar{P}_{G_t}$ and $\bar{P}_{R_t}$ to guarantee that the public electricity company has no profits.[8] Then, the price of gas and renewable energy are linked to the domestic price of oil, according to the following expressions: $\bar{P}_{G_t} = \bar{P}_{O_t} \cdot \beta / \alpha$ and $\bar{P}_{R_t} = \bar{P}_{O_t} / \alpha$. This implies that the government sets all the domestic prices of the economy: oil, natural gas, and renewable energy. Alternatively, the government could set different prices for the natural gas and renewable energy, leading to profits or losses in the electricity company. Simultaneously, the government compensates the company for the positive or negative result through public transfers. This strategy is also possible, given that the electricity company is state-owned. Both alternatives would lead to the same macroeconomic result. In the model, it is assumed that the electricity produced from renewable energy is consumed domestically, unlike Ummel and Wheeler (2008) and Bardolet (2014) who consider the implications of trading electricity from renewable energy for Europe and the MENA region.

2.3.2 Energy services sector

Aggregate production in the economy requires energy services such as transport, lighting, heating, power for industries, etc. We assume that the energy services (S_t) are produced by a competitive firm, using oil (O_{S_t}), and electricity using a CES technology given by:

$$S_t = [aE_t^{\lambda} + (1-a)O_{S_t}^{\lambda}]^{1/\lambda}, \tag{7}$$

where a is a share parameter and λ determines the elasticity of substitution between electricity and oil in the production of energy services. Energy services are demanded by both the representative household and representative firm producing final goods: $S_t = S_{H_t} + S_{F_t}$. From the profit maximization problem, we obtain the usual first order conditions for the firm, linking input marginal productivity and prices: $P_{S_t} \cdot \dfrac{\partial S_t}{\partial O_{S_t}} = \bar{P}_{O_t}$ and $P_{S_t} \cdot \dfrac{\partial S_t}{\partial E_t} = P_{E_t}$.

2.3.3 Final goods sector

Final goods and services (Y_t) are produced by a competitive, representative firm using labor, capital, and energy services according to a nested production function:

$$Y_t = n_t^{\theta}[(1-b)k_t^{v} + bS_{F_t}^{v}]^{\frac{1-\theta}{v}}. \tag{8}$$

where b is a share parameter, v controls the elasticity of substitution between private capital and energy services in production and θ is the labor share. The first order conditions for profit maximization of the firm link relative input prices to its marginal productivity: $w_t = \partial Y_t / \partial n_t$, $r_t = \partial Y_t / \partial k_t$ and $P_{S_t} = \partial Y_t / \partial S_{F_t}$.

8. This alternative is equivalent to assuming that $\bar{G}_t$ and $\bar{R}_t$ are chosen to maximize the profits of the electricity company, with marginal productivity of inputs being equal to relative input prices.

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2.4 Competitive equilibrium

The competitive equilibrium for this economy is a set of allocation and price paths that satisfy the following conditions:

i) $\{c_t, S_{H_t}, k_t, b_t\}$ solve the household's problem, given prices $\{r_t, w_t, P_{S_t}, r_t^*\}$ and policies $\{TR_t\}$.
ii) $\{O_{E_t}\}$ maximize the profits of the electricity firm, given inputs prices $\{\bar{P}_{G_t}, \bar{P}_{O_t}, \bar{P}_{R_t}\}$ and the exogenous endowments $\{\bar{G}_t, \bar{R}_t\}$.
iii) $\{E_t, O_{S_t}\}$ maximize the profits of the energy services firm, given inputs prices $\{P_{E_t}, P_{S_t}\}$ and the exogenous endowments $\{\bar{G}_t, \bar{R}_t\}$.
iv) $\{n_t, k_t, S_{F_t}\}$ maximize the profits of the firm that produces the aggregate good, given input prices $\{w_t, r_t, P_{S_t}\}$.
v) The government budget constraint holds at each period.
vi) All markets clear.

3. CALIBRATION

The model is calibrated for the KSA using data from 1995 to 2014. The prices of the model are in constant terms and in thousands of Saudi Riyals with 2010 as the base year (tSAR2010). The quantities of energy are given in millions of tons of oil equivalent (mtoe).

The production of oil and international prices: We assume that the production of oil is exogenous at 481.9 mtoe annually, which corresponds to the average for 1995 to 2014, around 9.7 Million barrels per day. In addition, the international price of oil is assumed to be 1.64 tSAR2010, which corresponds to \$60 (2010 prices) per barrel.

Production function of electricity: The calibration of electricity production is based on two technical parameters, α and β, that measure technical or caloric efficiency of the oil and natural gas power plants and, using information from the EIA (n.d.), α is 0.32 and β is 0.42.

The quantity of natural gas used in the production of energy is assumed exogenous, which for the KSA is a reasonable assumption, given that prices are administered and net exports of natural gas are virtually equal to zero.[9] In particular, and consistent with the information reported by the Electricity and Cogeneration Regulatory Authority (2015), the share of natural gas in electricity generation in 2014 is 0.32. The remainder of the production parameters are generated using oil and petroleum products. According to BP (2015), the electricity generated in the KSA in 2014 was 26.1 mtoe.

The cost of the renewable technology: The cost of the renewable technology is key when interpreting the results of the model. The price of renewable energy varies substantially among technologies and even among projects with the same technology. However, to calibrate the model we need to choose a specific technology. In this case, and given the solar conditions of the Arabian Peninsula, we opt for photovoltaic (PV) solar power. In addition, each project depends on factors such as the weather, financial conditions, labor environment, the cost of land, permissions, etc. In this work, we use, as a benchmark, the cost of PV solar crystalline silicon cells in the United Arab

9. It should be noted that this does not represent the total consumption of natural gas in the KSA. A large KSA petrochemical sector consumes a significant amount of natural gas—but this is ignored, given it is not an input used to provide energy services.

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Emirates, given that, as far as we know, no information has been reported for the KSA. According to Bloomberg New Energy Finance (2015), for the KSA, the average capital cost of one MW of PV is 4.4 Million SAR and the capacity factor is 19%.[10] However, it is worth highlighting that there is a significant dispersion in the cost of capital—according to Bloomberg New Energy Finance (2015), Germany has the cheapest, with 3.8 million SAR per MW, whereas in Turkey the cost is 7.8 million SAR. We assume also that the depreciation rate of renewable technology is 5%, which is standard in these technologies. Using $4.4 Million (2010 prices) as the cost of capital, 19% as the capacity factor, and 5% as the depreciation rate, we obtain a levelized cost of electricity (LCOE) of 3.56 tSAR2010 per toe, consistent with Bloomberg New Energy Finance (2015).

This relative low cost of the technology is critical to understanding the results of the model. Oil can only compete with solar technology in the electricity sector if the price is around $18 (2010 prices) per barrel. In other words, from a purely technological perspective, moving towards solar energy and shifting away from oil is an economic decision when petroleum is valued at international prices. This positive environment for the deployment of solar energy in the KSA and in the GCC region as a whole is consistent with IRENA (2016), which states that solar technology at utility scales is competitive with a price of oil of $20 (2010 prices) per barrel.

The LCOE reflects the cost of individual projects, but not the cost of the integration of renewable technologies. A fossil fuel electricity system can easily integrate a small percentage of renewables without relevant costs. However, the cost of the system increases as renewable penetration becomes significant, which we take into consideration. Mai et al. (2012) suggest that in the USA the cost of electricity increases by 5% when the penetration of renewables increases by 10%. Based on this, we set the price of renewable technology using the marginal productivity defined in expression (3) as $\dfrac{1}{3.56*\left(1+\psi\dfrac{renewable\ production}{total\ electricity\ production}\right)}$ with $\psi = 0.5$ in the base scenario. However, given that the cost of integration is a critical variable, we run the model using different integration costs. In particular, we run the model for $\psi = \{0,\ 0.5, 1, 2, 3\}$ which corresponds to no integration costs, 5% increase in the cost of the system per 10% increase in renewable penetration, 10% increase in the cost, 20% increase in the cost and 30% increase in the cost, respectively.

Production function of energy services: The production is a combination of oil (mostly for transportation), and electricity. The interfuel elasticity of substitution between oil and electricity is assumed equal to 0.795 and is taken from Stern (2012)[11] who undertook a meta-analysis using over 40 primary studies, which corresponds to a parameter λ of -0.26 in our model. Once we have a value for λ, and using the first order conditions derived from the profit maximization process for the energy services company, we calibrate the distribution parameter a for the period 1995–2014 and obtain a value of 0.33.

Production function of final goods and services: The calibration of this production function requires some intermediate steps. Final goods and services output is defined as the difference between gross domestic product in real prices and oil exports in real terms. We create a capital stock series for the KSA, using the aggregate investment from national accounts and a depreciation

10. The capacity factor of a renewable plant is the ratio of its actual electricity generation to its potential and the published Bloomberg New Energy Finance (2015) figure is used in the analysis. However, the figure of 19% might be viewed as a little on the low side given that according to the EIA (2016) the USA's average capacity factor of 2015 is around 30% and that Saudi Arabia has one of the highest solar radiation rates in the world.

11. The interquartile range for the shadow elasticity presented in Table 2 of Stern (2012; p.321).

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Table 1: Structural parameters of the model

Caloric efficiency of oil to produce electricity	$\alpha = 0.32$
Caloric efficiency of natural gas to produce electricity	$\beta = 0.42$
Parameter associated with the production of energy services	$\lambda = -0.26$
Labor elasticity in the production of final goods and services	$\theta = 0.58$
Parameter associated with capital and energy services in the production of final goods and services	$\upsilon = -1.38$
Parameter associated with the risk aversion in the utility function of households	$\sigma = 0.5$
Parameter associated with private consumption and energy services in the utility of households	$\sigma_c = -0.33$
Parameter associated with relative preference between private consumption and energy services of the households	$d = 2.8*10^{-3}$

rate of private capital of 0.10, a standard value on the macroeconomic literature (see, for example, King and Rebelo, 1999, among many others). Additionally, we calculate the demand for energy services by firms, following Plante (2014). In particular, we use the expenditure by the firms on 'Coke, refined petroleum products and nuclear fuel' and 'Electricity, gas, steam and hot water supply' reported by OECD (2016) as a reference for our model. Given that the OECD (2016) does not report data for the KSA, we calculate the average expenditure on energy services during the period 2000–2009 for the USA, the UK, Mexico, and Norway, which are the OECD countries that have a significant production oil and natural gas. Expenditure on energy services by firms represents 0.02 of total expenditure.

The parameter θ represents the share of labor income in GDP and, using data from the Penn World Table Data (see Feenstra et al., 2013), is found to be 0.58. The elasticity of substitution between energy services and capital is assumed 0.42, which represents the average of the elasticity of substitutions reported by Koetse et al. (2008) for the period post 1979. This elasticity of substitution is consistent with a parameter υ equal to -1.38. Finally, the distribution parameter b for the period is $3*10^{-5}$.

The utility function of the representative household: The intertemporal elasticity of substitution σ is assumed 0.5, which is consistent with Havranek et al. (2015). The elasticity of substitution between goods and services and energy services, σ_C, is set equal to -0.33, based on Plante (2014). And, given these two elasticity of substitution parameters, the calibrated parameter d for the period 1995–2014 is $2.8*10^{-3}$.

The trade balance and the bond market: The trade balance in the model is calibrated as the average account balance, being a surplus of 0.16 of GDP. This figure also determines the financial international position in the bond market.

The calibration of the domestic and subsidized price of oil: The 'domestic price of oil' is not an observable variable since there is no 'unique' subsidized price of oil. The KSA energy system is heavily regulated, which means that there is a large variety of regulated prices, depending on the final consumer (as noted by Matar et al., 2015). To overcome this, the domestic price of oil is calibrated. We therefore calibrate the domestic and administered price of oil to match the percentage of oil that is exported and the oil that is used to generate electricity. The domestic price of oil is 0.50 tSAR2010 per toe, with is consistent with a price of oil of $18 (2010 prices) per barrel.

Table 1 summarizes the calibration of the key parameters of the model. To assess the extent to which the calibration of the model is able to reproduce the long-run characteristics of the KSA economy, some key average ratios of the KSA economy produced from the steady state of the model are compared with actual data taken from SAMA (2016) and BP (2015). Table 2 presents

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Table 2: Selected macroeconomic variables

	Actual data 1995–2014	Model
Oil exports / Oil produced	0.81	0.78
Electricity generation from oil / Electricity[a]	0.68	0.66
Total consumption / GDP	0.58	0.63
Private consumption / GDP	0.35	0.38
Public consumption (public transfers in the model) / GDP	0.23	0.25
Investment / GDP	0.21	0.21

[a] Data are for the year 2014.

the comparison and shows that the model performs well, with a close correspondence between the model outcomes and the actual data.

4. ASSESSMENT OF THE MACROECONOMIC EFFECTS OF RENEWABLES PENETRATION IN THE KSA

We focus on two scenarios: a 5% renewable penetration ('5% policy') and the 20% renewable penetration ('20% policy'). The first scenario is derived from the strategic economic plan Vision 2030 (2016) that envisages 9.5 GW of renewable installed capacity. This level of installed capacity implies around 5% penetration in the electricity system. The second policy scenario assumes a more aggressive level of penetration, similar to those in some European countries such as Germany, Italy, the UK, or Spain.[12] For all scenarios, the analysis focuses on the long-run equilibrium of the model and therefore the steady state.

4.1 Shifting electricity production from oil to renewables

In an initial stage, we analyze the impact of shifting electricity production from oil to renewable technology, keeping administered energy prices constant. We define welfare gains (losses) as the increase (decrease) in non-energy consumption that leaves households indifferent to the new situation, compared with the original situation with no renewables and the implicit energy subsidies in place (expressed as percentage changes). The main result is that economic welfare increases as renewable penetration increases, when the cost of integration is low ($\psi = 0$, $\psi = 0.5$, $\psi = 1$). In these cases, the relationship between welfare and renewable penetration is positive. However, for high integration costs ($\psi = 2$ and $\psi = 3$), there is a certain level of renewable penetration, around 30% and 40% respectively, that maximizes welfare, as shown in Figure 1 (a). These results suggest that the cost of integration is critical. An initial conclusion, from an economic point of view and regardless of the integration cost, is that both policy scenarios, the '5% policy' and the '20% policy' lead to higher levels of welfare in the long run.[13]

12. It is worth highlighting that both policy options do not really imply a liberalization of the economy; the government is simply replacing oil-fired electricity production by renewable generation of electricity, but we do not consider other possible alternatives.

13. It is worth noting that we ran a sensitivity analysis on the impact of a change in technology cost and the results show that the lower the cost of the technology, the larger are the welfare effects; however, there is no qualitative change in the results.

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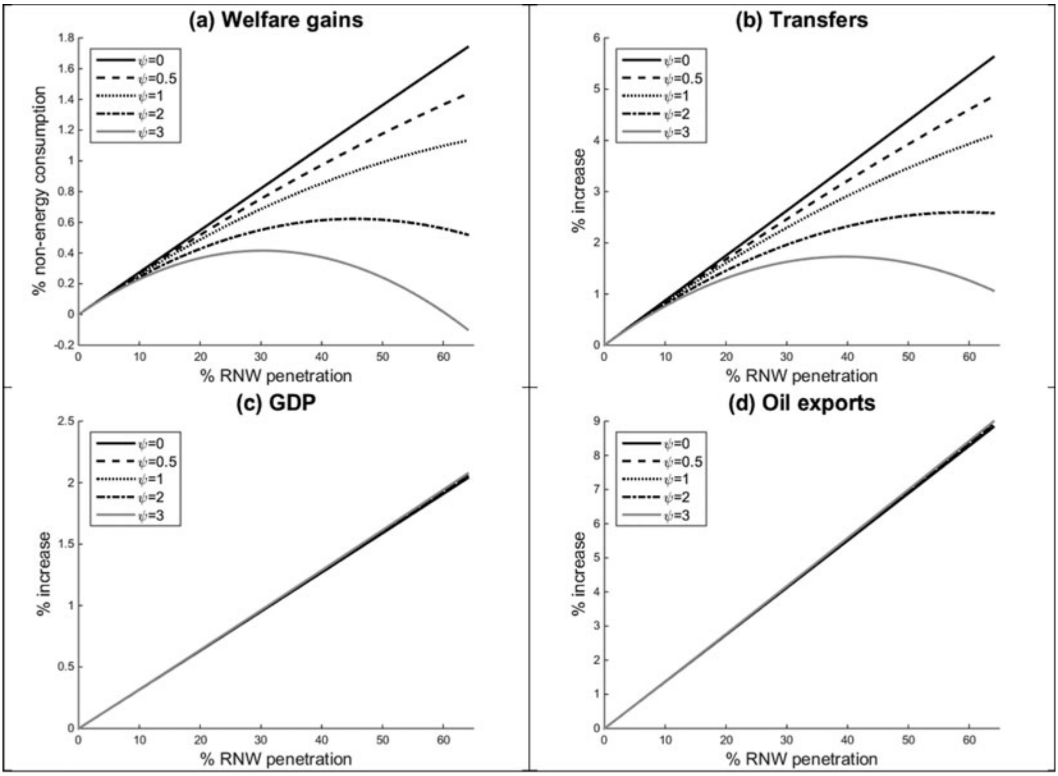
Figure 1: Steady state under different renewable energy (RNW) integration costs



In both policy scenarios, shifting electricity production from oil to renewable technology frees barrels of oil for export and results in a higher level of GDP. However, non-energy domestic production does not change; a result that might, at first, appear counterintuitive. However, the shift in electricity generation does not change the prices that drive national production, that is, the domestic price of oil, the price of natural gas, the price of electricity, the price of energy services, and the cost of capital. Therefore, this policy does not incentivize local production at a macro level, despite its positive effect on welfare.

As Figure 1 (b) shows, a higher level of oil exports lead to higher levels of public transfers to households. These higher levels of transfers imply a direct income for households, increasing their levels of private consumption. As a result, the model suggests that a higher level of non-energy consumption and energy consumption and, of course, a higher level of welfare.

Figure 1 (c) shows the impact on GDP, illustrating the positive relationship between GDP and renewable penetration. This arises as renewable penetration increases because oil would be released for exporting as shown in Figure 1 (d), thus leading to a higher level of GDP. Nonetheless, it should be noted that both policies would increase the oil export dependence of the KSA economy.

Table 3 summarizes the impact of renewable penetration compared with no renewable penetration, showing the results under both scenarios for a selection of macroeconomic variables in the steady state. Hereafter, the benchmark for the following simulations is based upon integration costs represented by $\psi = 0.5$. Under the '5% policy', there is an increase in oil exports of 0.7%, which is around 52 thousand barrels of oil per day. The positive impact on GDP and welfare is

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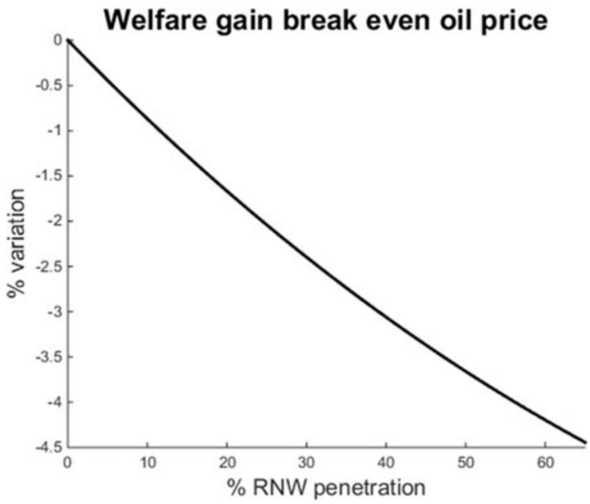
Table 3: Change in selected macroeconomic variables due to renewable technology deployment

	'5% policy'	'20% policy'
Electricity production	0.0%	0.2%
Energy services	0.0%	0.2%
Oil exports	0.7%	2.8%
GDP	0.2%	0.6%
Non-energy domestic production	0.0%	0.0%
Public transfers	0.4%	1.7%
Welfare gains	0.1%	0.5%
Additional barrels of oil exported (thousands per day)	52	207

Figure 2: Contour line for welfare for different levels of renewable (RNW) penetration



relatively small, with increases of only 0.2% and 0.1% respectively. This policy can be thought of as a first step towards the de-carbonization of the KSA electricity system, with a reduced impact on the economy. By contrast, the model suggests that the '20%' policy' would have a much larger impact on the economy. Oil exports would increase by 2.8%, which represents around 207 thousand barrels per day, with a small increase in the production of electricity and energy services, given that there is an increase in households' income due to a 1.7% increase in public transfers, and an increase in GDP of 0.6%.

4.2 The impact on welfare of a decrease in the international price of oil

The analysis so far has assumed that the new policy has no impact on the international oil market. However, the KSA is a key player in this market and if it releases more oil onto the market, there is likely to be an impact on prices, at least in the short run. We therefore conducted a sensitivity analysis to link the welfare gains from switching to renewable energy and the welfare losses from a decline in the international oil price and the results are shown in Figure 2. This shows, for each level of renewable penetration, the decline in international oil prices that offsets the potential welfare gain from renewable penetration. It is clear that a relatively small decline in the international oil

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price offsets the benefits from the shift from oil to renewables. In particular, a permanent decline in the international oil price of 4.5% that corresponds to $2.7 (2010 prices) per barrel, balances completely any potential welfare gains from a change of policy.

4.3 Increasing administered oil price

As a complementary policy to switching electricity production towards renewable energy, the government could reduce the level of implicit energy subsidies in the economy by increasing the administered energy prices. This reduction could be carried out for different levels of renewable penetration and with different levels of intensity. Figure 3 presents the model prediction for the evolution of welfare if the administered prices were increased and shows that withdrawing the implicit subsidies would lead to a higher level of welfare in both the '5% policy' and the '20% policy' scenarios. However, the welfare gains are not linear, with the initial increase in welfare quite strong, as the domestic oil price rises, reaching a maximum when the domestic oil price is around 1.2 tSAR2010, corresponding to an oil price of about $44 (2010 prices) per barrel, and then declining slowly. The reason for this is that a decrease in the oil subsidy implies higher revenues to the government that are transferred to households, but at the same time there is a negative impact, given that energy services in the KSA become more expensive. Consequently, once the domestic oil price reaches a certain level, this negative impact on welfare due to the increased price of energy services starts to outweigh the positive impact from the higher public transfers to households.

According to the model, an increase in the administered price of oil would increase the prices of natural gas, renewables, electricity, and energy services. Moreover, in the extreme case where the implicit domestic subsidy disappears so that the domestic oil price is equal to the international market price, all prices in the KSA energy system would increase by a factor of over three. This change in the domestic price of energy would discourage non-energy domestic production, which would decrease by 5.6%.

5. CONCLUSIONS

The objective of this paper is to understand the impact of increasing the deployment of renewable energy at significant scale in the KSA electricity system—an economy with significant implicit energy subsidies due to administered domestic prices below the international market price. This deployment frees up barrels of oil, currently used to produce electricity, for export. In addition, the reduction in the amount of domestic oil used to produce electricity diminishes the economic distortion caused by the subsidy.

Using a calibrated dynamic general equilibrium model, we find that if the KSA government were to deploy a relatively small quantity of renewable technology, consistent with the country's recent Vision 2030 (2016) plans, there would be a positive impact on both the KSA's long-run GDP and on consumers' welfare. The reason is that solar technology, regardless of the cost of integration, is cheaper than oil for producing electricity, something that has been addressed in other studies (such as IRENA, 2016 and indirectly Matar et al., 2016). However, we show that integration costs of renewable technology into the grid do play a critical role. If the integration cost of renewables is high, there is a certain point that maximizes consumers' welfare—around 30–40% based on our assumptions. Accordingly, the results suggest that the Vision 2030 (2016) plan to deploy 9.5 GW (which is around 5% penetration) of renewable energy, would bring about a positive impact in GDP and welfare.

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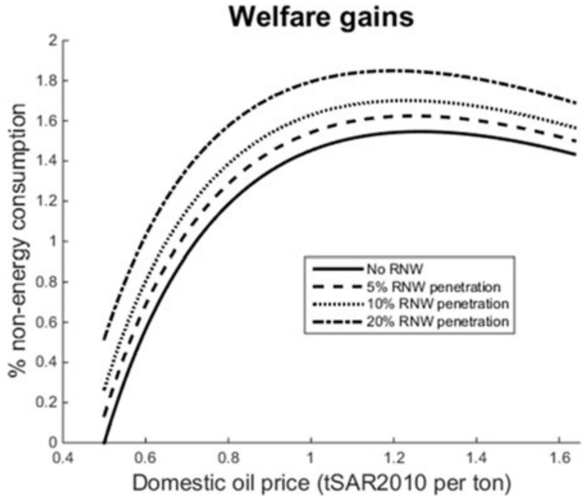
Figure 3: Welfare gain for different renewable (RNW) penetrations as the administered domestic price of oil increases



However, two potential issues should be taken into consideration. First, a policy in favor of renewable policy will increase the dependence of KSA on oil, given that a larger share of GDP would be linked to oil exports and, potentially, to oil price shocks. Second, exporting significantly more oil onto the international market could have a negative impact on prices. We do not model this explicitly; nonetheless, our analysis shows that the potential benefits of the policies considered in this paper, which could result in releasing oil onto the international market, would become negative if the price were impacted in the long run—even if only marginally.

We also analyze the potential effects from reducing implicit oil price subsidies by increasing domestic administered prices, based on the principle that intuitively an economy not distorted by policies and regulations would perform better and have higher household welfare. Higher domestic oil prices reduce the domestic consumption of oil, leading to a higher level of oil exports. This would produce positive welfare results initially, but the analysis suggests that the welfare gains would eventually peak and then start declining when the domestic price increases to about 1.2 tSAR2010, about $44 (2010 prices) per barrel.[14]

Interestingly, the analysis suggests that the positive impact on welfare of further domestic price increases stagnates and, at some point, turns negative because household welfare depends on private consumption and energy services. Reduction in the implicit subsidy implies a higher level of public transfer and higher income but at the same time an increase in the price of energy services. As in the previous case, increasing administered KSA domestic energy prices increases GDP, but increases the dependence of GDP on oil, given the increase in oil exports and the reduction in non-

14. Of course, technical change in the fossil fuel sector or the renewable sector is not considered in the model. Technical progress in the oil sector would likely lead to lower prices (assuming that global oil demand remains constant) so that the shift to renewable technology would become less attractive in the model in terms of welfare gains. Technical progress in the renewable sector would have the opposite effect, since this would imply a lower cost of the technology or a higher capacity factor, thus favoring a shift towards renewable technology.

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energy domestic production resulting from the increase in the domestic price of energy. In addition, in all probability, the dependence of the KSA financial markets on oil would also increase, but further research is needed to explore how important this would be.[15] Furthermore, given that this research focuses on the long term and therefore does not consider the short-run dynamics, future research could also analyze the transition costs of moving towards an electricity mix in the KSA that is less dependent on oil, especially since renewable energy is very capital intensive, so that heavy initial investments are required.

ACKNOWLEDGMENTS

We are grateful to anonymous referees for their comments and suggestions that have helped to considerably improve the paper; nonetheless, we are, of course, responsible for all errors and omissions. Furthermore, the views expressed in this paper are those of the authors and do not necessarily represent the views of their affiliated institutions. Baltasar Manzano acknowledges the financial support from the Spanish Ministry of Economy and Competitiveness and FEDER through grant ECO2015-68367-R (MINECO/FEDER).

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15. It is worth noting that Malik and Hammoudeh (2007) and Bouri and Demirer (2016) found that there is generally a strong link between oil prices and the performance of the KSA financial and equity markets.

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APPENDIX

The household maximizes the intertemporal expected discounted flow subject to the budget constraint:

$$\max_{c_t, S_{H_t}, k_{t+1}, b_{t+1}} \sum_{t=0}^{\infty} \beta^t \frac{\left([c_t^{\sigma_c} + dS_{H_t}^{\sigma_c}]^{\frac{1}{\sigma_c}} \right)^{\sigma}}{1-\sigma}$$

subject to:

$$b_{t+1} + c_t + P_{S_t} S_{H_t} + k_{t+1} - (1-\delta)k_t + \frac{\phi}{2}\left(\frac{k_{t+1} - k_t}{k_t} \right)^2 = w_t n_t + r_t k_t + (1 + r_t^*) b_t + TR_t.$$

The first order conditions that define the optimal behavior of the household are:

$$\frac{\partial U}{\partial S_{H_t}} \bigg/ \frac{\partial U}{\partial c_t} = P_{S_t},$$

$$\frac{\partial U}{\partial c_t} = \beta \frac{\partial U}{\partial c_{t+1}} (1 + r_{t+1}^*),$$

$$\frac{\partial U}{\partial c_t}\left(1 + \phi \frac{k_{t+1} - k_t}{k_t} \cdot \frac{1}{k_t} \right) = \beta \frac{\partial U}{\partial c_{t+1}} \left(1 - \delta + r_{t+1} \phi \frac{k_{t+2} - k_{t+1}}{k_{t+1}} \cdot \frac{k_{t+2}}{k_{t+1}^2} \right),$$

jointly with the household budget constraint.

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