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Highlights

- We calibrate a hybrid dynamic recursive CGE model of Saudi Arabia on original data
- We acknowledge the Saudi specifics of currency peg and investment stability
- We explore 3 scenarios of international and domestic energy prices
- Low global prices affect Saudi GDP little but lower national and public savings
- Reformed domestic prices restore activity but not national or public savings

Abstract

We analyse the mid-term macroeconomic challenge to Saudi Arabia of a global low-carbon transition reducing oil revenues, versus the opportunity of national energy reforms. We calibrate a compact, dynamic recursive model of Saudi Arabia on original energy-economy data to explore scenarios. We first assess the consequences of oil prices declining from their levels in the *New Policies Scenario* (NPS) of the IEA, to their levels in its *Sustainable*

Development Scenario (SDS). By 2030, the Saudi economy loses 1.4 GDP points, 1.6 employment points and USD 504 billion trade surplus accumulation. Its cumulated public deficit rises to 92.8% of GDP. National reforms gradually aligning Saudi energy prices on international prices and inducing structural change of Saudi activity away from energy-intensive industries mitigate these costs if a share of the public income from energy-price deregulation is directed to investment. However, they reduce the cumulated trade surplus and fail to control public deficit accumulation. Sensitivity analysis confirms the capacity of national energy reforms to mitigate the activity cost of global mitigation action, but aggravates the threat of an escalating public deficit. These results underline the importance of broader economic and fiscal reforms as part of the ambitious *Vision 2030* Saudi initiative.

Keywords

Saudi Arabia, low-carbon transition, hybrid energy-economy modelling, administered energy prices

1. Introduction

The Kingdom of Saudi Arabia (KSA) remains highly reliant on oil revenues, which generated around 83% of both government income and exports earnings over the past decade (SAMA, 2017). This is despite several plans to diversify the Saudi economy since 1970 (Albassam, 2015). As a direct consequence, global climate mitigation action challenges the Saudi economic model as that of other oil-exporting countries, because it should lead to a structural weakening of export revenues (IPCC, 2015; Barnett et al., 2004; Bauer et al., 2016; Waisman et al., 2013). However, the Intergovernmental Panel on Climate Change (IPCC) highlights that differences across countries could exist (IPCC, 2015). In this paper, we investigate this issue in the case of the largest oil exporter: KSA.

In addition to the threat on oil exports, Saudi energy consumption is on a substantially increasing trend due to energy prices publicly administered at levels largely below international references (ECRA, 2014). Between 2007 and 2017, Saudi consumption of oil, refined products and gas increased by almost 60%, consumption of electricity by 70%, when real GDP only increased 42% (SAMA, 2017). As a response to this unsustainable trend, the Saudi government started reforming its energy pricing policy to curb energy demand by better reflecting opportunity costs.

Quantifying economic pathways related with both challenges is crucial for Saudi policymakers and other oil-dependent economies. To the best of our knowledge, ours is the first endeavour to produce such quantification.

Modelling the Saudi economy raises specific methodological issues concerning the interplay of a prominent public sector, integrated energy branches, administered energy prices and the nominal peg of its currency. Compared to previous efforts at modelling KSA in a Computable General Equilibrium (CGE) framework,[1] our specific contribution has several dimensions. Firstly, we work on an original dataset that reconciles national accounting and energy balance data. Secondly, we perform a dynamic exploration of medium-term growth rather than a static, counterfactual analysis. Thirdly, we consider exogenous energy consumption pathways backed by a bottom-up (BU) model of the Saudi economy designed and maintained at KAPSARC, in Riyadh. Lastly, we consider imperfections of primary factor markets—sluggishness of the average real wage and imperfect mobility of capital—as well as regulated market prices of energy at consumer-specific levels.

Our work builds on research material of the RISKERGY programme (see Acknowledgments), which aimed at developing an original economic modelling capacity open to BU expertise on energy systems and covering many individual countries (Ghersi, 2016). The compact 2-sector KLEM general equilibrium model designed in response to these specifications builds on the tradition of "hybrid" energy/economy exercises (Hourcade et al., 2006), carried on at the *Centre International de Recherche sur l'Environnement et le Développement* (CIRED) to contribute to the economics of climate policies.

Our paper develops as follows. In Section 2, we introduce our KLEM model. In Section 3, we detail the exogenous energy and non-energy drivers that back up the scenarios that we present and comment upon in Section 4. Finally, we conduct a sensitivity analysis of our results

[1] See De Santis (2003), Chemingui and Lofgren (2004), Al-Hawwas (2010) and Al-Thumairi (2012).

with regard to key elasticities and the real effective exchange rate specification of KLEM in Section 5.

2. The KLEM model

The purpose of KLEM (for Capital, Labour, Energy and Materials) is to compute macroeconomic trajectories under constraint of exogenous energy flows and prices informed by BU modelling, on both international and domestic markets. KLEM is indeed meant as a macroeconomic model to 'soft-link' with any BU modelling experiment, in the spirit initiated by Hoffman and Jorgenson (1976) with numerous recent applications (see, e.g., Messner and Schratenholzer, 2000; Schäfer and Jacoby, 2006; Martinsen, 2011; Dai et al., 2014; Fortes et al., 2014; Labriet et al., 2015). Our focus on overall macroeconomic impacts is the reason why we aggregate KLEM in two sectors only, one sector representing energy branches and the other sector the rest of the economy. One important assumption underlying such aggregation is that further sectoral specificities in the non-energy sector are without significant influence on our simulation results.[2] In this section, we describe the main features of KLEM. Annex A presents its exhaustive nomenclature and formulary.

[2] This assumption is fairly innocuous in the absence of significant structural change within the non-energy good. Considering structural change requires the careful introduction of productivity gains differentiated by input, to shape the cost structure of the aggregate non-energy sector in the direction expected from such changes (see below our *Reformed* scenario). We postpone to further publication a more thorough analysis of the diversification challenge of non-energy activities, which we are currently investigating in a multisector expansion of our KLEM model.

2.1 A constrained Solow growth model

KLEM is a dynamic, recursive model deriving from a Solow-Swan growth model. It pictures economic growth in yearly time steps as driven by exogenous assumptions on the supply and productivity of labour and on the investment rate. The vector of domestic energy and non-energy outputs at year t, Y_t, is a function f_t of the stock of capital K_t, of the labour force L_t, and of the intermediate consumption of energy and non-energy resources. The t index to f conveys that f varies with time via exogenous labour productivity gains (the Harrod-neutral assumption on technical progress). Capital stock dynamics follow the standard accumulation rule $K_{t+1} = (1 - \delta)\, K_t + I_t$, with δ the depreciation rate, constant over the modelled horizon. Investment I_t is the amount of non-energy output used to build up K at period t. Beyond these core specifications, KLEM deviates from the Solow standard model by a set of constraints imposed by its treatment of energy systems and called for by its modelling of trajectories encompassing short-term horizons—as advocated by Solow himself (Solow, 2000).

One foremost constraint is full exogeneity of the energy system, on account of KLEM being designed to couple with BU energy modelling (Ghersi, 2015). The growth trajectories traced by KLEM thus build around exogenous energy volumes. The cost structure of energy supply beyond its own energy intensity, as well as the specific net taxes and trade margin on each energy sale, can also be exogenously adjusted to match any assumption on the dynamics of annualised investment, operational expenses or domestic and trade prices—typically, assumptions on administered energy prices. These constraints on volumes, costs and prices weigh on economic growth, by reserving part of value-added to a fixed energy expense and part of primary factors endowments to the supply of some exogenous volume of energy.

Outside energy systems, one first short-term constraint, especially meaningful when modelling large energy producers such as KSA, is on capital mobility: KLEM forbids any reallocation of energy-supply capital to the non-energy sector by imposing that the capital stock of energy supply K_E does not contract faster than the depreciation rate δ (Equation 21).

One second short-term constraint is on the potential under-utilization of labour, particularly relevant to the rigid nature of the Saudi labour market (Devaux, 2013). KLEM considers that some inertia of real wages prevents full market clearing, i.e. induces unemployment. Rather than specifying labour supply behaviour, it merely correlates the unemployment rate and the real wage in a "wage curve" following Blanchflower and Oswald (2005). It relates the dynamics of this static correlation to labour productivity ϕ by conditioning a stable unemployment rate to real wages progressing at the same rate as ϕ (Equation 16).[3]

2.2 Behavioural specifications

Because all dimensions of energy trade, supply and demand including the input intensities of energy supply are exogenous, the behavioural specifications of KLEM are limited to non-energy trade-offs in the production of non-energy goods and to non-energy trade specifications.

KLEM models non-energy production as a nested structure of trade-offs between inputs, which are settled via Constant Elasticity of Substitution (CES) functions. At the foot of the

[3] This aggregate treatment of unemployment disregards the documented segmentation of the Saudi labour market between Saudi nationals and foreigners. Proper differentiation of these two markets would require additional information on labour mobility, wage gaps, immigration as well as on public policies aiming at a 'Saudization' of the workforce. We postpone such investigation to further research and only comment upon the potential consequence of increased labour market flexibility in Section 5.1.

structure, labour and capital combine into value-added KL, which combines with energy into the aggregate input $KLE,$ which finally combines with the non-energy good into non-energy output (see Figure A.1 and Equations 2 to 6 of Annex A). Capital costs are calibrated on fixed capital consumption accounts rather than on the full gross operating surplus. KLEM models the net operating surplus as a constant mark-up rate on output costs (see Equation 24). This is a simple way of assuming the constancy of non-optimal market characteristics.[4]

Regarding international trade of the non-energy good, KLEM relies on price elasticities that impact, for imports M_Q, the share of foreign production in total (domestic and foreign) resource (Equation 10 of Annex A); for exports X_Q, an exogenous trend (Equation 11). Regarding the trade balance, our KLEM application to KSA (hereafter KLEM-KSA) considers a 'fixprice' assumption (Robinson, 1989) to acknowledge the specific pegging of the Saudi riyal (SAR) currency to the US dollar (Equation 13). However, we lift this assumption when analysing energy pricing reforms, which induce an inflation differential between KSA and its trading partners (Annex B).We additionally analyse the sensitivity of our results to an alternative, more statistically robust specification in Section 5.3.

One last behavioural specification concerns KLEM's treatment of the investment decision. Because economy-wide models must accommodate the basic national accounting constraint of resources equating uses, they would be overdetermined equation systems if they enforced behavioural specifications to all resources and uses elements. The "closure rule" (Sen, 1963) is how models address this issue, with quantitative and qualitative consequences on their

[4] This feature is particularly relevant to the Saudi Arabia case, where a large proportion of economic activity operates far from standard market mechanisms.

results (Decaluwé et al., 1987). Concerning investment and savings, the neoclassical closure of standard CGE models considers endogenous investment efforts balancing out domestic and international savings flows. Conversely, 'Johansen closure' (after Johansen, 1960) enforces some exogenous level of investment (controlled by public policy) and endogenises savings to let them adjust. We choose the latter closure to KLEM-KSA (Equation 9 of Annex A), to acknowledge the relative stability of the Saudi investment rate compared to the Saudi savings rate as reported by e.g. The World Bank's gross fixed capital formation versus gross savings series.[5] This also reflects the documented use by resource-exporting countries of foreign assets (foreign reserves in the case of Saudi Arabia) as a buffer against world market fluctuations (Bems and de Carvalho Filho, 2011).

2.3 Calibration of KLEM-KSA

We calibrate KLEM-KSA at base year 2013 on an extensive, original energy-economy dataset that reconciles national accounting and energy flows and prices data (see Annex C). To improve the relevance of modelled trajectories and estimates of cumulated deficits and surpluses, we further calibrate the model dynamically to replicate GDP, unemployment and the trade balance of years 2014 to 2017, under constraint of observed investment efforts. Lastly, beyond 2017 we specifically calibrate the model's exogenous trend of investment efforts (our choice of a Johansen closure, see above) to deliver a stable unemployment trajectory under baseline conditions. Annex D provides full detail of the three calibration procedures.

[5] The standard deviation of the series (as shares of GDP) over the 2006 to 2016 period is 2.5 for GFCF versus 9.3 for gross savings.

3. Scenario description

Our scenario exploration rests on exogenous driver trajectories, which we present in two sets: conventional macroeconomic drivers and energy system trajectories. Macroeconomic drivers are common to all scenarios (Section 3.1). Energy system trajectories resort to three scenarios based on BU expertise and complementary assumptions (Section 3.2). For reference purposes, we use KLEM notations of Annex A to describe scenario drivers.

3.1 Non-energy drivers

The non-energy macroeconomic drivers of KLEM-KSA consist of three parameters: labour endowment, labour productivity and the trend of non-energy exports (Table 3.1). We project labour endowment L to follow the annual trajectory laid out by the International Labour Organisation (ILO, 2017), from 11.6 million workers in 2013 to 15.2 in 2030. The corresponding average annual growth rate is of 1.9%. We assume labour productivity ϕ to follow the data and projection of Oxford Economics.[6] The average annual growth rate between 2013 and 2030 is of 0.3%.[7] The labour endowment and productivity trajectories combine into an efficient-labour trend of +2.23% per year, which points at a potential increase of real GDP of 45.7% between 2013 and 2030.

[6] Available by subscription at https://www.oxfordeconomics.com/country-economic-forecasts.

[7] This assumption is in clear contradiction with the 'catch-up' hypothesis, whereby the productivities of developing countries grow at higher rates than those of developed countries. However, MGI (2015) reports that Saudi Arabia is one of two G20 countries only (with Mexico) whose productivity diverges from that of the US over the 2003-2013 period. The World Bank statistics confirm an almost stagnant GDP-per-worker in Saudi Arabia over the same period (+0.12% per year on average), and one declining when considering a larger period (-1% per year between 2000 and 2017).

Variable (index 1 in 2013)	2013	2030	AAGR
Labour endowment	1.00	1.38	1.9%
Labour productivity	1.00	1.05	0.3%
Non-energy exports trend	1.00	1.76	3.4%

Sources: Authors' computations based on data from ILO, Oxford Economics, and IMF. AAGR is the Average Annual Growth Rate.

Table 3.1 Macroeconomic drivers of KLEM-KSA

Non-energy exports X_Q represented around 16% of total KSA exports over the past decade (SAMA, 2017). Considering current Saudi export markets, we use the growth rate of the Middle-East and North Africa (MENA) region as their driver. The World Economic Outlook of the IMF (2016b) projects that rate up to 2021, when it reaches 3.6%. We assume that this rate holds until 2030.

3.2 Exogenous energy system trajectories

KLEM-KSA accommodates exogenous energy flows and prices from two main external sources: the KAPSARC Energy Model (KEM, see Matar et al., 2015, 2016), and the World Energy Outlook of the IEA (IEA, 2017). For reasons of KEM's partial coverage of energy flows, the export-oriented nature of KSA energy system and the limited flexibility of the refining capacity at our 2030 horizon, we limit the soft-linking to KEM to this one-way data flow and disregard feedbacks of the economy on the set of outputs that we extract from KEM. We complement KEM and IEA data with a set of other assumptions to define three scenarios. Our *Baseline scenario* assumes that current energy-price regulations hold and that energy uses keep on growing following past trends, under constraint of oil supply and the oil price following the trajectories of the New Policies Scenario (*NPS)* of the IEA (IEA, 2017).

By contrast, our *Reformed scenario* considers ambitious developments of the pricing reforms that Saudi Arabia initiated in 2016 to curb a galloping energy demand and reduce energy dependency (Alyousef and Varnham, 2010; Alyousef and Abu-Ebid, 2012), under constraint of the lower oil-price trajectory of the Sustainable Development Scenario (*SDS*) of the IEA. The energy pricing reforms that we contemplate eventually bring domestic tariffs in line with international references, reflecting anticipations from experts (IMF, 2016a; Jadwa, 2018) as well as ongoing reforms in Qatar and the United Arab Emirates (Krane and Hung, 2016). In 2030, this leads to a 30% increase of households' energy price as well as dramatic increases of ca 350% and 870% of the energy prices faced by respectively non-energy firms and energy firms, compared to the *Baseline scenario*. We assume that these price increases prompt energy savings by both consumers and non-energy producers. For the latter, we consider a 3% per year energy efficiency gain, which brings the Saudi final energy intensity in line with that of other countries at similar development stages (see Annex E.2).[8] To avoid any risk of further collapsing the international price of oil, the KSA does not export the oil saved by such efficiency gains and rather curtails its production, maintaining its exports at their *Baseline* level (see Annex E.4).

Importantly, the assumption of a fix REER is not compatible with the unilateral price increases of the *Reformed* scenario, which cannot but induce inflation differentials between Saudi Arabia and its trading partners. We therefore model the *Reformed scenario* under an alternative REER specification, which we further justify and detail in Annex B.

[8] For lack of precise assumptions, we do not adjust the productivity of any other input to non-energy production.

To disambiguate the influence of the oil-price trajectory, we also develop a *Low-oil-price scenario* identical to the *Baseline scenario* in all dimensions except that it considers the lower international oil price of the *Reformed scenario*.

Annex E sustains our choice of considering an exogenous oil price eluding the control of KSA in all scenarios. It also provides a detailed description of our assumptions to consolidate the energy datasets backing each scenario. We work out the information at a relevant level of aggregation, lower than that of KLEM. We then aggregate into the single E sector of KLEM via straightforward summing and price averaging.

4. Scenario results

4.1 A gradual recovery to past trends: the *Baseline scenario*

In our *Baseline scenario*, KLEM-KSA projects real GDP growth at an average 2.05% annual rate between 2013 and 2030 (Table 4.1). At this horizon, real GDP is 41.2% above its 2013 level, slightly below its potential of 45.7% above 2013 as defined by our labour supply and productivity assumptions. The main reason for this gap is the below-potential 31.9% growth of energy exports resulting from the IEA oil supply forecast and our assumptions on domestic demand and imports (see Annex E).

The decomposition of GDP highlights the specific dynamics of real private consumption, which grows 73.9% i.e. at 3.31% per year over our simulation period. This is the result of our choice of closure rule, which is to adjust domestic savings to balance out investment considering the evolution of foreign savings—in our national accounting framework, the opposite of the trade balance. Real exports increase by 38.3% as a result of slower dynamics of oil exports compared to their past trend (see above)—non-oil exports, driven by their exogenous trend (Section 3.1) improve their share in total exports, from 15% in 2013 to 20% in 2030. Real imports grow a faster 52.5%, in line with non-energy output for their non-energy share (fix REER assumption), but as fast as potential growth for their energy share. The resulting trade balance contribution to GDP recedes to 18.1%, which points at a higher contribution of foreign savings to investment. Additionally, real investment requirements, which we calibrated to balance the labour market (Annex D), only increase by 24.6%. With public consumption a fixed share of GDP, these combined evolutions leave ample room for the domestic savings rate to decrease i.e. real private consumption to outgrow real GDP.

Macroeconomic variable	2013	2030	Variation
GDP, Bn 2013 SAR	2,773	3,916	+41.2%
Real private consumption, Bn 2013 SAR	801	1,394	+73.9%
Real public consumption, Bn 2013 SAR	629	868	+38.0%
Real investment, Bn 2013 SAR	662	825	+24.6%
Real exports, Bn 2013 SAR	1,477	2,043	+38.3%
Real imports, Bn 2013 SAR	796	1,214	+52.5%
Trade balance, % GDP	+24.6%	+18.1%	-6.4 pts
Cumulated trade surplus, Bn 2013 USD	-	1,750	-
Unemployment rate	5.6%	6.2%	+0.6 pts
Public budget balance, % GDP	+5.8%	+3.7%	-2.1 pts
Cumulated public deficit, % GDP	-	44.8%	-

Source: KLEM-KSA simulation. To warrant accounting balance, 2030 GDP and its components are reported at 2013 prices. Pts stands for percentage points.

Table 4.1 Macroeconomic results of the *Baseline scenario*

The 18.1% contribution of trade to GDP in 2030 is also the consequence of the gradual oil price catch-up towards its 2013 level. It is a significant recovery from the -8% extreme low of 2015, although the contribution remains slightly below its 18.5% average during the high oil-price period of 2011 to 2014. Between 2013 and 2030, the cumulated net trade surplus amounts to 2013 USD 1,750 billion or SAR 6,562 billion.

At 6.2%, 2030 unemployment is at a level slightly above the 5.6% rate targeted by calibration of the investment trajectory, an artefact of the calibration procedure.[9]

To estimate public budgets dynamics, we define public income as the sum of the oil rent and of the specific margins on domestic energy sales and public expenditures as the sum of current public expenses and public investment.[10] We compute the former as a fixed share of GDP (Equation 7) and the latter as a share of total investment, which we set constant throughout the years at its 2013 value of 38% (SAMA, 2017). Based on these rules-of-thumb, the public budget balance continually improves over time from its lowest of -19.0% of GDP in 2016, under the combined effects of oil prices increasing and the energy tariffs reforms (in 2016 and 2018). It reaches balance in 2025 and further rises into a surplus of 3.7% of GDP in 2030. Still, over our projection period, the net accumulation is that of a public deficit reaching 2013 SAR 1,670 billion or 44.8% of GDP in 2030.

From a broader viewpoint, the *Baseline scenario* projects 2030 GDP components at relative levels close to observed statistics over the past decade, i.e. a Saudi economy gradually

[9] The 2017 investment rate pinpointed by our calibration procedure as raising the 2018 capital stock at a level warranting the targeted 2018 unemployment rate (Annex D) is substantially higher than the 2017 investment rate statistics. We chose to stick to statistics and do not surmise any compensation of this investment gap in further years.

[10] In the notations of KLEM (see Annex A), public expense is $p_{G_Q} G_Q$ and public income is $\tau_{R_E}\, p_{YE}\, Y_E + \, p_{QE}\, (\tau_{MS_{EQ}} \alpha_{EQ}\, Y_Q + \tau_{MS_{EE}} \alpha_{EE}\, Y_E + \tau_{MSC_E} C_E + \tau_{MSX_E} X_E)$. The computation must account for specific margins because international oil price variations are forced via adjustments of τ_{MSX_E} the specific margin on exports.

recovering from the 2014-2015 oil price shock on its formerly prevailing trends. However, the lower trend of oil exports and the low oil prices of early years induce a build-up of public deficit if public expenses and investment keep on growing at a pace similar to that of GDP. This build-up happens in a context where the Saudi economy accumulates a massive trade surplus i.e. excess savings capacity. It means that Saudi households and/or firms accumulate budget surpluses while public authorities accumulate deficits. This points at a distributive issue between domestic agents.

4.2 The challenge of global mitigation action: the *Low-oil-price scenario*

The *Low-oil-price scenario* only differs from the *Baseline scenario* by considering a depressed oil price resulting from more ambitious global climate action. As a direct consequence, the trade balance trajectory of the *Low-oil-price scenario* abates markedly and the trade surplus only reaches half its GDP share of the *Baseline scenario* in 2030 (Table 4.2). Although total trade surplus accumulation remains positive, it is cut down by 28.8% or USD 504 Billion compared to *Baseline*. The peg of the Saudi riyal to the US dollar forbids any exchange rate fluctuation to mitigate this loss of trade surplus, i.e. this increase of foreign savings at the expense of the Saudi economy.

Maintaining an exogenous investment effort (our choice of Johansen closure reflecting KSA statistics, see Section 2.2) tends to deprive this variation of foreign savings of any impact on economic activity, at the cost of decreased national savings. It is only because the investment effort is defined as a share of GDP at current prices (Equation 9 of Annex A) that real investment drops following relative price shifts.[11] The lower investment trajectory develops into a 2030 capital stock 3.0% below its level in the *Baseline scenario*. The rental price of capital consequently increases, which induces a decrease of the purchasing power of wages, i.e. of activity (-1.4% GDP) and employment (-1.6 points).

Macroeconomic variable	2030	Variation from *Baseline*
GDP, Bn 2013 SAR	3,860	-1.4%
Real private consumption, Bn 2013 SAR	1,491	+7.0%
Real public consumption, Bn 2013 SAR	762	-12.2%
Real investment, Bn 2013 SAR	725	-12.2%
Real exports, Bn 2013 SAR	2,059	+0.8%
Real imports, Bn 2013 SAR	1,177	-3.1%
Trade balance, % GDP	+10.0%	-8.1 pts
Cumulated trade surplus, Bn 2013 USD	1,246	-28.8%
Unemployment rate	7.7%	+1.6 pts
Public budget balance, % GDP	-3.3%	-7.0 pts
Cumulated public deficit, % GDP	92.8%	+47.9 pts

Source: KLEM-KSA simulations. GDP components are in billions of 2013 SAR. Pts stands for percentage points.

Table 4.2 Macroeconomic results of the *Low-oil-price scenario*

In the absence of any REER variation, real imports broadly reflect the activity drop, while real exports benefit from the reduced domestic energy consumption to increase slightly via their energy share.[12] Public consumption, also a share of GDP at current prices (Equation 7 of Annex

[11] The "price" of real GDP i.e. the GDP deflator is significantly lowered by the 26% drop of the oil export price considering the weight of energy exports in GDP—they reach 40.7% of 2030 GDP in the *Baseline scenario*. Conversely, real investment is priced as the non-energy good and thus virtually not impacted by the oil price drop.

[12] Market clearing warrants that energy exports adjust to the decrease of domestic consumptions of non-energy production prompted by the lower activity level, considering that the *Low-oil-price scenario* replicates all other energy-flow assumptions of the *Baseline scenario*, including those on energy supply.

A), declines as real investment in real terms, facing the same relative-price shifts. Private consumption adjusts to balance out activity, i.e. increases considering the sharp declines of investment and public consumptions, and the increase of foreign savings. It should not be considered any proxy of welfare, which should also somehow reflect the strong drops in public consumption and accumulated trade surplus i.e. national savings. Lastly, our estimated public budget balance significantly suffers from the reduced oil rent on foreign markets, which drops by SAR 381 Billion (USD 102 Billion) in 2030 only, compared to the *Baseline scenario*. The 12.2% lower public expenditures are not enough to compensate this income loss and the 2030 public budget exhibits a deficit amounting to 3.3% of GDP. Over our simulation period, similar if not larger deficits cumulate into a massive SAR 3,025 billion amounting to 92.8% of 2030 GDP. The cumulated trade surplus, at USD 1,246 billion or SAR 4,672 billion, remains higher but much less so than in *Baseline*.

4.3 The opportunity of national reforms: the *Reformed scenario*

Our *Reformed scenario* means to test some policy adjustments that Saudi Arabia could adopt in the face of lower international oil prices. It captures the two fronts of the energy reforms programme: increasing domestic energy tariffs and enacting efficiency initiatives (Section 3.2). It also considers a gradual structural change away from energy-intensive activities, leading to additional energy savings. The expected outcome of such policies is to increase fiscal income as the government phases out energy subsidies, while improving the overall energy efficiency of the Saudi economy. The much higher pace of energy price increases warrants that the two objectives do not contradict (see below).

How the government recycles the increased fiscal income in the economy is key to the macroeconomic consequences of the scenario. Our numerical results demonstrate that the *Low-oil-price scenario* primarily threatens the balance of public budgets. However, using the increased fiscal income to restore that balance would come at a high cost to the economy, which would face a dramatic increase of domestic energy prices, without any form of compensation other than the 3% annual energy efficiency gains that we surmise in non-energy activities from 2018 on. Compounding into a 32.7% decrease of the energy intensity of non-energy output in 2030, these gains are far from compensating the 389% increase of the price of that energy at the same horizon. For this reason, we assume that only part of the increased fiscal income decreases public deficits, while the other part fuels additional investment into economic activity. [13]

For an illustrative 50% split of the additional rent recycling into budget balance versus investment, our *Reformed scenario* improves upon our *Low-oil-price scenario* for many indicators, and even upon our *Baseline scenario* for some (Table 4.3). Real GDP thus ends 0.6% above its *Baseline* level in 2030. This gain stems from the combined effects of the additional investment effort raising the 2030 capital stock close to its Baseline level and the energy efficiency gains in production, which allows some decoupling of output and hence imports from GDP. The distribution of the gain among GDP components again betrays relative-price shifts. These decrease real public consumption (a fixed share of GDP measured at 2030 prices including a depressed oil export price) at the benefit of private consumption via model closure.

[13] Our assumption reflects those provisions of the *Vision 2030* public programme that concern stimulus to the private sector with a view to support industries affected by the pricing reforms, as stated e.g. in the recent pre-2019 budget statement by the Saudi Ministry of Finance.

Macroeconomic variable	2030	From *Low-oil-price scenario*	From *Baseline scenario*
GDP, Bn 2013 SAR	3,938	+2.0%	+0.6%
Real private consumption, Bn 2013 SAR	1,505	+0.9%	+8.0%
Real public consumption, Bn 2013 SAR	780	+2.4%	-10.1%
Real investment, Bn 2013 SAR	808	+11.6%	-2.1%
Real exports, Bn 2013 SAR	2,049	-0.5%	+0.3%
Real imports, Bn 2013 SAR	1,205	+2.4%	-0.7%
Trade balance, % GDP	+8.7%	-1.3 pts	-9.5 pts
Cumulated trade surplus, Bn 2013 USD	1,219	-2.2%	-30.4%
Unemployment rate	7.0%	-0.8 pts	+0.8 pts
Public budget balance, % GDP	-3.0%	+0.3 pts	-6.7 pts
Cumulated public deficit, % GDP	86.3%	-6.5 pts	+41.4 pts

Source: KLEM-KSA simulations. Pts stands for percentage points.

Table 4.3 Macroeconomic results of the *Reformed scenario*

Although total employment improves compared to the *Low-oil-price scenario*, it remains below that of the *Baseline scenario*. This is partly explained by our constraining energy exports at their *Low-oil-pric*e levels to avoid the risks attached to a “market-flooding” strategy (see Annex E), which induces reducing 2030 energy output by 13.4% compared to *Baseline*, dragging down energy sector employment (1.4% of the labour force in 2013). It is also the direct consequence of the loss of purchasing power induced by the increase of energy prices and its impact on non-energy prices.

The 50% share of the additional rent on domestic sales captured by public budgets allows reducing public deficit to 3.0% of GDP in 2030, a 0.3 percentage-point improvement compared to the *Low-oil-price scenario*. However, the cumulated budget deficit still amounts to SAR 2,989 billion or 86.3% of GDP in 2030. This is an improvement of 6.5 points compared to the

Low-oil-price scenario, but the level remains high compared to the current public debt. This result underlines the importance to implement broader economic and fiscal reforms as part of the ambitious programme planned by KSA under its *Vision 2030* initiative.[14]

5. Sensitivity analysis

In this last section, we test the sensitivity of our results to variations of key parameters as well as to an alternative specification of the REER. Considering our focus on macroeconomic balances and the relative uncertainty surrounding the parameters of KLEM-KSA, we focus our parameter tests on the influence of the CES and unemployment elasticities and of our assumption of energy efficiency gains in non-energy activity.[15]

5.1 Sensitivity to selected elasticities

To test the sensitivity of KLEM-KSA results to its elasticities, we increase and decrease the reference values of three central elasticities by multiplying them by 0.5 (low variant) and 1.5 (high variant). We limit our analysis to the *Reformed scenario*. Nevertheless, for the sake of consistency, we duly update all elements of that scenario originating in the *Baseline* (calibration of the investment trajectory) and in the *Low-oil-price scenario* (trajectory of the price of value-added to approximate the currency peg, see Annex B). In the light of the results

[14] See https://vision2030.gov.sa/en/.

[15] For the sake of concision, we do not report the very low sensitivity of our results to trade elasticities. In the format of Table 5.1, it is barely perceptible even for trade because of the fix REER assumption of the *Baseline* and *Low-oil-price* scenarios, and because of the over-determining weight of exogenous oil exports in the *Reformed scenario* (see Annex E) where the REER is allowed to vary (see Annex B).

of our sensitivity analysis (Table 5.1), we first comment on activity and employment variations, then on trade and public deficit.

In the central KLEM-KSA parameterisation, we set the elasticity of real wage to unemployment σ_{wu} at 10% following Blanchflower and Oswald (2005). A higher σ_{wu} elasticity i.e. a higher adaptability of wages to labour market conditions expectedly benefits GDP and unemployment. The sensitivity of unemployment results is higher: in 2030, the unemployment differential between the two extreme σ_{wu} parameterisations reaches 0.9 percentage points, while the GDP differential is of 0.23 points. The sensitivity of macroeconomic results to σ_{wu} provides insights not only on the robustness of our estimations, but also on the impacts of potential reforms by Saudi policymakers. Rigidity of the Saudi labour market stems from its segmentation, i.e. Saudi versus non-Saudi labour, which induces high wage differentials and a general preference of Saudi nationals for public sector jobs.

Macroeconomic variable	Low $\boldsymbol{\sigma_{wu}}$	High $\boldsymbol{\sigma_{wu}}$	Low $\boldsymbol{\sigma_{KL}}$	High $\boldsymbol{\sigma_{KL}}$	Low $\boldsymbol{\sigma_{KLE}}$	High $\boldsymbol{\sigma_{KLE}}$
Real GDP	-0.14%	+0.09%	-0.01%	+0.06%	-0.30%	+0.07%
Unemployment rate	+0.6 pts	-0.3 pts	-0.4 pts	+0.3 pts	+0.1 pts	-0.0 pts
Trade balance, % GDP	+0.2 pts	-0.1 pts	+0.1 pts	-0.1 pts	+0.2 pts	-0.0 pts
Cum. trade surplus, Bn 2013 USD	+9.8	-6.1	+3.5	-5.1	+5.8	-1.5
Public budget balance, % GDP	+0.1 pts	-0.1 pts	+0.1 pts	-0.1 pts	+0.0 pts	-0.0 pts
Cum. public deficit, % GDP	-0.7 pts	+0.4 pts	-0.8 pts	+0.9 pts	+0.0 pts	-0.0 pts

Source: KLEM-KSA simulations. Pts stands for percentage points.

Table 5.1 Sensitivity of 2030 results of the *Reformed scenario* to elasticities

Elasticities of input substitutions in non-energy production have a smaller bearing on GDP results. The elasticity of substitution between capital and labour (σ_{KL}) embodies the ease of moving production factors at the base of our non-energy production structure. For lack of estimate of σ_{KL} for KSA, to produce the value of our central parameterisation we average values estimated by Okagawa and Ban (2008) weighted by each sector's contribution to our aggregate non-energy output. The resulting elasticity is of 0.29. Decreasing it expectedly reduces GDP, but turns out increasing employment because of the relative scarcity of capital and labour.

Increasing σ_{KLE} the elasticity of substitution of value-added to energy improves GDP and reduces unemployment, by facilitating the substitution of value-added to energy in non-energy production. The central elasticity value is of 0.63, extrapolated from Okagawa and Ban (2008) similarly to σ_{KL} .

For the three tested elasticities, the contribution of the trade balance to 2030 GDP and the cumulated trade surplus up to that horizon react contrary to GDP. This stems from our trade specifications: both our assumptions of oil exports and the non-oil export trend are irrespective of elasticity choices, whereas non-energy imports (which largely dominate energy imports, see Figure C.1 of Annex C) follow non-energy output variations (see Equation 10 of Annex A). The trade balance therefore degrades as activity increases.

For similar reasons, public budgets react opposite to GDP: public income i.e. the oil rent stands irrespective of activity, whereas public expenses increase with it. This is again demonstration that the threat of public debt increasing with growth is inscribed into the structures of public income and expenditures.

5.2 Sensitivity to energy efficiency gains in non-energy production

Our *Reformed* scenario considers energy efficiency gains in non-energy activity at the pace of 3% per year (see Annex E.2). This is a best case scenario of successful efficiency improvement and diversification of non-energy activity. Considering lesser efficiency gains affects Saudi GDP in a limited and non-systematic way (Table 5.2).

2030 macroeconomic variable	0% annual gain	1% annual gain	2% annual gain
Real GDP, Bn 2013 SAR	+0.06%	+0.09%	+0.07%
Unemployment rate	+0.4 pts	+0.2 pts	+0.1 pts
Trade balance, % GDP	-0.4 pts	-0.3 pts	-0.2 pts
Cumulated trade surplus, Bn 2013 USD	-11.0	-8.1	-4.4
Public budget balance, % GDP	+0.6 pts	+0.4 pts	+0.2 pts
Cumulated public deficit, % GDP	+3.5 pts	+2.2 pts	+1.1 pts

Source: KLEM-KSA simulations. Pts stands for percentage points.

Table 5.2 Sensitivity of 2030 results of the *Reformed scenario* to annual energy efficiency gains in non-energy production

The cost share of energy in non-energy production, at 4.4% under the 3% efficiency gain assumption, helps interpreting these results. It induces that the limit case of the absence of any efficiency improvement only increases the non-energy output cost by 2.3%. The low import trade elasticity drawn from IMF (2016a) (see Annex A.3) warrants that this increase does not significantly affect domestic output—bearing in mind that the rent on increased energy sales is recycled in the economy. This shows in the low sensitivity of the trade balance and cumulated trade surplus to the energy efficiency assumption.

Additionally, larger energy expenses increase the GDP price index, which causes the relative price of investment to decrease. The constant share of GDP dedicated to investment therefore translates into slightly higher capital accumulation. This induces a decrease of capital costs, which is the cause of the activity increase. It also allows containing the decrease of the purchasing power of wages i.e. the increase of the unemployment rate.

The impacts on public budgets and the cumulated public deficit directly reflect the loss of rent on domestic sales as energy efficiency improves, i.e. energy consumptions decrease.

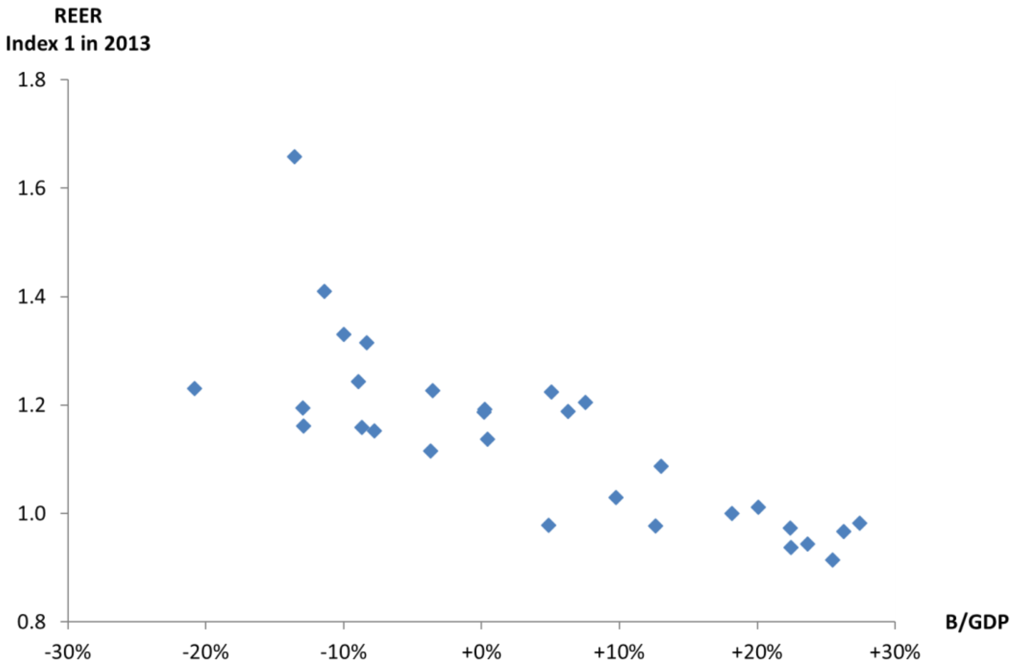
5.3 Sensitivity to the REER specification

To approximate the macroeconomics of the currency peg, our *Baseline* and *Low-oil-price* simulations of Section 4 build on the assumption of a fix REER and a flexible trade balance, following Al-Thumairi (2012) and Al-Hawwas (2010). In our *Reformed scenario* (Section 4.3) we open the door to REER adjustments by acknowledging the necessary impact of unilateral pricing reforms on the relative Saudi versus foreign prices (see Annex B). In this section, we systematise the possibility of simultaneous trade balance and REER variations, as statistics warrant (see below). We must therefore devise some intermediate between the 'flexprice' (flexible REER, fixed balance) and 'fixprice' (fixed REER, flexible balance) options.

Our solution builds on statistical observation of a significant, negative correlation of the REER and the trade balance contribution to GDP (B/GDP) since the currency pegging of 1986 (Figure 5.1).[16] With the peg barring any significant nominal exchange rate fluctuation, it is inflation differentials that explain the revealed negative slope. Domestic Saudi prices are less sensitive

[16] This correlation echoes the results of Allegret et al. (2016), who establish a negative relationship between the oil price and the REER of Saudi Arabia versus a positive one for four other oil exporters with floating currencies. In an earlier paper, Habib and Kalamova (2007) conclude on the absence of such a relationship, probably because they analyse quarterly data over a 1980-2006 period that reaches before the 1986 pegging decision: extending our own range to 1980 shrinks the R^2 of our estimation to 0.12.

to international oil prices than the prices of Saudi trading partners, because of energy self-sufficiency, stable energy costs and administered energy prices. When the international price of oil rises, the Saudi trade surplus rises as well, but foreign prices rise more than Saudi prices and the Saudi REER decreases.



Source: Authors' computation on the World Bank and IMF data.
Points are yearly observations from 1986 to 2015. B/GDP is the ratio of the trade balance to GDP.

Figure 5.1 Saudi REER and trade contribution to GDP, 1986-2015

We run again our *Baseline* and *Low-oil-price* scenarios under constraint of this relationship rather than that of a constant REER (see Equation 13c of Annex A). We also run again our *Reformed scenario* with the trajectory of value-added price stemming from the updated *Low-oil-price* scenario.[17] We perform all runs with due attention to indexation issues raised by considering the REER sensitivity to oil prices (see Annex B).

[17] The dramatic price reforms of the *Reformed Scenario* cannot but perturb the recorded relationship between the REER and the trade contribution to GDP, considering the explanation of this relationship. Running the *Reformed scenario* under direct

In all three scenarios, combined REER and trade balance flexibilities significantly improve GDP and employment (Table 5.3). These gains stem from the REER appreciation compared to 2013 level, prompted by oil prices remaining below their 2013 levels up to 2030. REER appreciation improves the purchasing power of wages by reducing the real cost of imported goods, which benefits activity despite the negative response of international trade showing in its lower contribution to GDP.

2030 macroeconomic variable	*Baseline*	*Low-oil-price*	*Reformed*
Real GDP, Bn 2013 SAR	+1.03%	+1.41%	+1.45%
Unemployment rate	-0.5 pts	-1.4 pts	-1.3 pts
Trade balance, % GDP	-4.1 pts	-3.2 pts	-3.0 pts
Cumulated trade surplus, Bn 2013 USD	-219	-160	-166
Public budget balance, % GDP	-2.1 pts	-2.3 pts	-2.1 pts
Cumulated public deficit, % GDP	+33.0 pts	+30.6 pts	+28.6 pts

Source: KLEM-KSA simulations. Pts stands for percentage points.

Table 5.3 Sensitivity of 2030 scenario results to change of REER specification

The alternative REER specification also reduces the GDP gap between the *Baseline* and *Low-oil-price* scenarios, while increasing that between the *Baseline* and the *Reformed* scenario, at the advantage of the latter. The main reason for the increased performance of the *Reformed scenario* is accounting for how REER appreciation increases the purchasing power in imported goods of the Saudi economy. This shows in the even-more pronounced reduction of the unemployment gap—bearing in mind that KLEM correlates variations of unemployment and the purchasing power of wages via a wage curve. The *Reformed* scenario ends at the same

constraint of this relationship does not therefore make sense. Rather, we must again derive the *Reformed scenario* from the *Low-oil-price scenario* following Annex B.

5.6% rate as the *Baseline* scenario, which is also the recorded rate of our 2013 calibration year. The *Low-oil-price* scenario ends at 6.4%, close to the 6.3% rate of the *Baseline* under the restrictive constant REER assumption. This sheds more favourable light on the macroeconomics of both lower international oil prices and domestic reforms, although the cuts in cumulated trade surplus i.e. the decreases of national savings remain compared to *Baseline*.

However, REER appreciation also has a marked negative effect on public budgets. The reason is that public expenditure and investment still increase faster than public income i.e. the oil rent, despite the indexation of energy prices on the price of Saudi value-added (see Annex B), because input-output relationships amplify any increase of the price of value-added into higher increases of public expenditure and investment prices. The resulting cumulated public deficit overcomes 100% of 2030 GDP in the case of oil prices depressed by global climate action, at 123% and 115% of 2030 GDP for the *Low-oil-price* and the *Reformed* scenarios. Importantly, in both scenarios it now supersedes the cumulated trade surplus, which reaches 104% of 2030 GDP in the *Low-oil-price* scenario and 98% in the *Reformed* scenario. Under our alternative REER specification, balancing public budgets at our assumed levels of public investment and expenditure implies forcing a cumulated net deficit on either Saudi households or firms.

6. Conclusion and policy implications

In this paper, we assess the combined medium-term macroeconomic impacts on the Saudi economy of global climate-change mitigation action inducing significantly lower international oil prices, and of national reforms of energy tariffs aimed at both the control of domestic energy demand and the amelioration of public budget balance. To this end, we mobilise a computable general equilibrium model that has for innovative features, compared to the literature on models of the Saudi economy, to calibrate on original hybrid energy-economy data. To perform dynamic recursive rather than static—counterfactual—analysis. To constrain its dynamic recursive simulation of the Saudi energy system on results of the dedicated KEM BU model. And to consider imperfections of the labour and capital markets as well as public regulations of the energy markets via administered prices.

Our simulation results show that global mitigation effort in line with the *SDS* scenario of the IEA World Energy Outlook is likely to harm the Saudi economy in a medium term when compared to the more modest action of the IEA's *NPS* scenario, even if only depressing the oil price without reducing Saudi export volumes. Our central estimation of the impact is a 1.4% decline of real GDP, a 1.6 percentage-point increase of the unemployment rate and a 504 billion 2013 USD decrease (a 29% cut) of the trade surplus cumulated between 2013 and 2030. In parallel, the lower oil rent on international markets induces a cumulated public budget deficit of 2013 SAR 3,025 billion or 92.8% of projected 2030 GDP. At that horizon, the public budget deficit still amounts to 3.3% of GDP, although recovering from even lower levels thanks to the gradual increase of oil prices.

Implementing reforms to align Saudi energy tariffs with international reference prices generates additional public income that offsets some of the losses stemming from decreased oil export prices. If half invested, and under the assumption of strong energy-efficiency gains implying successful diversification of the Saudi economy, this additional income allows economic growth to catch up on that triggered by the higher oil prices of the *NPS* scenario. However, even though benefitting half the additional income, budget deficit accumulates to

86.3% of 2030 GDP over the 2013 to 2030 simulation period—notwithstanding cumulated interests. The pricing reforms and diversification do not allow balancing the public budget under our set of assumptions. The basic reason for this is that public expenses, proportional to economic activity, still increase faster than the unique source of public income i.e. the oil rent, even if extended to domestic energy sales. Obviously, the gap is all the wider as energy efficiency gains induced by the reform are high.

Importantly, a more accurate description of REER dynamics minimises the activity impacts of lower international prices at 1% real GDP loss and 0.7-point increase of the unemployment rate by 2030. It also raises the activity gains from the pricing and diversification reforms to a 1% real GDP gain and a stabilisation of unemployment at the same 2030 horizon. However, it aggravates public deficit, which cumulates to over 100% of 2030 GDP, and indeed supersedes the cumulated trade surplus, with or without policy reforms.

This persistence of public budget unbalances across scenarios and sensitivity analyses underlines the importance of implementing broader economic and fiscal reforms as part of the ambitious programme planned by KSA under its *Vision 2030* initiative. Particularly, the oil rent cannot remain the close-to only source of public income if public expenditures follow on economic activity, as they commonly do in most economies.

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Annex A KLEM-KSA formulary and reference tables

This Annex provides full detail of KLEM-KSA. For reference purposes, we list and describe all variables and parameters below (Table A.1), with the exception of a series of constants calibrated on 2013 values. The model counts 43 variables and 43 equations: equations 1, 14, 15, 18, 26, 28 and 31 cover both sectors and thus count twice; equation 27 defines the prices of the IO matrix and thus counts 4 times. Equation 13, which effectively constrains the ratio of domestic to foreign prices, comes in three alternative variants that aim at reflecting the currency peg of the Saudi Riyal to the US dollar in our different runs (see Annex B). All equations prevail at each annual time period of the model, from 2013 (calibration year) to 2030. However, we drop time index t except when necessary. We index good-specific notations with subscript E for the aggregate energy good and subscript Q for the aggregate non-energy good.

Notation	Description	Status
L	Labour endowment	1 parameter from ILO (see Section 3.1)
K	Capital endowment	1 parameter set exogenously in 2013 then from perpetual inventory (see Section 2.1)
ϕ	Labour productivity (index 1 in 2013)	1 parameter from Oxford Economics (see Section 3.1)
L_i	Volume of labour in good i production	2 variables
K_i	Capital stock in good i production	2 variables
KL	Value-added aggregate of K_Q and L_Q in the production of good Q	1 variable
KLE	Aggregate of value-added KL and energy E in the production of good Q	1 variable
E_i	Consumption of energy in the production of good i	1 variable E_Q, 1 parameter E_E from KEM data (see Annex E)
C_i	Consumption of good i by households	1 variable C_Q, 1 parameter C_E set exogenously (see Annex E)
G_Q	Consumption of good Q by public administrations	1 variable
I_Q	Investment in good Q	1 variable
X_i	Export of good i	1 variable X_Q, 1 parameter/variable X_E depending on scenario (see Section 3.2 and Y_E below).
M_i	Import of good i	1 variable M_Q, 1 parameter M_E set exogenously (see Annex E)
Y_i	Output of good i	1 variable Y_Q, 1 parameter/variable Y_E depending on scenario (see Section 3.2 and X_E above).
S_i	Total supply of good i	2 variables
α_{ij}	Intensity of good j in good i	2 variables α_{QQ}, α_{EE}, 2 parameters α_{QE} calibrated in 2013, α_{EQ} exogenous (see Annex E)
λ_i	Labour intensity of good i	1 variable λ_Q, 1 parameter λ_E calibrated in 2013
κ_i	Capital intensity of good i	1 variable κ_Q, 1 parameter κ_E (see Annex E)
w	Average wage	1 variable
p_K	Rental price of capital	1 variable
p_{KL}	Price of value-added KL in good Q production	1 variable
p_{KLE}	Price of aggregate KLE in good Q production	1 variable
p_{Y_i}	Output price of good i	2 variables
p_{Si}	Average price of good i supply	2 variables
p_{ij}	Price of good i used in the production of good j	2 variables p_{Qj}, 2 parameters p_{Ej} (see Annex E)
p_{C_i}	Price of good i for households	1 variable p_{C_Q}, 1 parameter p_{C_E} (see Annex E)
p_{G_Q}	Price of good Q for public administrations	1 variable

Table A.1a KLEM-KSA notations

Notation	Description	Status
p_{I_Q}	Price of good Q for investment	1 variable
p_{X_i}	Export price of good i	1 variable p_{X_Q}, 1 parameter p_{X_E} from IEA data (see Annex E)
p_{M_i}	Import price of good i	1 parameter p_{M_Q} price of the numéraire M_Q 1 parameter p_{M_E} from IEA data (see Annex E)
CPI	Consumer Price Index (chained Fischer index)	1 variable
MPI	Import Price Index (chained Fischer index)	1 variable
u	Unemployment rate	1 variable
GDP	Gross Domestic Product	1 variable
B	Trade balance value	1 variable
Ω_B	Adjustment factor inversely affecting imports and exports of the non-energy good (index 1 in 2013)	1 parameter calibrated on 2014-2017 dynamics (see Section D.2)
Ω_L	Adjustment factor affecting labour productivity (index 1 in 2013)	1 parameter calibrated on 2014-2017 dynamics (see Section D.2)
Ω_K	Adjustment factor affecting capital productivity (index 1 in 2013)	1 parameter calibrated on 2014-2017 dynamics (see Section D.2)
Ω_w	Adjustment factor affecting real wage correlated to unemployment via the wage curve (index 1 in 2013)	1 parameter calibrated on 2014-2017 dynamics (see Section D.2)
α_{KL}	Coefficient of K_Q in the KL CES function	1 parameter calibrated in 2013
β_{KL}	Coefficient of L_Q in the KL CES function	1 parameter calibrated in 2013
σ_{KL}	Elasticity of substitution between K_Q and L_Q in KL	1 parameter from Okagawa and Ban (2008)
α_{KLE}	Coefficient of KL in the KLE CES function	1 parameter calibrated in 2013
β_{KLE}	Coefficient of $\alpha_{EQ}\ Y_Q$ in the KLE CES function	1 parameter calibrated in 2013
σ_{KLE}	Elasticity of substitution between KL and $\alpha_{EQ}\ Y_Q$	1 parameter from Okagawa and Ban (2008)
α_Y	Coefficient of *KLE* in the Y_Q CES function	1 parameter calibrated in 2013
β_Y	Coefficient of $\alpha_{QQ}\ Y_Q$ in the Y_Q CES function	1 parameter calibrated in 2013
σ_Y	Elasticity of substitution between KLE and $\alpha_{QQ}\ Y_Q$ in Y_Q	1 parameter from Van der Werf (2008)
σ_{wu}	Elasticity of real wage to the unemployment rate	1 parameter from Blanchflower and Oswald (2005)
σ_{Mp}	Elasticity to relative prices of the share of imports in the total non-energy resource	1 parameter (see Equation 10)
σ_{Xp}	Elasticity to relative prices of the non-energy export trend	1 parameter (see Equation 11)
δ	Depreciation rate of the capital stock	1 parameter (0.04).
s_G	Ratio of public expenditure to GDP	1 parameter calibrated in 2013
s_G	Ratio of public expenditure to GDP	1 parameter calibrated in 2013
s_I	Ratio of investment to GDP	1 parameter dynamically calibrated (see Section D.3)
τ_{ST_i}	Sales tax on good i sales	2 parameters calibrated in 2013
τ_{Yi}	Output tax on good i production	2 parameters calibrated in 2013

Table A.1b KLEM-KSA notations

Notation	Description	Status
$\tau_{MS_{ij}}$	Specific margin on good i sales to good j production	2 parameters $\tau_{MS_{Qi}}$ calibrated in 2013 (nil), 2 variables $\tau_{MS_{Ei}}$
τ_{MSC_i}	Specific margin on good i sales to households	1 parameter τ_{MSC_Q} calibrated in 2013 (nil), 1 variable τ_{MSC_E}
τ_{MSX_i}	Specific margin on good i exports	1 parameter τ_{MSX_Q} calibrated in 2013 (nil) 1 variable τ_{MSX_E}

Table A.1c KLEM-KSA notations

A.1 Production

Trade-offs in the production of the energy good are exogenous assumptions based on KEM and IEA data (see Section 3.2 and Annex E). The only required equation is the breakdown of the energy consumption of production—which holds for the non-energy sector too:

$$E_i = \alpha_{Ei} \, Y_i \tag{1}$$

Non-energy production follows a "production tree" of nested CES functions (Figure A.1).

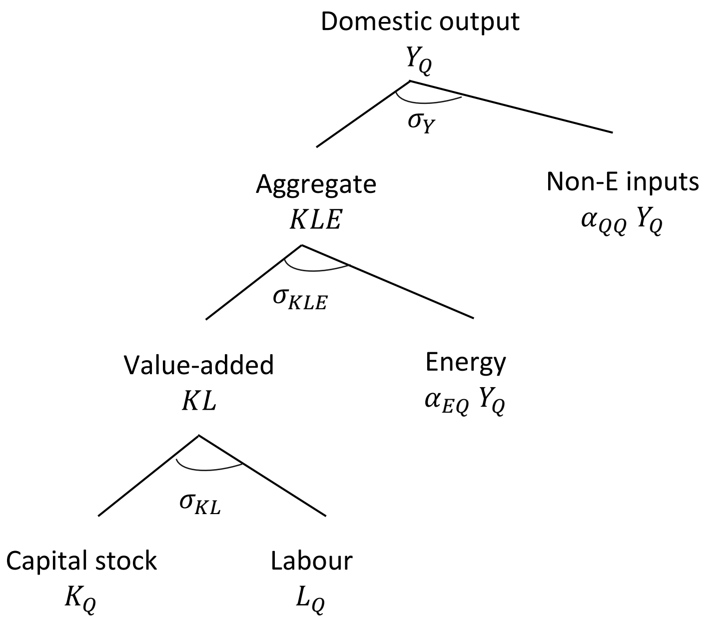

Figure A.1 Production structure of the non-energy good

At the foot of the tree, capital and labour trade off with a constant σ_{KL} elasticity of substitution to form a KL aggregate. The mobilized quantity of labour L_Q is however augmented by a productivity factor ϕ, while both the labour and capital inputs are also adjusted by factors Ω to warrant dynamic calibration on key macroeconomic variables (see Section D.2): $KL = \left(\alpha_{KL}\,(\Omega_K K_Q)^{\rho_{KL}} + \beta_{KL}\,(\Omega_L \phi\, L_Q)^{\,\rho_{KL}}\right)^{\frac{1}{\rho_{KL}}}$, with here and elsewhere, for convenience, $\rho_i = \frac{\sigma_i - 1}{\sigma_i}$. Facing prices p_K and p_L, cost minimization induces

$$L_Q = \frac{1}{\Omega_L\,\phi}\left(\frac{\Omega_L\,\phi\,\beta_{KL}}{p_L}\right)^{\sigma_{KL}}\left(\alpha_{KL}^{\sigma_{KL}}\left(\frac{p_K}{\Omega_K}\right)^{1-\sigma_{KL}} + \beta_{KL}^{\sigma_{KL}}\left(\frac{p_L}{\Omega_L\,\phi}\right)^{1-\sigma_{KL}}\right)^{-\frac{1}{\rho_{KL}}} KL \tag{2}$$

$$K_Q = \frac{1}{\Omega_K}\left(\frac{\Omega_K\,\alpha_{KL}}{p_K}\right)^{\sigma_{KL}}\left(\alpha_{KL}^{\sigma_{KL}}\left(\frac{p_K}{\Omega_K}\right)^{1-\sigma_{KL}} + \beta_{KL}^{\sigma_{KL}}\left(\frac{p_L}{\Omega_L\,\phi}\right)^{1-\sigma_{KL}}\right)^{-\frac{1}{\rho_{KL}}} KL \tag{3}$$

Higher up the tree, aggregate factor KL (value-added) and energy E_Q again trade off with a constant σ_{KLE} elasticity of substitution to form a KLE aggregate. However, E_Q is forced following BU expertise (see section 3.2). As a consequence KL is deduced from KLE being a CES of it and energy: $KLE = \left(\alpha_{KLE}\,KL^{\rho_{KLE}} + \beta_{KLE}\,E_Q{}^{\rho_{KLE}}\right)^{\frac{1}{\rho_{KLE}}}$, which yields:

$$KL = \left(\frac{KLE^{\rho_{KLE}}}{\alpha_{\mathrm{KLE}}} - \frac{\beta_{\mathrm{KLE}}}{\alpha_{\mathrm{KLE}}} E_Q{}^{\rho_{KLE}}\right)^{\frac{1}{\rho_{KLE}}} \tag{4}$$

On the tier immediately above, the KLE aggregate and non-energy input $\alpha_{QQ}\,Y_Q$ trade off with a constant σ_Y elasticity of substitution to form domestic output Y_Q. Facing prices p_{KLE} and p_{QQ}, cost minimization induces

$$KLE = \left(\frac{\alpha_{\mathrm{Y}}}{p_{KLE}}\right)^{\sigma_{\mathrm{Y}}}\left(\alpha_{\mathrm{Y}}^{\sigma_{\mathrm{Y}}}\,p_{KLE}^{1-\sigma_{\mathrm{Y}}} + \beta_{\mathrm{Y}}^{\sigma_{\mathrm{Y}}} p_{QQ}^{1-\sigma_{\mathrm{Y}}}\right)^{-\frac{1}{\rho_{\mathrm{Y}}}} Y_Q \tag{5}$$

$$\alpha_{QQ} Y_Q = \left(\frac{\beta_{\mathrm{Y}}}{p_{QQ}}\right)^{\sigma_{\mathrm{Y}}}\left(\alpha_{\mathrm{Y}}^{\sigma_{\mathrm{Y}}}\,p_{KLE}^{1-\sigma_{\mathrm{Y}}} + \beta_{\mathrm{Y}}^{\sigma_{\mathrm{Y}}} p_{QQ}^{1-\sigma_{\mathrm{Y}}}\right)^{-\frac{1}{\rho_{\mathrm{Y}}}} Y_Q \tag{6}$$

A.2 Final consumption and investment

Household consumption of energy C_E is exogenous (see Annex E) while household consumption of the non-energy good C_Q adjusts to close the model considering the domestic savings demand resulting from the investment and trade balance assumptions ('Johansen' closure, see Section 2.2).

Public spending $p_{G_Q} G_Q$ is a constant share s_G of GDP (public spending in energy goods is zero by national accounting convention):

$$p_{G_Q} G_Q = s_G GDP \tag{7}$$

with GDP defined on the expenditure side as

$$GDP = \sum_{i=E,Q} p_{C_i} C_i + p_{G_Q} G_Q + p_{I_Q} I_Q + \sum_{i=E,Q} p_{X_i} X_i - \sum_{i=E,Q} p_{M_i} M_i \tag{8}$$

Investment expenses $p_{I_Q} I_Q$ are an exogenous ratio s_I of GDP (investment in energy goods is zero except for stock variations that are cancelled out in our hybrid data, see Annex C):

$$p_{I_Q} I_Q = s_I GDP \tag{9}$$

A.3 International trade

Imports M_E are exogenous and exports X_E are either the remainder of energy supply following Equation 14 (Baseline and *Low-oil-price* scenarios) or fixed at their *Low-oil-price* scenario level (*Reformed* scenario). For the non-energy good, the share of imports M_Q in total supply S_Q has a σ_{Mp} elasticity to terms-of-trade and is corrected by the inverse of the export adjustment factor Ω_B (see Section D.2):

$$\frac{M_Q}{S_Q} = \frac{1}{\Omega_B} A_M \left(\frac{p_{Y_Q}}{p_{M_Q}}\right)^{\sigma_{Mp}}, \tag{10}$$

with A_M one constant calibrated on 2013 data. We follow IMF (2016a) using elasticities from Hakura and Billmeier (2008) and set σ_{Mp} at -0.09. We regard this elasticity as compatible with the import structure of the Kingdom, composed of goods with very few domestic substitution opportunities.

Exports X_Q are elastic to terms of trade around the exogenous trend δ_{X_Q} (see Section 3.1):

$$X_Q = \Omega_B \left(1 + \delta_{X_Q}\right) A_X \left(\frac{p_{X_Q}}{p_{M_Q}}\right)^{\sigma_{Xp}}. \tag{11}$$

They are adjusted by Ω_B following dynamic calibration on 2014 to 2017 data (see Section D.2). Similar to the price elasticity of imports, we derive σ_{X_p} from IMF (2016a) based on Hakura and Billmeier (2008) estimating the elasticity of non-oil exports at 0.69. A_X is a constant calibrated in 2013. The trade balance B is:

$$B = \sum_{i=E,Q} p_{X_i} X_i - p_{M_i} M_i \tag{12}$$

In the model applied to our *Baseline* (Section 4.1) and *Low-oil-price* (Section 4.2) scenarios, the real effective exchange rate—the ratio of the consumer price index CPI and the import price index MPI—remains constant at calibration-year value 1:

$$\frac{CPI}{MPI} = 1. \tag{13}$$

In our *Reformed* scenario, (Section 4.3) we drop the constant REER assumption to rather acknowledge the impact of the massive increase of regulated energy prices on the REER by constraining the price of value-added in the non-energy sector on the same $\delta_{p_{KL}}$trajectory that it follows in our *Low-oil-price* scenario (see Section B.1):

$$p_{KL} = \left(1 + \delta_{p_{KL}}\right) B_{REER}, \tag{13b}$$

with B_{REER} the value of p_{KL} at calibration year.

In Section 5.3, we propose a third way of constraining the REER reflecting our observation of a significant statistical relationship between the REER and the trade balance contribution to GDP. To specify the relationship, we tested several functional forms including a linear link (with an R^2 of 0.622), with little impact on model results. We settle on an exponential form, which exhibits an R^2 of 0.674. This relationship defines the REER as an exponential function of the trade-balance-to-GDP ratio:

$$\frac{CPI}{MPI} = C_{REER} + \ D_{REER}\ e^{E_{REER}\frac{B}{GDP}}, \tag{13c}$$

with D_{REER} and E_{REER} calibrated on 1986 to 2015 statistical observation of the two variables (see Figure 5.1 of Section 5.3), and C_{REER} the adjustment that allows fitting 2013 data.

A.4 Market clearings

Market balance for each good i stems from the definitions of total domestic supply S_i seen from the use and resource sides:

$$S_i = \ \textstyle\sum_{j=1}^{n} \alpha_{ij}\, Y_j + \ C_i + \ G_i + \ I_i + X_i, \tag{14}$$

$$S_i = Y_i + M_i. \tag{15}$$

On the labour market, a 'wage curve' describes the elasticity of real wage (the purchasing power of wage w) to unemployment u. The real wage w/CPI attached to unemployment at

2013 level (5.6%) is defined as the 2013 real wage multiplied by labour productivity increase ϕ and a wage moderation factor Ω_w via the calibration of one constant A_u:

$$\frac{w}{CPI} = \phi\, \Omega_w\, A_u\, u^{\sigma_{wu}}. \tag{16}$$

Labour demands of the 2 productions and unemployment balance out labour endowment L:

$$\sum_{i=E,Q} L_i = (1-u)\, L \tag{17}$$

For each sector, labour consumption and output are conventionally related via labour intensity:

$$L_i = \lambda_i\, Y_i \tag{18}$$

On the capital market, demands of the two productions balance out capital endowment K:

$$\sum_{i=E,Q} K_i = K \tag{19}$$

With for the non-energy sector, similarly to labour:

$$K_Q = \kappa_Q\, Y_Q \tag{20}$$

However, as stated in Section 2.1 the amount of capital for the production of the energy good follows a constraint under which the capital stock of energy production K_E cannot contract faster than the depreciation rate δ fixed at 4%:

$$K_{E,t} = max\left((1-\delta)\, K_{E,t-1}; \kappa_E\, Y_E\right). \tag{21}$$

A.5 Producer and consumer prices

Primary factor payments w the wage and p_K the price of capital rental are common to both sectors. They adjust according to their market balances.

The price of the KL aggregate p_{KL} is the canonical function (KL being a CES product of K and L) of prices p_K and p_L and of the elasticity of substitution of the two inputs σ_{KL}:

$$p_{KL} = \left(\alpha_{KL}^{\sigma_{KL}} \left(\frac{p_K}{\Omega_K}\right)^{1-\sigma_{KL}} + \beta_{KL}^{\sigma_{KL}} \left(\frac{w}{\Omega_L\, \phi}\right)^{1-\sigma_{KL}}\right)^{\frac{1}{1-\sigma_{KL}}} \tag{22}$$

Contrary to p_{KL}, p_{KLE} the price of the KLE aggregate specific to non-energy production cannot be defined as a function of prices p_{KL} and p_{EQ} and of the elasticity of substitution of the two inputs σ_{KLE}, because exogenously setting E_Q in the KLE aggregate truncates the underlying cost-minimisation programme. Consequently, p_{KLE} is rather inferred from the simple accounting equation:

$$p_{KLE}\, KLE = p_{KL}\, KL + p_{EQ}\, E_Q \tag{23}$$

The producer price of the non-energy good p_{YQ} is again the canonical CES price of the KLE aggregate and the non-energy input to production $\alpha_{QQ}\, Y_Q$, to which a constant *ad valorem* output tax τ_{Y_Q} as well as a constant rent mark-up τ_{R_Q}, are added:

$$p_{Y_Q}\left(1 - \tau_{Y_Q} - \tau_{R_Q}\right) = \left(\alpha_Y^{\sigma_Y}\, p_{KLE}^{1-\sigma_Y} + \beta_Y^{\sigma_Y}\, p_{QQ}^{1-\sigma_Y}\right)^{\frac{\rho_Y - 1}{\rho_Y}} \tag{24}$$

For the energy good, the producer price is simply the sum of production costs:

$$p_{YE} = p_{QE}\, \alpha_{QE} + p_{EE}\, \alpha_{EE} + w\, \lambda_E + p_K\, \kappa_E + \tau_{R_E}\, p_{YE} + \tau_{Y_E}\, p_{YE} \tag{25}$$

The import prices of both goods are exogenous: p_{MQ} is constant because the imported non-energy good is the chosen numéraire of the model; and p_{ME} follows an exogenous trajectory described in Annex E.

The average supply price of good i, p_{Si}, is inferred from:

$$p_{S_i} S_i = p_{Y_i} Y_i + p_{M_i} M_i \tag{26}$$

Turning to purchasers' prices, the price of good i for the production of good j, p_{ij}, is equal to the supply price of good i augmented from agent-specific margins $\tau_{MS_{ij}}$ and *ad valorem* sales taxes τ_{ST_i}:

$$p_{ij} = p_{S_i} \left(1 + \tau_{MS_{ij}}\right)\left(1 + \tau_{ST_i}\right) \tag{27}$$

The consumer prices of households, public administrations, the investment good and exports are constructed similarly but drop the unnecessary specific margins when energy is not concerned (public consumption, investment), as well as sales taxes as regards exports:

$$p_{C_i} = p_{S_i}\left(1 + \tau_{MSC_i}\right)\left(1 + \tau_{ST_i}\right) \tag{28}$$

$$p_{G_Q} = p_{S_Q}\left(1 + \tau_{ST_i}\right) \tag{29}$$

$$p_{I_Q} = p_{S_Q}\left(1 + \tau_{ST_i}\right) \tag{30}$$

$$p_{X_i} = p_{S_i}\left(1 + \tau_{MSX_i}\right) \tag{31}$$

In the case of the energy good, the specific margin τ_{MSX_E} endogenously adapts to accommodate the exogenous p_{X_E} prescription (see Annex E). The consumer and import price indexes CPI and MPI are computed as chained indexes, i.e. from one period to the next, according to Fisher's formula:

$$CPI_t = CPI_{t-1} \sqrt{\frac{\sum p_{Ci,t}\, C_{i,t-1}}{\sum p_{Ci,t-1}\, C_{i,t-1}} \frac{\sum p_{Ci,t}\, C_{i,t}}{\sum p_{Ci,t-1}\, C_{i,t}}} \tag{32}$$

$$MPI_t = MPI_{t-1} \sqrt{\frac{\sum p_{Mi,t}\, M_{i,t-1}}{\sum p_{Mi,t-1}\, M_{i,t-1}} \frac{\sum p_{Mi,t}\, M_{i,t}}{\sum p_{Mi,t-1}\, M_{i,t}}} \tag{33}$$

Annex B Modelling the Saudi currency peg

The Saudi currency peg has been fixing the nominal exchange rate of the Saudi Riyal (SAR) to the US dollar (USD) at 3.75 since 1986. To this date, models of the Saudi economy that do not explicitly represent money have approximated the peg by making the “fixprice” assumption of a constant real effective exchange rate (REER) and an endogenous trade balance (see Al-Hawwas, 2010 and Al-Thumairi, 2012), by opposition to the “flexprice” standard of constraining the trade balance by adjustment of a flexible REER. We stick to this approximation when evaluating our *Baseline* and *Low-oil-price* scenarios in sections 4.1 and 4.2 (see Equation 13 of Annex A).

However, the approximation cannot hold when modelling domestic energy pricing reforms. In section B.1 below, we explain why and introduce the alternative specification sustaining our evaluation of the *Reformed scenario* of section 4.3 (Equation 13b). In section B.2, we comment upon indexation issues that arise when considering the third alternative REER specification that we introduce in section 5.3 (Equation 13c).

B.1 REER adjustments following the Saudi pricing reform

Real effective exchange rate variations reflect either variations of the nominal exchange rate or variations in the relative “real” output prices, or costs, of an economy and its trading partners. The energy-price reforms of our *Reformed scenario* substantially increase KSA output costs relative to their foreign counterparts, all other things equal. This increase is unlikely to induce any adjustment of foreign output costs, considering the small weight of Saudi exports other than oil (whose export price is unaffected by the reforms) in the cost structures of its partners. The reforms will therefore increase the REER of KSA. Its modelling consequently requires amending the fix REER assumption of the *Baseline* and *Low-oil-price* KLEM-KSA implementations (Equation 13). To that end, we alternatively consider that the reform does not alter the ratio of primary-factor prices to foreign prices. This effectively anchors the Saudi price system to the foreign price system—reflecting the currency peg—while allowing market prices to rise relative to foreign prices, under the impact of the reform, as well as relative price shifts between primary factors. Our runs of the *Reformed scenario* therefore substitute, to the fix REER constraint, a trajectory of the average price of value-added in the non-energy sector constrained to its *Low-oil-price scenario* pathway (Equation 13b).[18]

B.2 REER sensitivity to oil prices and indexation of exogenous energy price trajectories

The alternative REER and trade balance specification of Section 5.3 improves upon the specifications backing Section 4 results by considering the REER variations linked to oil-price-induced inflation differentials between KSA and its trading partners (see Section 5.3). This raises complex indexation issues with important bearing on the evolution of relative prices. Both the *NPS* and *SDS* oil-price trajectories of our scenarios remain below the 2013 oil price up to 2030. The constant-USD output cost of the basket of imported non-energy goods M_Q should therefore decrease to mark the decrease of international oil prices. There is no reason to assume that this cost decrease will affect constant-USD international oil prices, or indeed

[18] Our specification overlooks the fact that the level effectively reached by the REER under the pricing reform also depends on the indirect impacts of the reform on primary factor markets. Pinpointing this level would require a thorough numerical exploration outside the scope of our paper, with a small quantitative impact on our results.

constant-USD (constant-SAR) Saudi domestic energy prices, all other things equal. With M_Q the numéraire of KLEM-KSA (p_{MQ} constant), this means that the exogenous price trajectories of energy consumptions and trade should rise when the REER of KSA rises because of low oil prices. The increase should remain below the REER rise in itself, which embarks the impact of pricing reforms in our *Reformed* scenario. We approximate this increase by again assuming indexation on the price of value-added in the Saudi non-energy sector. The three modelling runs of Section 5.2 therefore extend KLEM-KSA to five additional variables, domestic and international energy prices p_{ME}, p_{EQ}, p_{EE}, p_{CE}, p_{XE}, and to five additional equations forcing each of these prices at the exogenous levels defined for each scenario (Annex E), augmented by indexation on p_{KL} variation from its 2013 level.

Annex C A hybrid energy/economy KSA dataset

Developing a hybrid energy/economy dataset is a prerequisite to energy/economy modelling because it induces statistical adjustments that have significant bearing on modelling results (Combet et al., 2014). The argument is particularly strong for KSA considering the weight of oil extraction activities and related industries in the economy. Producing our hybrid KSA dataset implied the following steps:[19]

- Constructing an Input-Output table (IOT) from the uses and resources tables of the Saudi national accounts from the General Authority of Statistics (GAS) for 2013 (CDSI, 2014).
- Aggregating the IOT into two products, energy and non-energy. Energy covers the Oil and Gas extraction, Petroleum products, and Electricity sectors. Non-energy embraces the remainder of economic activity.
- Computing commercial energy flows in million tons-of-oil equivalent (Mtoe), at identical level of aggregation, from the International Energy Agency (IEA) energy balance of KSA (IEA, 2015).
- Comparing the resulting prices with prices from other statistical sources e.g. ENERDATA (see https://www.enerdata.net/), and discriminating based on plausibility.

[19] For the sake of concision, we only provide a synthetic description of each step. Combet et al. (2014) and Le Treut (2017) detail the hybridisation procedure with an application on France. The particulars of its implementation on KSA are available from the authors upon request.

- Substituting reconstructed energy expenses to irreconcilable national accounting data.[20]
- Imputing the induced accounting imbalance to the non-energy good, considering that the difference between national accounting "energy" expenses and energy flows valued at administered or market prices are mainly service activities of energy companies.
- Reassessing the oil rent based on the difference between extraction costs, estimated at 4.24 US dollars (USD) *per* barrel,[21] and total expenses on oil, which are dominated by exports at international prices. The resulting oil rent amounts to 272.8 billion USD or 37.5% of GDP in 2013.[22]
- Reassessing net energy taxes and subsidies. Our main effort regarded electricity subsidies, which we computed from electricity sales in volume and the difference between the average electricity cost of 99.2 USD per MWh reported by Alyousef and Stevens (2011)[23] and the average selling price of 35.7 USD per MWh revealed by our reconstruction of energy sales and administered prices. The resulting effective electricity subsidies amount to 17.7 billion USD in 2013. This estimation is broadly in line with that of Alyousef and Stevens (2011) of an electricity subsidy of 13.3 billion

[20] Because the energy sector of KSA is highly integrated, we treat energy data to only account for those energy flows corresponding to actual commercial transactions.

[21] This cost is that charged by Saudi Aramco to Saudi Electricity Company for Arabian Light crude oil (ECRA, 2014). There is no official estimation of extraction costs proper. Various sources confirm that this cost ranges between 4 and 5 USD per barrel (Smith, 2009; Ramady and Mahdi, 2015).

[22] We thus deviate from the 43.4% contribution of oil rent to GDP reported by the World Bank (available at https://data.worldbank.org/indicator/NY.GDP.PETR.RT.ZS?locations=SA). This estimate appears closer to the contribution of the gross operating surplus of the extraction and refining branches of national accounts.

[23] Alyousef and Stevens (2011) report 2010 costs, which we assume unchanged in 2013.

USD in 2010 when taking account of the growth of electricity consumption between 2010 and 2013.

- Scaling the remaining elements of the cost structure of the energy sector (non-energy good expenses and value-added components) to balance out uses.

The third step of this procedure, i.e. the computation of commercial energy flows from IEA energy balance, required a series of sub-steps:

- Excluding energy products exclusively used for non-energy purposes, irrelevant to our energy/economy focus.
- Absorbing statistical differences between resources and uses by distributing half of them on supply/production and the other half on demand *pro rata* consumptions.
- Reassigning international bunkers and domestic marine and air consumptions to exports (sales to foreign transport companies) vs. consumptions of resident firms according to the national accounting distinction between domestic vs. foreign agents.
- Correcting for auto-production by distributing its energy inputs to energy consumers and reducing the electricity and heat consumptions of such consumers proportionally to their consumption increases.[24]
- Reassigning transfers to the consumptions of the refining industry, more specifically to the subcategory "Oil refineries".

[24] National accounts only record expenses on autoproduction inputs and overlook transformation into electricity or heat.

IOT, MSAR	Prod. Q	Prod. E	C	G	I	X	
Q uses	943 502	169 883	787 068	628 521	662 455	217 893	3 409 323
E uses	34 748	14 215	14 133	-	-	1 259 117	1 322 214
L	510 881	38 899					
Y taxes	7 515	1 047					
K	1 099 394	116 884					
R	4 415	1 039 365					
M	787 958	7 946					
SM use in Q	-	-196 745					
SM use in E	-	-219 412					
SM use in C	-	19 639					
SM use in X	-	396 518					
Sales T	20 908	267					
Subsidies	-	-66 294					
	3 409 323	1 322 214					

E flows, Mtoe	Prod. Q	Prod. E	C	G	I	X	
E uses	119.8	120.9	22.8	-	-	432.5	696.1
Imports		23.7					
Output		672.4					

E prices, SAR/toe	Prod. Q	Prod. E	C	G	I	X
E uses	290.0	117.5	619.7	-	-	2910.8
Imports		334.4				

Totals may not add up due to rounding.

Figure C.1 Hybrid 2-sector dataset of 2013 KSA

The resulting IOT in million SAR (MSAR) and underlying price/quantity disaggregation is organised as follows (Figure C.1). On the side of resources (columns), production of the non-energy good Q or the energy good E proceeds from intermediate consumptions (Q or E uses); labour costs L; capital costs K (net of output taxes 'Y taxes'); the rent on natural resources R;

imports M; specific margins SM and net 'Sales taxes'. Specific margins on energy uses (in Q and E production, in household consumption C, in exports X), our original addition to the standard national accounting framework, are one major consequence of hybridising calibration data and a salient feature of KLEM. For each energy use, they are the difference between sales at observed prices and sales at the average resource price p_{S_E} (an average of output and import prices, see Annex A) augmented by net product taxes—by construction their sum is thus zero. They allow modelling agent-specific prices (see Equations 27 to 31 of Annex A), i.e. circumventing the undesirable consequences of the uniform pricing standard explored by Combet et al. (2014).[25] All specific margins of Q uses are individually zero in the absence of any underlying matrix of physical flows that could necessitate agent-specific pricing.

On the side of uses, produced or imported goods contribute to productions of Q and E, are consumed by households (C) and public administrations (G), used as investment (I) or exported (X). As regards energy, correspondence with energy balance aggregates is as follows. The energy consumption of the non-energy sector ('E uses' in 'Prod Q') aggregates total final energy consumption net of households' consumption C, which covers residential energy consumptions and a share of refined products consumptions for transportation purposes. The energy consumption of the energy sector ('E uses' in 'Prod E') embraces all commercial flows between energy firms: crude oil, refined products and natural gas inputs into electricity production as well as crude oil inputs into the refining industry for the part of that industry

[25] Pricing of the aggregate energy good cannot be homogeneously based on the average energy cost structure because of energy mix differences across energy uses as well as because of actual heterogeneous pricing of even the most homogeneous energy goods (electricity and natural gas).

that is not vertically integrated. The corresponding flows of crude oil into refineries are not represented in national accounts. For instance, the state-owned crude oil producer Saudi Aramco operates as much as 71% of the refining capacity in 2013. We assume that this share remains constant over the projection horizon and use it to compute commercial flows in the process of building energy consumption trajectories from KEM outputs (Annex E).

By national accounting convention, the consumption of energy goods by public administrations is nil.[26] Investment of energy goods is nil as well, once stock variations have been cancelled out by adjusting output. Exports (X) and imports (M) are close matches to their energy balance counterparts. The price of each energy use is specific thanks to specific margins SM (see above). Note that the energy output balancing domestic consumption and net trade is a mix of primary and transformed energy. This 'double counting', from an energy engineer's perspective, is a standard feature of national accounting frameworks.

Our hybrid dataset (Figure C.1) confirms that, in 2013, the energy sector remains a significant contributor to Saudi economic activity: it weighs 28% of total uses or resources, 51% percent of total gross operating surplus (K + R in the table of Figure C.1) and 85% of total exports. Before hybridisation, the corresponding indicators were at 30%, 57% and 85% respectively.

Annex D Calibration of KLEM-KSA

To improve the relevance of modelled trajectories, which particularly bears on our modelling results concerning trade surplus and public deficit accumulation, we calibrate KLEM-KSA both

[26] The consumption of public institutions is registered as intermediate consumption by the public services sector, which is aggregated to the non-energy good in our 2-sector dataset.

statically on extensive original 2013 energy-economy data, and dynamically, in two additional steps, on focused macroeconomic data. We detail the three calibration steps in subsections below.

D.1 Static calibration on 'hybrid' energy/economy 2013 data

We perform the static calibration of KLEM-KSA on original 2013 data reconciling information on national accounts, oil trade, oil extraction costs, the energy balance and administered prices (see Annex CFigure C.1). Although this data extends to original elements as specific margins allowing differentiation of energy consumer prices beyond taxes and subsidies, our calibration procedure follows the standard practice of inverting parameters and variables and solving model equations. The only base-year variable lacking statistics is the capital stock. We define the 2013 capital stock K_0 as:

$$K_0 \;= I_{Q,0}\,\frac{1}{\delta+g_1}$$

which means recognizing the commensurability of I and K, with:

- δ the depreciation rate, which divides $I_{Q,0}$ to account for the amount of capital ($\delta\ K$) that will be retired at the end of 2013 and must therefore be replaced by $I_{Q,0}$.
- g_1 is the potential growth rate between 2013 and 2014, resulting from the combined growth of labour supply and labour productivity.[27] Dividing $I_{Q,0}$ by g_1 warrants that the capital stock starts growing at a pace compatible with that of efficient labour.

[27] See Section 3.1 for our data sources on these parameters.

D.2 Dynamic calibration on 2014 to 2017 macroeconomics

Beyond 2013 data, we first extend the calibration of KLEM-KSA to statistically available years (2014-2017 at the time of our research): we compute what disturbances of the productivity of primary factors, wages and non-energy trade allow KLEM-KSA to replicate observed trends of key macroeconomic series under constraint of reported energy trajectories.

Each year from 2014 to 2017, this first dynamic calibration procedure extends the model to 4 additional variables: Ω_L and Ω_K, impacting labour and capital productivity; Ω_w, impacting the real wage considered in the wage curve when linking it to the unemployment rate; and Ω_B, inversely impacting non-energy exports and imports. It also extends KLEM to three additional constraints: that the GDP, unemployment rate and trade balance computed by the model match statistical observation. Minimising the disturbances allows selecting one of the infinite number of solutions induced each year by adding more variables than constraints to the model. Beyond 2017, we assume that all disturbances converge at a constant rate to their average 2013-to-2017 values in 2030.[28]

The adjustment factors resulting from the above procedure are additional parameters of all further simulations of KLEM-KSA (Table D.1). They remain within 4.0% of their 2013 values for those that concern labour, capital and real wage expectations. They reach 11.8% for the non-energy trade factor Ω_B, which reflects the fact that non-energy trade, although dwarfed by oil trade, must compensate any statistical discrepancy between our sources for the oil price and exports on one side (IEA data), and the aggregate trade balance contribution to GDP on the

[28] The alternative option of fading out all disturbances by 2030 would unduly lend more weight to the 2013 balance of factors and macroeconomic performance and disregard potential misalignments on underlying trends.

other side (World Bank data). Interestingly, they do not particularly reflect the 48% drop of the oil price that happened between 2014 and 2015. This fact confirms that our choice of a Johansen closure is more adapted to the Saudi macroeconomics than the standard neoclassical closure (see Section 2.2). Neoclassical closure would translate the 2015 oil price drop into a drop of investment via collapsed foreign savings. The 2016 capital stock would be lower and would require more positive capital productivity adjustments to strike the (quite unaffected) 2016 GDP. In other words, the neoclassical closure would require larger ad hoc productivity adjustments to match observation.

	2014	**2015**	**2016**	**2017**	2020	2025	2030
Ω_L	**1.024**	**1.017**	**1.032**	**1.023**	1.022	1.020	1.019
Ω_w	**1.004**	**0.999**	**1.005**	**1.008**	1.007	1.005	1.003
Ω_B	**0.879**	**0.861**	**1.030**	**1.118**	1.084	1.029	0.978
Ω_K	**1.020**	**1.040**	**1.029**	**0.994**	0.999	1.008	1.017

Calibrated values appear in bold script, projections to 2030 for selected years in light script.

Table D.1 Adjustment factors resulting from 2014-to-2017 calibration

D.3 Full-horizon calibration of investment dynamics

We perform a second dynamic calibration of KLEM-KSA on the specific issue of the investment rate. The reason for this additional calibration is the sensitivity of our unemployment results to the available stock of capital. This sensitivity comes from our wage curve specification, which translates into employment variations any change of the purchasing power of wages induced by nominal wage adjustments. Nominal wage adjustments flow in turn from our various specifications of the real effective exchange rate (our translation of the Saudi currency peg, see Annex B), depending on the dynamics of the rental price of capital—hence the importance of controlling capital stock i.e. investment rate dynamics.

Beyond 2017,[29] we thus assume that the investment rate follows a trajectory that allows maintaining a stable unemployment rate in our *Baseline scenario* (see Section 3 for the full description of this scenario). To estimate such trajectory, we run our *Baseline scenario* with constant investment effort and compute what level of capital stock allows, each year, to reach the close-to-stable unemployment level projected for KSA by Oxford Economics forecasts.[30] We translate the resulting capital stock trajectory in an investment trajectory based on the perpetual-inventory equation. The resulting investment trajectory is fairly stable when expressed as a share of GDP, remaining within 2 percentage points from its 2013 level up to 2030.

This extra calibration procedure is not some mere modelling artefact but does reflect actual Saudi macroeconomics. Despite the global economic crisis and its dramatic impact on oil markets, the Saudi unemployment rate only marginally fluctuated (+/- 0.3 pts) around its average of 5.6% over the past decade, which points at public policy intervention. Our calibration procedure assumes that this policy intervention mainly takes the form of public control on the investment trajectory—which is already our justification for settling on a Johansen closure of some exogenous investment trajectory guaranteed by endogenous

[29] From 2013 to 2017, we set the investment rate at the value reported by the IMF. The calibration on 2014 to 2017 macroeconomics (see Section D.2) warrants that the unemployment rate matches available statistics over that period.

[30] See https://www.oxfordeconomics.com/.

adjustment of the national saving rate (see Section 2.2). This requires qualifying our GDP and unemployment results with trade surplus accumulation results (see Section 4).

Annex E Energy scenarios

E.1 Domestic energy prices

After a long period of nominal energy tariffs stagnation—i.e. of real energy price decrease, Saudi Arabia recently started a broad reform of energy pricing (APICORP, 2018). In 2016, the first phase of that reform saw the natural gas and ethane tariffs increase by respectively 67% and 133%, while tariff hikes for transport fuels (gasoline and diesel) ranged between 50% and 79%. In 2018, the second phase of the reform raised the price of gasoline between 83% and 127% (according to fuel grade) and that of residential electricity by 260% (for consumption levels below 6,000 kWh per month). Our *Baseline* and *Low-oil-price* scenarios assume domestic tariffs remaining constant relative to the price of the imported non-energy good (see Annex B for indexation issues linked to the currency peg), at the levels where the two phases of the reform brought them.

By contrast, our *Reformed scenario* assumes that further reforms eventually bring tariffs in line with international references.[31] More precisely, we assume that domestic oil and gas tariffs (e.g. for power generation or water desalinisation) converge towards international reference prices by 2030. Those reference prices consist of the projected international oil price and American natural gas price in the *SDS* scenario of the IEA (2017). This corresponds

[31] Although public authorities announced further energy pricing reforms, they did not reveal what targets would be pursued (Ministry of Finance, 2018).

to raising the oil price from 6.35 USD per barrel (2017 price) to 69 USD per barrel and the natural gas price from 1.25 USD per million British Thermal Units (MMBTU) to around 4 USD per MMBTU by 2030.[32]

In SAR per TOE	2013	2030, *Baseline*	AAGR	2030, *Reformed*	AAGR
Energy consumption of non-energy firms	290.0	419.1	+2.2%	1,907.7	+11.7%
Energy consumption of energy firms	117.5	145.7	+1.3%	1,412.0	+15.7%
Energy consumption of households	619.7	1,813.9	+6.5%	2,349.7	+8.2%

Source: Authors' computations based on KLEM-KSA and other assumptions. AAGR is the annual average growth rate. The Low-oil-price *scenario shares all* Baseline *assumptions.*

Table E.1 Domestic energy prices of KSA scenarios

These reforms would reflect real production cost for utilities and would foster competiveness by removing subsidies burden (i.e. the national oil company would be indifferent between selling oil domestically or abroad at international price). For the transport sector, we link fuel prices to the price of crude oil by deriving a ratio of crude oil price to refined products weighted by shares of diesel of gasoline using EIA data for the US. We assume that this ratio remains constant over time. It is of 1.43 for households (who mainly consume gasoline) and 1.38 for other transports (who mainly use diesel).[33] Finally, for electricity, we assume that the tariff increase follows the increase of the natural gas price. We aggregate these vector-specific assumptions according to the consumption volumes of Section E.2 to feed into KLEM for each scenario (**Table** E.1).

[32] 2030 prices are in 2016 dollars.

[33] For industrial uses i.e. mainly heavy fuel oil this ratio is equal to 0.92 (the price of heavy fuel oil is 8% lower than that of crude oil).

E.2 Domestic energy consumptions

The KAPSARC Energy Model KEM, based on the above energy pricing assumptions, projects the energy consumptions of 6 sectors, which covered 71% of primary and final energy consumptions in 2013. We report here what assumptions we make to cover sectors outside the scope of KEM.

In the *Baseline scenario,* KEM reports an increase of the crude oil and natural gas inputs into power generation and water desalinisation of 171% and 50% by 2030. The weighted average of the two increases is an 88% increase of energy input into energy supply. For the energy consumption of non-energy firms, we assume a constant energy intensity—notwithstanding KEM's projection of the petrochemicals and cement sectors considering their minority shares in the total consumption of non-energy branches.[34] This assumption reflects the fact that, even after the tariffs hikes of 2016 and 2018, Saudi energy prices remain well below international references.

For households' consumption, we assume a gradual alignment of the growth of residential consumptions on that of total population by 2030. With regard to refined product uses, we assume that light duty vehicles will reach 20 million units[35], of which 96% personal cars based on current shares as reported by GAS (2017).[36] We assume that fuel economy will increase to reach average CAFE standards of 17.1 km/l, up from 8 km/l in 2012 (Alabbadi, 2012). We

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[34] Petrochemicals and cement accounted for 36% of the total energy consumption of non-energy firms in 2013.

[35] https://www.onlyelevenpercent.com/energy-efficiency-saudi-arabia/.

[36] Extracted from the series 'Car plates issued in the Kingdom by type' issued by the GAS.

derive average annual car mileage from IEA (2009) estimates. According to these assumptions, households' fuel uses will increase by 60% in 2030 compared to 2013.

In the *Reformed scenario,* by 2030, KEM projects a phase out of crude oil uses for power generation and water desalinisation, and a decline of 67% of refined products (as a result of phase out of diesel) uses in this sector. The slowdown is mainly caused by the phase-out of crude oil and a significant cut of refined products uses for power generation and water desalination, as the Saudi power mix shifts towards renewable (mainly solar) energy and nuclear. The two trends combine into a low 15% increase of the aggregate energy input into energy firms between 2013 and 2030.

For the energy consumption of non-energy production, we expect that the increases of energy tariffs will foster both energy efficiency measures and structural change away from energy-intensive industries (petrochemicals, cement industry), in favour of manufacturing and services.[37] To approximate the impact of such transformations, we assume that the energy intensity of non-energy activities converges towards the average energy intensity of a sample of 9 developing and middle-income countries by 2030, as projected by the RISKERGY project (Ghersi, 2016).[38] This induces considering an annual energy-efficiency gain of 3.0% in non-energy production from 2018 on.

[37] For national energy efficiency measures, see the Saudi Energy Efficiency Centre (SEEC) annual reports at http://www.seec.gov.sa/.

[38] This sample comprises Brazil, China, the Czech Republic, Indonesia, India, Mexico, Malaysia, Turkey and South Africa. The RISKERGY-project energy intensities result from coupling KLEM models dedicated to each of these countries to their counterparts in the POLES model of global energy systems (see https://www.enerdata.net/solutions/poles-model.html).

For households' consumption, we assume that reforms will contain residential electricity uses to grow in line with population only. Regarding transport, we hold to the assumptions of the *Baseline scenario*, except for fuel economy. We assume that the latter reaches the upper bound of CAFE standards of 22 km/l by 2030. As a result, households' fuel uses will increase by only 24% in 2030 compared to 2013 (Table E.2).

In MTOE	2013	2030, *Baseline*	AAGR	2030, *Reformed*	AAGR
Energy consumption of non-energy firms	119.8	227.9	+3.8%	140.3	+0.9%
Energy consumption of energy firms	120.9	177.5	+2.3%	119.1	-0.3%
Energy consumption of households	22.8	37.5	+3.0%	29.2	+1.5%

Source: Authors' computations based on KLEM-KSA and other assumptions. AAGR is the annual average growth rate. The Low-oil-price *scenario shares all* Baseline *assumptions.*

Table E.2 Domestic energy consumptions of KSA scenarios

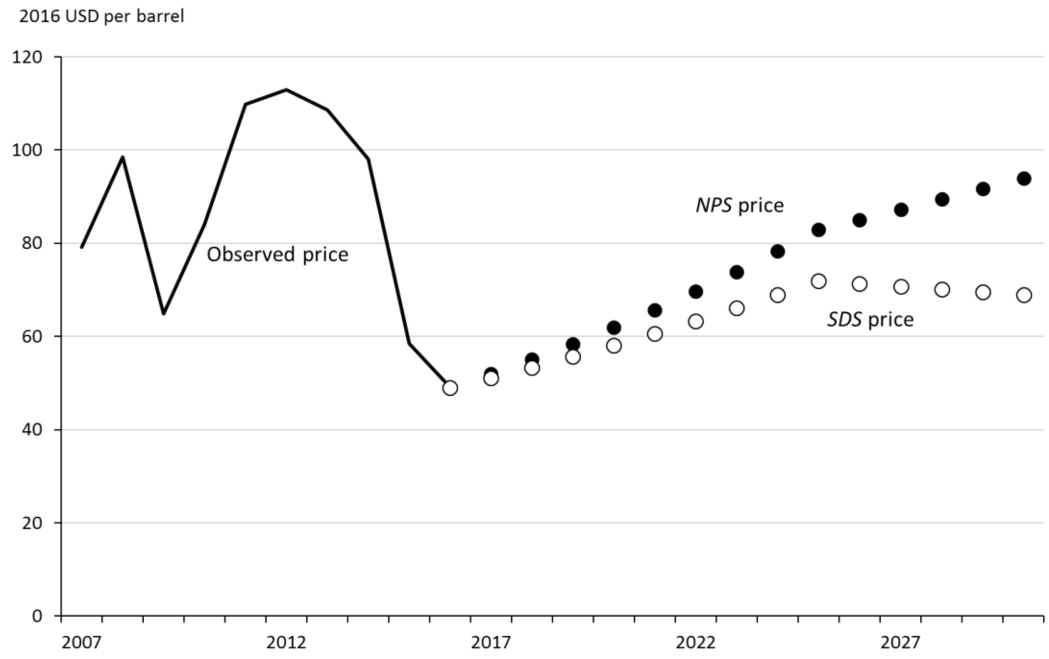
E.3 Energy trade prices

Oil trade accounts for 83% of Saudi exports earnings, of which 73% derived from crude oil exports of around 7 million barrels per day (mb/d) during the past decade (SAMA, 2017). This makes crude oil price the main variable of interest for energy trade. Although OPEC supplies 40% of world oil demand, and Saudi Arabia acts as leader with 30% of the Organization's supply, its impact on oil price is not established. In fact, there is no agreement about OPEC's market power. Many authors argue that the 'cartel' strategy was established only during some periods, and that the strategy of OPEC has been evolving over time (Fattouh and Mahadeva, 2013). Indeed, Brémond et al. (2012) show that OPEC has been acting as a price taker for most of the period following the first oil shock (1973), and that cartel behaviour only concerns a sub-group of the organization. Cairns and Calfucura (2012) or Colgan (2014) even argue that

OPEC has never constituted a cartel. In light of such evidence, we assume exogenous oil price trajectories in all our scenarios.

Our oil price scenarios derive from IEA (2017). Saudi oil export prices in our *Baseline scenario* and *Reformed scenario* correspond to the *NPS* and *SDS* of the IEA, respectively. In both scenarios, the oil price decline of 2014 has resulted in historically low investment levels (IEA, 2016). Given that oil demand is projected to increase in both scenarios (global oil demand in the *SDS* peaks in the mid-2020), current under-investment in oil resources is projected to raise oil prices up to 2025.[39] Beyond this horizon, outlooks diverge: moderate climate policy will sustain oil demand, driving oil price up in the *NPS*. In contrast, higher penetration of electric vehicles and larger efficiency gains in the transport sector in addition to climate policy tightening will cause the oil price to decline under the *SDS*. In fact, global oil demand in the *SDS* is projected to be some 15.4 mb/d or 15% below that of the *NPS* by 2030. At this horizon, the price gap between the two scenarios is of 26.6% (Figure E.1).

[39] This upward trend is similar across reference scenarios of EIA (2017) and OPEC (2017).



Source: Authors' computations based on IEA data and projections.

Figure E.1 Oil price statistics and projections

To price the fraction of Saudi energy exports that consists of refined products, we consider a ratio to crude oil prices constant over time. We calibrate on the ratio of the weighted average of petroleum products export prices over the crude oil export price, which is around 0.96. [40] This figure is consistent with that reported in SAMA (2017) of average refined products export price. Finally, we assume that the price of imported fuels is indexed on that of exported fuels, and that this indexation remains constant over time.

E.4 Energy supply and trade flows

In our calibration year (2013), KSA exported 7.5 mb/d of crude oil representing 88% of energy exports in addition to around 1 mb/d of refined products accounting for the remaining 12%.

[40] For our calibration data, oil product exports consist of LPG (29%), gasoline (2%), kerosene (9%), diesel (10%), heavy fuel oil (24%) and naphtha (26%). We extract these shares from the Saudi energy balance. The high shares of low-grade products (e.g. heavy fuel oil) accounts for the average price being below that of crude oil.

By 2017, Saudi Arabia exported around 7 mb/d crude oil,[41] whereas refined products exports had increased to around 1.8 mb/d.

In our *Baseline scenario*, KEM reports natural gas output and electricity generation based on energy prices as previously described. Concerning gas, although the Kingdom is and will remain a major producer, we direct all production to the domestic market. This is a common assumption across Saudi energy models (see Matar et al., 2017). For the remaining sectors, i.e. crude oil and refined products, we assume that (1) the Saudi output of crude oil reaches 12.7 mb/d by 2030. This corresponds to the Saudi oil supply projected by the IEA (2017) in the *NPS*. This requires additional output of around 2 mb/d compared to current levels. However, according to existing estimates, Saudi Arabia already has a spare capacity that could lift production to that level (IEA, 2018). (2) The Saudi refining capacity increases from the current 2.9 mb/d to reach 3.3 mb/d by 2030.[42] (3) Imports of refined products, which in fact correspond to total Saudi energy imports, follow potential growth at 2.23% per year up to 2030 (see Section 3.1). Under our domestic consumption assumptions, these supply and import assumptions point at Saudi energy exports increasing by around 25%, with refined products contributing more than 3/4th of this growth.

In the *Reformed scenario*, KEM provides natural gas output and electricity generation based on reformed tariffs. We maintain the assumption that both supplies meet domestic demand only. Concerning oil, we assume that Saudi Arabia keeps its export volume unchanged

[41] This resulted from an output cut following OPEC and non-OPEC accord.

[42] After the opening of the Jazan refinery (0.4 mb/d).

compared to the *Low-oil-price scenario*, and adjusts its output accordingly.[43] This reflects the fact that Saudi Arabia has one of the lowest extraction costs, and that oil-exporters with high marginal costs will bear the oil demand decline (see Barnett et al., 2004; Verbruggen and van de Graaf, 2015). Modelling the Saudi export-policy response to the climate-policy impact on oil demand would require additional assumptions on factors such as the elasticity of the international oil price to Saudi output and the market power of KSA (and the OPEC), which are beyond our scope in this paper.[44] Additionally, we consider that refined fuel imports, rather than increasing as potential output, remain constant at their 2013 level, consequently to the substantial efficiency gains from diversification reforms.

One last feature differentiating scenarios is the capital intensity of energy production. We work out sector-specific capital intensities in SAR per ton of oil-equivalent output for the four energy vectors crude oil, natural gas, refined fuels and power, and compute variations of the aggregate capital intensity coefficient by averaging with weights corresponding to output shares. In all scenarios, we assume a constant capital intensity of crude oil and natural gas production. In all scenarios as well, we increase the capital intensity of refined fuels production by the annuity of investment in the new capacity of the Jazan refinery.[45] Finally, the capital intensity of power generation changes across scenarios to reflect the shifts of power mix simulated by KEM. In the *Baseline* scenario, the mix remains dominated by fossil-fuel capacity, although gradually shifting toward natural gas, which has a lower capital cost

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[43] This induces substituting Y_E to X_E as variable of the model (see Table A.1 of Annex A).

[44] Blazquez et al. (2017) find that exporting the oil production surplus from renewable energy deployment in KSA could have a negative impact on oil price and potentially offset the gains associated with renewable energy penetration.

[45] We assume a lifetime of 25 years and a discount rate of 8% to compute annuities of the initial SAR 26.3 billion investment.

than alternative technologies (e.g. solar or nuclear). We use capital cost from the WEO (IEA, 2016). In our *Reformed* scenario, the penetration of renewables and nuclear increases the capital cost of power generation.

The resulting aggregate capital intensity of energy production remains broadly stable in the *Baseline* (and hence *Low-oil-price*) scenario, although ending some 2.5% below its 2013 level in 2030 thanks to increased utilisation rates—output increases faster than capital expenditures relative to the base year (+45.6% vs. +25.1%). In the *Reformed* scenario, the capital intensity ends 1.2% above 2013 level in 2030, i.e. around 4% above its level in the *Baseline* scenario. They capture the higher investment costs of the alternative sources made profitable by the sharp increase of energy prices.