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## GREEN POWER FOR AFRICA: OVERCOMING THE MAIN CONSTRAINTS

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# Exploring the Macroeconomic Impacts of Low-Carbon Energy Transitions: A Simulation Analysis for Kenya and Ghana

Dirk Willenbockel, Helen Hoka Osiolo and Simon Bawakyillenuo

**Abstract** The study applies purpose-built dynamic computable general equilibrium models for Kenya and Ghana with a disaggregated country-specific representation of the power sector, to simulate the prospective medium-run growth and distributional implications associated with a shift towards a higher share of renewables in the power mix, up to 2025. In both countries, the share of fossil fuel-based thermal electricity generation in the power mix will increase sharply over the next decade and beyond according to current national energy sector development plans. The overarching general message suggested by the simulation results is that in both countries it appears feasible to reduce the carbon content of electricity generation significantly without adverse consequences for economic growth and without noteworthy distributional effects.

**Keywords:** low-carbon growth, scenario analysis, CGE, green growth, renewable energy, climate change mitigation, sustainable energy.

## 1 Introduction

This study provides a forward-looking simulation analysis of economy-wide and distributional implications associated with alternative pathways for the development of the electricity sector in Kenya and Ghana. From an economic perspective, significant shifts in the power mix of an economy, as well as policy measures to induce or support such shifts, are bound to affect the structure of domestic prices across the whole economy with repercussions for the growth prospects of different production sectors and for the real income growth paths of different socioeconomic groups. Understanding these economy-wide repercussions is crucial for a study concerned with the obstacles to – and political feasibility of – adopting a low-carbon growth strategy. The analysis requires the adoption of a multisectoral general equilibrium approach that allows the capture of the input–output linkages between

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the electricity sector and the rest of the economy, as well as the linkages between production activity, household income and expenditure, and government policy.

Thus, we employ purpose-built dynamic computable general equilibrium (CGE) models for Kenya and Ghana with a detailed country-specific representation of the power sector to simulate the prospective medium-run growth and distributional implications associated with a shift towards a higher share of renewables in the power mix, up to 2025.

The following section explains the methodological approach and describes the key features of the CGE models in a non-technical manner. Each model is calibrated to a social accounting matrix (SAM) which reflects the observed input–output structure of production, the commodity composition of demand, and the pattern of income distribution for the country at a disaggregated level at the start of the simulation horizon. Section 3 spells out the data sources for the construction of the social accounting matrices and outlines the model calibration process. Sections 4 and 5 present the results of the dynamic simulation analysis for Kenya and Ghana respectively. In each case, we first develop a stylised baseline scenario that simulates the evolution of the economy under current power sector expansion plans up to 2025 and then contrast this baseline with an alternative lower-carbon energy scenario. Furthermore, the sensitivity of results to alternative projections for world market fossil fuel prices is explored. Section 6 draws conclusions.

## **2 The analytic framework**

### **2.1 Rationale for the adoption of a CGE approach**

CGE models are widely used tools in energy and climate mitigation policy analysis.<sup>1</sup> The prime appeal of adopting a general equilibrium approach to energy policy and energy-related environmental policy analysis arises from the fact that energy is an input to virtually every economic activity. Hence, changes in the energy sector 'will ripple through multiple markets, with far larger consequences than energy's small share of national income might suggest' (Sue Wing 2009: 2). The unique advantage of the CGE approach over partial equilibrium approaches is its ability to incorporate these 'ripple effects' in a systematic manner.

In contrast to partial equilibrium approaches, CGE models consider all sectors in an economy simultaneously and take consistent account of economy-wide resource constraints, intersectoral intermediate input–output linkages, and interactions between markets for goods and services on the one hand, and primary factor markets including labour markets on the other. CGE models simulate the full circular flow of income in an economy from (i) income generation through productive activity, to (ii) the primary distribution of that income to workers, owners of productive capital, and recipients of the proceeds from land and other natural resource endowments, to (iii) the redistribution of that income through taxes and transfers, and to (iv) the use of that income for consumption and investment (Pueyo *et al.* 2015).

## 2.2 Specification of the dynamic CGE models for Kenya and Ghana

In terms of theoretical pedigree, the CGE models for Kenya and Ghana employed in this study can be characterised as modified dynamic extensions of standard comparative-static single-country CGE models for developing countries in the tradition of Dervis, de Melo and Robinson (1982), Robinson *et al.* (1999), and Lofgren *et al.* (2002). Models belonging to this class have been widely used in applied development policy research. Apart from the incorporation of capital accumulation, population growth, labour force growth, and technical progress,<sup>2</sup> the main difference to the standard model is a more sophisticated specification of the electricity sector as detailed in Sections 2.2.2 and 3.2.

### 2.2.1 Domestic production and input demand

Domestic producers in the model are price-takers in output and input markets and maximise intra-temporal profits subject to technology constraints. The technologies for the transformation of inputs into real outputs are described by sectoral constant-returns-to-scale production functions. In line with common practice in energy-focused, top-down CGE models,<sup>3</sup> technology specifications belonging to the generic class of KLEM (Capital (**K**), Labour, **E**nergy, **M**aterials) production functions are employed to capture substitution possibilities among energy and non-energy inputs and among different energy sources.

### 2.2.2 Electricity supply

In standard energy-focused top-down CGE models, electricity generation and distribution is typically treated as a single production activity. In these models, a transition towards a higher share of hydro, solar, or wind in the power mix is represented in a highly stylised abstract form as a substitution of fossil fuel inputs by physical capital under the assumption of a continuous space of available technologies. The lack of explicit detail with regard to the characterisation of current and future technology options entails the danger that simulation results may violate fundamental physical restrictions such as the conservation of matter and energy (Böhringer and Rutherford 2008) or exceed other technical feasibility limits (McFarland, Reilly and Herzog 2004; Hourcade *et al.* 2006). Moreover, the lack of technological explicitness limits the ability of top-down models to incorporate detailed information on cost differentials among alternative energy technologies from engineering cost studies (Hourcade *et al.* 2006). In response to these limitations of conventional top-down CGE models, various approaches to the incorporation of detailed ‘bottom-up’ information on energy technology options into a CGE modelling framework have emerged.<sup>4</sup>

The present study adopts a similar hybrid top-down bottom-up approach by decomposing electricity generation according to power source and by treating transmission and distribution (T&D) as a separate activity. This approach enables us to incorporate extant information on levelised cost of electricity (LCOE) differentials by power source into the simulation analysis and to consider exogenous policy-driven changes in the power mix that are not necessarily driven by changes in

relative market prices. A consideration of off-grid renewable generation scenarios is beyond the remit of the present study and beyond the scope of the models applied here.<sup>5</sup>

### 2.2.3 Primary factor supply

The model distinguishes skilled and unskilled labour. The dynamic labour supply paths are exogenous and both types of labour are intersectorally mobile. The supply of agricultural land and natural resource endowments is imperfectly elastic, i.e. the supply of these primary factors varies endogenously in response to changes in the corresponding factor price. The accumulation of productive capital by sector is co-determined by capital return differentials – i.e. sectoral investment is a positive function of a sector's rate of return to capital relative to the economy-wide average return to capital.

### 2.2.4 Final domestic demand

Consumer behaviour is derived from intra-temporal utility-maximising behaviour subject to within-period budget constraints. The commodity composition of investment and government demand is kept constant according to the observed shares in the benchmark SAM, while the total volumes of government and investment demand grow in line with aggregate income and are determined by the macro closure rules detailed in Section 2.2.6.

### 2.2.5 International trade

In all traded commodity groups, imports and goods of domestic origin are treated as imperfect substitutes in both final and intermediate demand. The equilibrium ratio of imports to domestic goods in any traded commodity group varies endogenously with the corresponding relative price of imports to domestically produced output in that commodity group. On the supply side, the model takes account of product differentiation between exports to the rest of the world and production for the domestic market in all exporting sectors. The equilibrium ratio of exports to domestic goods in any exporting sector is determined by the price relation between export and home market sales. Both Kenya and Ghana are treated as small open economies – i.e. changes in their export supply and import demand quantity have no influence on the structure of world market prices.

### 2.2.6 Equilibrium conditions and macro closure

The prices for goods, services, and primary factors are flexible and adjust in order to satisfy the market clearing conditions for output and factor markets. Foreign savings and hence the current account balance follow an exogenous time path. This time path is kept fixed across the simulation scenarios considered in subsequent sections in order to enable meaningful welfare comparisons across the scenarios. This external sector closure entails that the real exchange rate adjusts endogenously to maintain external balance-of-payments equilibrium. A standard balanced macroeconomic closure rule (Lofgren *et al.* 2002) is adopted, according to which the shares of government demand,

**Table 1 Levelised cost of electricity by technology and country (US cents/KWh)**

	Ghana	Kenya
Hydro	6.8–11.2	7.4–10.9
Wind	12.6–19.5	7.7–10.3
Geothermal	Not applicable	4.7–7.5
Solar PV	16.0–26.9	9.9–14.8
Thermal – oil	19.0	26.0–42.0
Thermal – gas	13.0	13.3

Source Pueyo *et al.* (2016).

investment demand, and hence private household consumption demand in total absorption remain invariant. Under this macro closure, household and government saving rates adjust residually to establish the macroeconomic saving–investment balance.

### 3 Data sources and model calibration

#### 3.1 The social accounting matrices for Kenya and Ghana: overview

Each model is calibrated to a SAM which reflects the input–output structure of production, the commodity composition of demand, and the pattern of income distribution for the country at a disaggregated level at the start of the simulation horizon. Starting point for the construction of the model-conformable SAMs are the input–output matrices for Kenya and Ghana contained in the GTAP 9 database (Aguilar, Narayanan and McDougall 2016). This data set provides a detailed and internally consistent representation of the global economy-wide structure of production, demand, and international trade at a regionally and sectorally disaggregated level for the benchmark year 2011.<sup>6</sup>

The GTAP database treats electricity generation, transmission, and distribution as a single aggregate activity and the data on household income and household consumer expenditure are for a single aggregate household. For the purposes of the present study, both the electricity activity and the household sector are disaggregated as detailed in Sections 3.2 and 3.3.

#### 3.2 Disaggregation of the electricity sector

For Kenya, the electricity activity is disaggregated into T&D, hydro, geothermal, thermal, and wind. The electricity sector decomposition for Ghana splits the sector into T&D, hydro, and thermal. From a SAM perspective, the decomposition of the power activity for each country involves splitting the single electricity activity of the original GTAP input–output matrix into the various electricity subsectors distinguished in the CGE models in such a way that (i) the cost composition by input type in the subsectors is adequately represented; (ii) the contribution of each subsector to value-added and gross output value of the electricity sector is captured; and (iii) the accounting consistency of the SAM is

preserved. To perform this non-trivial task, we combine data on the cost composition for different power generation technologies as well as for transmission and distribution from Peters (2016), Sue Wing (2008), and Lehr *et al.* (2011) with the LCOE estimates for Kenya and Ghana (Table 1) by Pueyo, Bawakyillenuo and Osiolo (2016) and data on the power mix in the benchmark year reported in Republic of Kenya (2014) and EnCG (2016). A matrix-balancing algorithm is employed to establish full SAM consistency.<sup>7</sup>

### 3.3 Disaggregation of the household accounts

The household disaggregation for Ghana distinguishes five household groups – labelled H1 (bottom quintile) to H5 (top quintile) – by household income quintile in the benchmark year, and is based on income and expenditure data from the Ghana Living Standards Survey (GLSS 6; GSS 2014). The available data do not support a consistent rural–urban split at the level of detail required for SAM construction purposes. The household sector decomposition for Kenya draws upon the household disaggregation generated by Kiringai *et al.* (2007). The Kenya model distinguishes four household groups – labelled Rural Low, Rural High, Urban Low and Urban High – which represent respectively the bottom and top 50 per cent of rural and urban households by expenditure level.

### 3.4 SAM dimensions

The benchmark SAM for Kenya distinguishes 19 production activities, seven primary production factors including three sector-specific natural resource factors (forest, fish, and mineral stocks) beside skilled and unskilled labour, capital, and agricultural land, and four household categories. The Ghana SAM for the benchmark year contains 18 production activities, eight primary factors including oil/gas resource stocks in addition to the same factors as in the Kenya SAM, and five household groups. Both SAMs contain 18 commodity groups (Agriculture, Forestry, Fishing, Crude Oil, Natural Gas, Other Mining, Beverages and Tobacco, Processed Food, Textiles and Clothing including Footwear and Leather Goods, Refined Petrol, Chemicals including Plastic and Rubber Goods, Other Light Manufacturing, Other Heavy Manufacturing, Electricity, Construction Services, Trade Services, Transport Services and Other Services).

### 3.5 Model calibration

The numerical calibration process involves the determination of the initial model parameters in such a way that the equilibrium solution for the benchmark year exactly replicates the benchmark SAM. The selection of values for the sectoral factor elasticities of substitution, the elasticities of substitution between imports and domestically produced output by commodity group, and the target income elasticities of household demand is informed by available econometric evidence from secondary sources and uses estimates provided by the GTAP behavioural parameter database (Hertel and van der Mensbrugge 2016).

Table 2 Outline of scenarios for Kenya

	Business-as-usual power mix	Lower-carbon power mix
Low fossil fuel prices	<p><i>Baseline scenario</i></p> <p>Power mix follows current Ten-Year Plan:            Rising share of Thermal            Falling share of Hydro            Constant share of Geothermal            Rising but small share of Wind</p>	<p><i>Lower-carbon scenario</i></p> <p>Falling share of Thermal            Falling share of Hydro            Rising Share of Geothermal            Rising but small share of Wind</p>
	Oil import price 50% below 2011 level; Gas import price 55% below 2011 level	Oil import price 50% below 2011 level; Gas import price 55% below 2011 level
High fossil fuel prices (HFFP)	<p><i>HFFP scenario</i></p> <p>Power mix follows current Ten-Year Plan:            Rising share of Thermal            Falling share of Hydro            Constant share of Geothermal            Rising but small share of Wind</p>	<p><i>Lower-carbon HFFP scenario</i></p> <p>Falling share of Thermal            Falling share of Hydro            Rising Share of Geothermal            Rising but small share of Wind</p>
	Oil import price 19% below 2011 level; Gas import price 17% below 2011 level	Oil import price 19% below 2011 level; Gas import price 17% below 2011 level

Source Authors' own.

## 4 Dynamic scenario analysis: Kenya

### 4.1 Overview

The simulation analysis for Kenya considers four dynamic scenarios up to 2025 that differ with respect to (i) the evolution of the power mix in on-grid electricity generation, and (ii) the evolution of world market fossil fuel prices. Table 2 provides a concise outline of the alternative scenario assumptions along these two dimensions.

The specification of the lower-carbon scenarios is motivated by the results of the comparative LCOE analysis by Pueyo *et al.* (2016, 2017) which indicates a clear cost advantage of geothermal over all other electricity generation technologies, and by the presence of a considerable potential for the further expansion of geothermal capacity in the country. The consideration of alternative conceivable time paths for the evolution of international fossil fuel prices is motivated by the strong sensitivity of the cost differences between thermal and renewables to fossil fuel price projections.

### 4.2 Baseline scenario

The dynamic baseline scenario provides a projection of the evolution of Kenya's economy up to 2025 under the assumptions that international oil and gas prices remain at low 2015/16 levels and that the evolution of the electricity generation capacity from hydro, geothermal, and wind follows Kenya's Ten-Year Power Sector Expansion Plan 2014–2024 (Republic of Kenya 2014) under the Plan's moderate load growth scenario.

The construction of the baseline scenario starts from the 2011 benchmark SAM outlined in Section 3. For the period up to 2015,

the forward projection takes account of the most recent available data observations, while the projections from 2016 to 2025 draw upon expert forecasts for the determination of the main model-exogenous drivers of economic growth.

Population and labour force growth is based on UNDESA (2015) medium-variant projections according to which the total population of Kenya rises from 42.5 million in 2012 to 58.6 million in 2025. The second exogenous driver of economic growth in the model is the economy-wide total factor productivity (TFP) growth rate, which reflects the speed of autonomous technical progress. In the development of the baseline scenario, the time path for the annual TFP growth rate is determined indirectly by imposing a target growth path for Kenya's real gross domestic product (GDP) and by calibrating the TFP parameter of the model dynamically to match this target growth path. The GDP baseline growth rates up to 2015 are the reported actual national accounts figures and the projections up to 2018 are taken from KIPPR (2016). The assumed constant growth rate of 7.5 per cent per annum beyond 2018 is an optimistic compromise between the annual growth rate target of 10 per cent envisaged in Kenya's aspirational Vision 2030 development plan (Republic of Kenya 2007, 2013) for the same period and the growth rates projected by the CGE model under the assumption that TFP grows at a pace that is more in line with the country's actual observed growth performance over recent years.

The assumed evolution of the power mix in the baseline scenario draws upon Kenya's Ten-Year Power Sector Expansion Plan 2014–2024 (Republic of Kenya 2014) while taking into account that under the assumed baseline economic growth path, the electricity demand growth over the simulation horizon endogenously generated by the CGE model is significantly lower than in the Ten-Year Plan.

As shown in Table 3, the baseline scenario assumes that hydro, geothermal, and wind generation evolves in line with the moderate load growth scenario of the Ten-Year Plan while thermal (gas- and oil-fired) generation fills the gap between total demand and non-fossil-based supply. Correspondingly, the direction of the changes in the power mix over the period 2015–25 are broadly in line with the Ten-Year Plan moderate scenario, in the sense that (i) the hydro share drops markedly despite a substantial increase in absolute capacity; (ii) the geothermal share remains roughly constant following the rapid increase over the period 2011–15, which means that absolute geothermal generation grows strongly and approximately in proportion to total electricity demand; (iii) the share of thermal rises strongly; and (iv) the wind share roughly doubles but remains below 1 per cent. The main difference to the Ten-Year Plan scenario is that, due to the lower overall electricity demand growth, the baseline 2025 thermal share is slightly lower (35.2 per cent versus 39.2 per cent) and greener as it contains no coal-fired generation.

**Table 3 Domestic electricity generation by type – baseline scenario**

Electricity generation (GUWh)					
Year	Total	Hydro	Geothermal	Thermal	Wind
2011	7,250	3,427	1,453	2,352	18
2015	10,675	3,427	5,333	1,868	47
2020	22,735	4,466	11,343	6,829	97
2025	35,641	4,466	18,331	12,529	315
Shares (%)					
2011	100.0	47.3	20.0	32.4	0.2
2015	100.0	32.1	50.0	17.5	0.4
2020	100.0	19.6	49.9	30.0	0.4
2025	100.0	12.5	51.4	35.2	0.9

Source All figures for 2011 and all GUWh figures for Hydro, Geothermal, and Wind: Republic of Kenya (2014: Tables 6 and 33). Domestic total generation figures are model-determined and Thermal shares beyond 2015 follow residually.

### 4.3 Lower-carbon scenario

#### 4.3.1 Scenario specification

Considering alternative conceivable pathways towards a less carbon-intensive power mix, the LCOE analysis for the Green Growth Diagnostics for Africa (GGDA) project by Pueyo *et al.* (2015) identifies geothermal electricity generation as the most promising technology option for Kenya. This assessment is in line with the Kenyan government's own assessment:

In Kenya, more than 14 high temperature potential sites occur along the Rift Valley with an estimated potential of more than 10,000MW. Other locations include Homa Hills in Nyanza, Mwananyamala at the Coast and Nyambene Ridges in Meru. The expansion to existing geothermal operations offers the least-cost, environmentally clean source of energy (green) and highest potential to the country (Republic of Kenya 2014: 101).

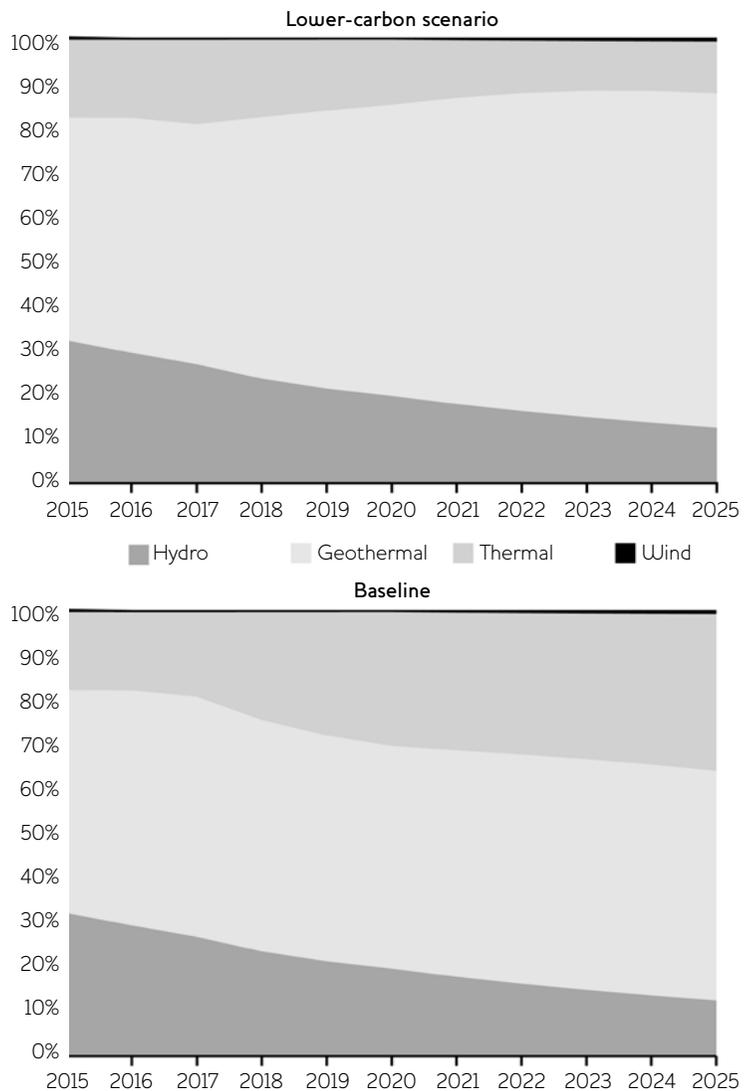
The following simulation analysis contemplates a deliberately drastic scenario in which the geothermal share in total domestic generation increases from 2018 onwards along a steep linear schedule to reach 75 per cent in 2025, so that the 2025 geothermal share is 23.6 percentage points higher than in the baseline. The thermal share drops correspondingly from 35.2 per cent in the 2025 baseline to 11.6 per cent (Table 4 and Figure 1). The hydro and wind shares remain unchanged. In absolute terms, this assumed expansion of geothermal electricity generation by 2025 is very close to the Ten-Year Plan's least-cost high growth scenario, in which geothermal is projected to generate 26,000GWh by 2024. The falling share of thermal does *not* imply an absolute contraction of thermal generation. Given the strong overall electricity demand growth, thermal generation still grows year on year, albeit at a lower rate than in the baseline.

**Table 4 Geothermal and thermal shares in total power mix – lower-carbon scenario (percentage shares)**

Year	Baseline		Lower-carbon	
	Geothermal	Thermal	Geothermal	Thermal
2015	50.0	17.5	50.0	17.5
2020	49.9	30.0	65.4	14.6
2025	51.4	35.2	75.0	11.6

Source Authors' assumptions as explained in text.

**Figure 1 Power mix in baseline and lower-carbon scenarios**



Source Authors' assumptions as explained in text.

**Table 5 Sectoral impacts for Kenya – lower-carbon scenario (percentage deviations from baseline level 2025)**

	Output	Exports	Imports	Producer price
Agriculture	0.1	-1.6	2.8	-0.4
Forestry	-0.6	-2.5		-0.3
Fishing	0.7	-1.4		-0.2
Crude oil	–	–	-9.7	–
Mining	-2.6	-2.7	1.6	-1.3
Food processing	0.2	-1.6	2.7	-0.4
Beverages and tobacco	0.6	-1.2	1.6	-0.4
Textiles and clothing	-0.4	-1.6	2.4	-0.7
Petrol refining	-9.7		-9.8	-1.2
Chemicals, rubber, plastics	0.3	0.0	1.5	-1.1
Other light manufacturing	0.1	-0.6	1.4	-0.9
Other heavy manufacturing	0.7	0.8	0.0	-1.4
Electricity	4.9			-12.5
Construction	1.0			-0.4
Trade services	0.1		2.0	-0.3
Transport services	-0.8	-1.7	3.0	-0.7
Other services	0.6	-1.3	2.8	-0.3

Source Authors' simulation results.

Note The reported trade flow changes exclude commodity groups with negligible trade volumes.

#### 4.3.2 Results

The assumed gradual shift from high-cost thermal to lower-cost geothermal electricity generation entails a notable drop in the effective average supply price relative to the baseline scenario (Table 5). In 2025, the domestic electricity price – here expressed relative to the equilibrium wage of unskilled workers – is over 12 per cent lower than in the baseline scenario. The reduction in the cost of electricity affects the production costs and thus the supply prices across all sectors and is more pronounced in sectors with a higher share of electricity in total cost such as mining, the chemical industry, and heavy manufacturing than in sectors with a low power intensity.

The assumed low-carbon transition entails a strong reduction in fossil fuel imports. Both refined petrol and crude oil imports drop by nearly

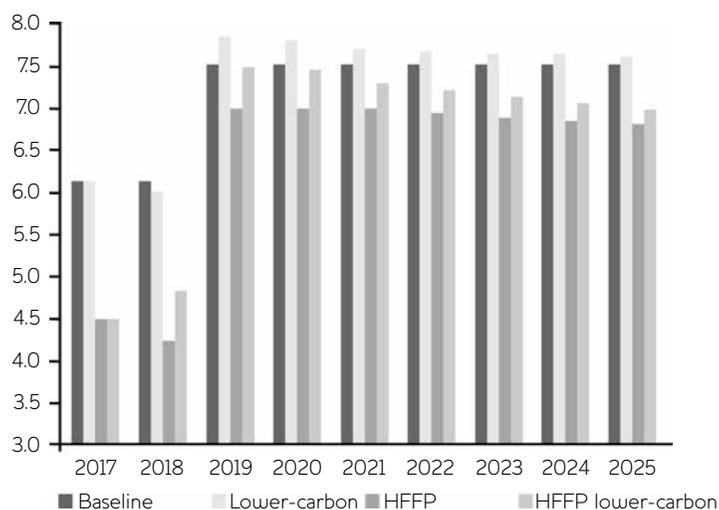
10 per cent in volume terms relative to the baseline scenario towards 2025 (Table 5). The indirect effect on crude oil imports arises due to the fact that in the baseline scenario, Kenya's domestic petrol-refining sector – which actually ceased production in the second half of 2013 – is reactivated as envisaged in the 2015 National Energy and Petroleum Policy (Republic of Kenya 2015). In the baseline projection, this sector operates at a modest scale using imported crude oil, with a negligible 2025 baseline contribution to GDP and total employment.

As Kenya remains a net importer of fossil fuels in the baseline scenario, the drop in the fossil fuel import bill is associated with a real exchange rate appreciation on the order of 0.7 per cent. The real appreciation lowers the prices of imports relative to domestically produced goods from the perspective of domestic residents. This induces a substitution effect towards imports for commodities in cases where the exchange rate effect dominates the simultaneous drop in the prices of domestic output due to the electricity cost reduction in the new equilibrium. A further positive effect on imports across all final goods arises due to the positive aggregate real income effects associated with the shift towards lower-cost electricity generation. Thus, Table 5 shows moderate welfare-raising increases in the import quantities relative to baseline levels for most traded non-fuel goods and services, and these are generally more pronounced for the commodity groups with smaller domestic supply price reductions.

On the export side, the real exchange rate appreciation effect *per se* reduces in tendency the price of exports relative to the price obtained in the domestic market from the viewpoint of domestic producers, and thus shifts the optimal profit-maximising output mix between export and home market production in favour of the latter. Correspondingly, Table 5 reports moderate drops in export quantities for most sectors. An exception is heavy manufacturing, which is the sector with the highest electricity cost share. In this case, the cost reduction effect dominates the exchange rate effect, so that exports expand. The trade effects can also be explained from a balance-of-payments perspective: the reduction in the fossil fuel import bill relaxes the balance-of-payments constraint as it allows domestic residents to enjoy simultaneously an increase in real imports and a higher share in domestically produced output, as less of that output needs to be shipped abroad to pay the import bill.

The equilibrium impact on real gross output by production sector for 2025 compared to the baseline scenario is also shown in Table 5. The sectoral employment effects have the same direction and broadly the same orders of magnitude, and are therefore not separately shown. Not surprisingly, in percentage terms the effect on the size of the small domestic oil refinery sector in relation to the baseline is most pronounced as the demand growth for fuel by thermal power plants slows down.

It is worth emphasising that no sector contracts in absolute terms and thus no sector sheds existing workers along the dynamic scenario time path.

**Figure 2 Annual growth rates of real GDP for Kenya by scenario (in per cent)**

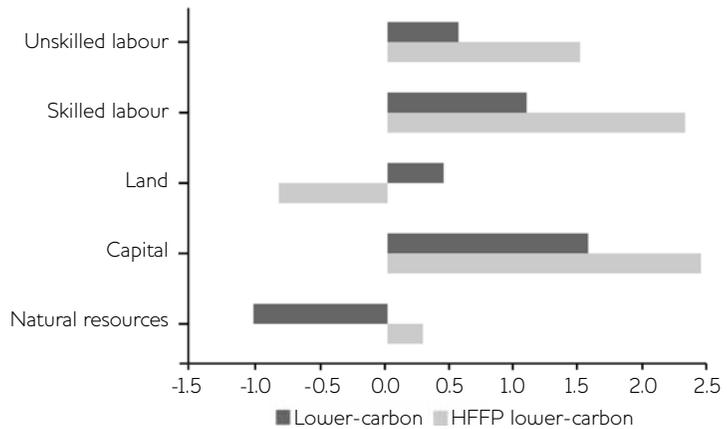
Source Authors' simulation results.

A negative-signed output effect in Table 5 merely indicates that the sector grows at a lower rate and that new workers are hired at a slower pace than in the baseline scenario, for example while the domestic refining sector at the 2025 endpoint of the simulation horizon is projected to be nearly 10 per cent smaller than in the baseline scenario for the same year, the sector is still 127 per cent larger in 2025 than in 2017.

In line with economic theory, the real exchange appreciation tends to shift productive resources from traded to non-traded activities. Among the non-power sectors that expand relative to baseline are all sectors that have simultaneously negligible or small export/output shares and negligible or little competition from imports in their domestic market, such as construction services, the fishery sector, and trade services. In contrast, the small domestic mining sector with its baseline export–output ratio of over 75 per cent and an import share of over 50 per cent in Kenya's domestic demand for mining products is squeezed noticeably as mining exports drop and mining imports rise. The sectors that expand despite relatively high trade shares are heavy manufacturing and chemicals, which are among the most electricity-intensive sectors and thus benefit disproportionately from the reduction in energy input costs. However, the main message is that the effects of the assumed low-carbon transition on the sectoral composition of output and employment are very moderate.

The real resource savings associated with the switch to a lower-cost mode of electricity generation is reflected in a moderately positive transitory effect on GDP growth, as shown in Figure 2. The cumulative effect of the small annual growth rate increments reported in Figure 2 over the period 2018–25 entails that the level of real GDP by 2025 is 1.1 per cent higher than in the baseline scenario.

**Figure 3 Impact on factor returns in Kenya by scenario (percentage deviation of factor prices relative to consumer price index (CPI) from baseline or high fossil-fuel price (HFFP) level 2025)**



Source Authors' simulation results.

Turning to the effects on the functional income distribution – i.e. the distribution of primary income by type of factor – Figure 3 displays the impacts on real factor prices (i.e. nominal factor prices deflated by the consumer price index) in 2025 relative to the baseline level in the corresponding year. By 2025, the real returns to all factors except mineral resources are slightly higher than in the baseline. Capital returns rise relative to labour wages and the wage gap between skilled and unskilled increases marginally.

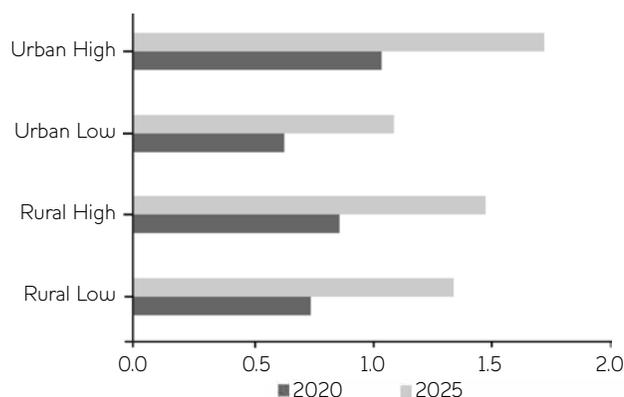
The differential factor price effect arises from factor intensity differentials between sectors that grow quicker and sectors that grow slower than in the baseline. On balance, the higher-growing sectors as a group are relatively skill- and capital-intensive and thus their additional factor input demand drives up capital returns and skilled wages more than unskilled wages.

For households with a single source of factor income, Figure 3 directly indicates the direction of the effects on total factor income. Figure 4 shows the implications for mixed-income households with factor income mixes equal to the income compositions of the four household categories the benchmark SAM. Both lower- and higher-income households gain. However, since the urban and rural high-income groups have higher shares of capital and skilled labour in their total income mix than the low-income groups, the former groups gain disproportionately. In other words, the low-carbon transition has a pro-poor effect in an absolute or 'weak' sense (i.e. the poorer households are better off than in the baseline), but is not pro-poor in a relative or 'strong' sense (i.e. the poorer households do not gain disproportionately).<sup>8</sup>

#### 4.4 Sensitivity of results to future fossil fuel prices

As the cost differentials between thermal and renewable technologies are necessarily contingent on the assumptions about future fossil fuel

**Figure 4 Impact on real household income – lower-carbon scenario (percentage deviation from baseline level 2020 and 2025)**



Source Authors' simulation results.

prices over the lifetime of thermal power plants, and the results of the quantitative low-carbon scenario analysis are driven by the size of these cost differentials, we now briefly assess the sensitivity of the findings in the previous section to a variation in the assumed exogenous international fossil fuel price time paths. In contrast to the baseline scenario, crude oil and refined petrol world prices are now assumed to return to higher levels beyond 2016. More specifically, between 2016 and 2018 oil prices rise linearly to a level that is 62 per cent higher than the 2018 baseline price (but still 19 per cent lower than the 2011 benchmark price) and then stay put at that level beyond 2018.

The high fossil fuel price (HFFP) scenario under *baseline* assumptions about the power mix provides the relevant reference scenario for comparison with the HFFP lower-carbon scenario. As the purpose of this study is not to provide an exhaustive analysis of the sensitivity of Kenya's economy to oil price shocks, the exposition of this reference scenario can be concise and focuses on key differences to the baseline scenario.

In macroeconomic terms, the simulated oil price shock is an adverse terms-of-trade shock, i.e. the aggregate ratio of import prices paid by Kenya to export prices paid by the rest of the world for Kenya's exports rises. Thus, Kenya must devote more domestic productive resources to export production at the expense of production for the home market in order to pay for the higher import bill. The welfare-reducing terms-of-trade shock requires a real exchange depreciation on the order of 7.6 per cent by 2025 relative to the baseline. The depreciation effect discourages imports and stimulates exports. The effects on GDP growth are displayed in Figure 2. GDP growth rates are hit strongly initially and then recover partially as international oil prices settle at the new higher level and the economy adapts to the shock. By 2025, the annual growth rate is still about 0.7 percentage points below the baseline growth rate. The simulation results suggest that by 2025 the level of GDP would be some 9 per cent below base.

Since higher fossil fuel prices increase the cost advantage of geothermal *vis-à-vis* thermal power generation, the positive effect of the shift to a higher geothermal share on real GDP growth is noticeably stronger than in the previous lower-carbon scenario. The cumulative effect of the increases in annual GDP growth means that by 2025 GDP is 2.6 per cent higher than in the HFFP reference scenario. The corresponding GDP increase reported in Section 4.3 for the low-oil-price case amounted to 1.1 per cent.

The real exchange rate appreciation associated with the lower dependency on fossil fuel imports is on the order of 1.2 per cent by 2025 and thus likewise slightly more pronounced than the corresponding real appreciation of 0.7 per cent reported in Section 4.3. The general pattern of the sectoral effects is the same as in the earlier lower-carbon scenario, but in quantitative terms the sectoral changes in output, employment, and trade flows are again moderately stronger.

The same conclusion applies to the impacts on the functional income distribution (Figure 3), except for the impact of the low-carbon transition on the real returns to agricultural land. The export–output ratio of agriculture is higher in the HFFP reference scenario than in the baseline scenario, since Kenya needs to export more to pay for the higher fossil-fuel import bill. Thus, the stronger real appreciation under the HFFP low-carbon scenario which slows down agricultural export growth has a stronger effect on agricultural output growth than in the low-carbon scenario under low oil prices. As a result, agricultural land rents grow slightly slower than in the HFFP reference scenario up to 2025.

## 5 Dynamic scenario analysis: Ghana

### 5.1 Overview

The scenario design for the Ghana study follows the same basic logic as the Kenya study (Table 2). The specification of the lower-carbon scenarios is again motivated by the results of the LCOE analysis by Pueyo *et al.* (2016, 2017), as detailed in Section 5.3.

### 5.2 Baseline scenario

The construction of the baseline scenario starts from the 2011 benchmark SAM for Ghana outlined in Section 3. According to the UNDESA (2015) medium-variant projections used here, the total population of Ghana rises from 25.5 million in 2012 to 33.7 million in 2025. The GDP baseline scenario growth rates up to 2014 are the reported official national accounts figures (GSS 2015) and the projections up to 2018 are taken from World Bank (2016). For the period beyond 2019, it is assumed that annual GDP continues to grow at rates just below the World Bank forecast for 2017/18. The growth rates imply that aggregate GDP in 2025 is 2.7 times higher than in 2011 and per capita GDP doubles over this period.

The assumed evolution of the on-grid power mix in the baseline takes account of the Strategic National Energy Plan 2006–2020 (EnCG 2006), the Energy Sector Strategy and Development Plan (Ministry of Energy

Table 6 Outline of scenarios for Ghana

	Baseline power mix	Lower-carbon power mix
Low fossil fuel prices	<i>Baseline scenario</i>	<i>Lower-carbon scenario</i>
	Rising share of Thermal Falling share of Hydro	Less steep rise of Thermal share Less steep drop of Hydro share
	Oil import price 50% below 2011 level; Gas import price 55% below 2011 level	Oil import price 50% below 2011 level; Gas import price 55% below 2011 level
High fossil fuel prices (HFFP)	<i>HFFP scenario</i>	<i>Lower-carbon HFFP scenario</i>
	Rising share of Thermal Falling share of Hydro	Less steep rise of Thermal share Less steep drop of Hydro share
	Oil import price 19% below 2011 level; Gas import price 17% below 2011 level	Oil import price 19% below 2011 level; Gas import price 17% below 2011 level

Source Authors' own.

2010), the Ministry of Petroleum's Gas Master Plan (Republic of Ghana 2015a), the Ghana Scaling-Up Renewable Energy Programme (SREP) (Republic of Ghana 2015b), and is also informed by a range of other sources including World Bank (2013), EnCG (2016), and IRENA (2015).

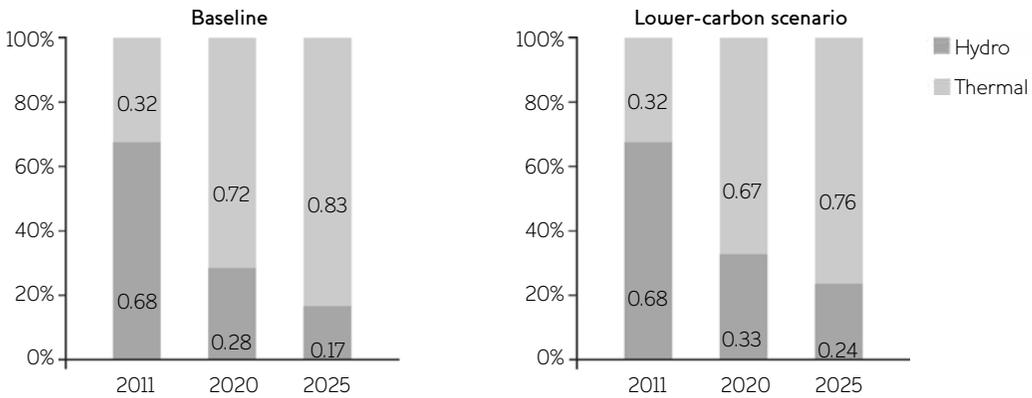
The key assumptions for the construction of the baseline scenario are that (i) hydro capacity remains constant beyond 2015 up to 2025, i.e. the hydro share drops as total generation grows (Figure 5); (ii) the on-grid share of non-hydro renewables remains negligibly small, i.e. the binding constraints to investments in renewable energy capacity in Ghana identified by Pueyo *et al.* (2017) are not relaxed, and thus Ghana's official aspirational target to reach a renewable share (excluding large-scale hydro) of 10 per cent by 2020 is not achieved; (iii) the rising gap between hydro generation and total demand for electricity is entirely bridged by additional thermal generation, and thus the share of thermal in total generation is rising; and (iv) the share of gas in total thermal generation is rapidly rising from 2018 onwards. In line with Ghana's Gas Master Plan and the recommendations in World Bank (2013), the baseline scenario assumes further that natural gas extraction from domestic sources develops at a fast pace, so that by the 2020s a significant fraction of the expanding gas demand by the power sector is covered by domestically sourced supplies.

### 5.3 Lower-carbon scenario

#### 5.3.1 Scenario specification

Pueyo *et al.* (2016) suggest that in comparison to Kenya, Ghana's renewable energy potential is considerably smaller and presently hydro is the only renewable energy option with a clear cost advantage over gas-fired thermal generation, yet the potential for a further expansion of hydro capacity is limited. Based on IRENA (2015) estimates for Ghana's untapped small- and medium-scale hydro power expansion potential, we consider a moderate lower-carbon transition scenario in which the hydro share in total generation by 2025 is seven percentage

Figure 5 Electricity generation shares in baseline and lower-carbon scenario



Source Authors' simulation results.

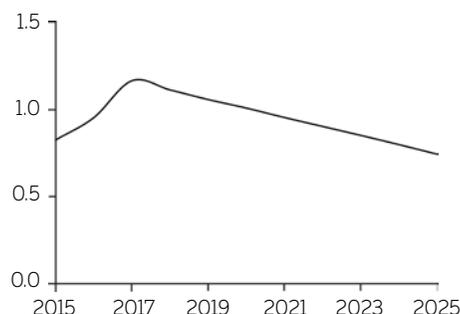
points higher than in the baseline scenario, and the 2025 thermal share drops from 83 per cent to 76 per cent. IRENA estimates suggest that the LCOE 'for new small hydropower projects is between 3 US cents and 11.5 US cents/KWh in developing countries',<sup>9</sup> which is within the range of the LCOE estimate used for the initial calibration of the hydro sector parameters in the CGE model for Ghana (Table 1).

### 5.3.2 Results

The moderate and gradual shift from thermal to hydro electricity generation entails modest changes in the system-wide average cost of electricity production over the period 2018–25. By 2025, the electricity supply price in this scenario is a moderate 1.1 per cent lower than in the baseline.

The dynamic macroeconomic adjustment process in this scenario is complicated by the fact that the baseline hydro-thermal generation cost differential endogenously generated by the CGE model has a hump-shaped time profile as shown in Figure 6: over the period 2015–17, the thermal generation costs drop sharply relative to hydro unit costs, so that by 2017 the initial cost advantage of hydro turns into cost disadvantage. Beyond 2017, this trend reverses as the thermal unit cost begins to rise relative to the hydro unit cost, and beyond 2021 hydro restores its status as the least-cost electricity technology.

Primarily, three features of the baseline scenario drive this peculiar time path of the hydro-thermal cost differential. First, fossil fuel import prices and particularly gas prices drop strongly over the period 2015–17, and entail a sharp drop in the thermal generation cost over this period. Second, the strong increase in demand for thermal electricity associated with the rise in the thermal share over the whole simulation horizon drives up the equilibrium rate of return to capital in the thermal sector – i.e. the return on investments in thermal capacity must rise in order to attract the new capital required for the expansion of the thermal sector. This effect raises the cost of capital in the thermal sector.

**Figure 6 Ratio of average hydro to average thermal generation cost, 2015–2025**

Source Authors' simulation results.

Third, as Ghana has an initial trade deficit with the rest of the world and the foreign savings required to cover the trade deficit grow at a lower exogenous rate than Ghana's real income and import demand, the real exchange rate depreciates slightly over the entire simulation interval. Thus, while fossil fuel prices remain constant beyond 2017 in foreign currency terms, they rise gradually from 2018 to 2025 from the perspective of domestic firms and households due to the depreciation effect. The first effect dominates the time profile of the hydro-thermal cost differential up to 2017, while the second and third effect become jointly dominant after 2018.

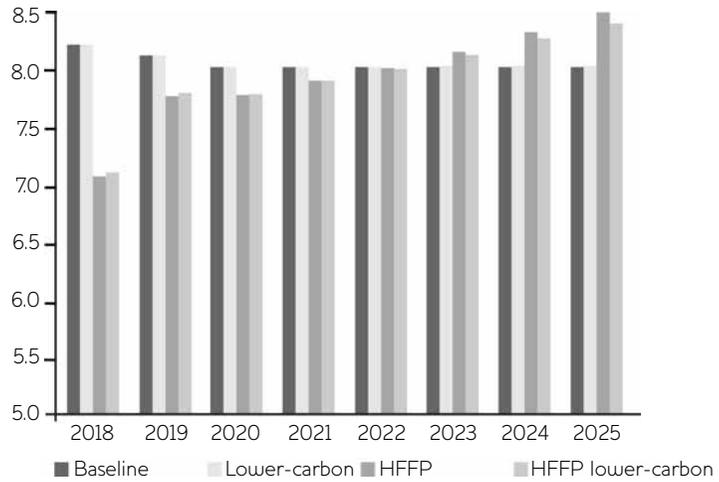
The small direct electricity cost reduction effect towards 2025 triggers only weak intersectoral spillover effects via input–output linkages and other general equilibrium repercussions. The equilibrium effects on the supply prices of other sectors are generally tiny. The only noteworthy indirect price effect is the 0.8 per cent drop in the domestic natural gas supply price. This effect occurs since the thermal sector expands at a lower rate than in the baseline, and thus its demand for gas grows at a lower rate.

For the same reason, fossil fuel imports drop relative to the baseline. As in the case of Kenya, the reduction in the fossil fuel import bill entails a mild real exchange rate appreciation effect, i.e. the additional 'space' in Ghana's external balance-of-payments account created by the reduced fossil fuel import payments enables a simultaneous increase in the volume of non-fuel imports and a reduction in the volume of exports that must be shipped to the rest of the world in order to pay for imports.

In an aggregate macroeconomic sense, the net welfare effect for Ghana associated with the low-carbon transition scenario considered here is unambiguously positive: using virtually the same total real resources as in the baseline, Ghana can simultaneously command a higher real volume of imports and retain a higher share of total domestic output as less of this output is exported than in the baseline.

This positive welfare effect is reflected in a positive but very small increase in real GDP. The cumulative effect of the tiny annual growth rate

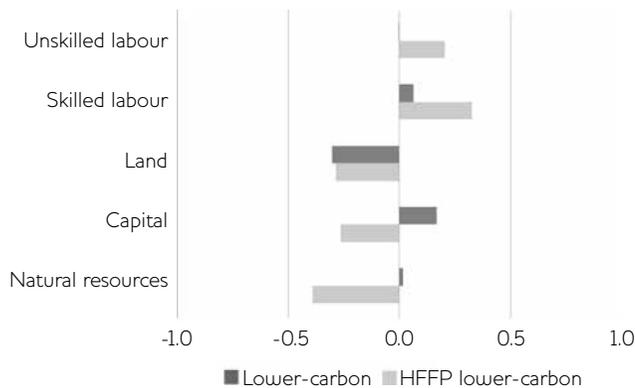
Figure 7 Annual growth rate of real GDP for Ghana by scenario (in per cent)



Source Authors' simulation results.

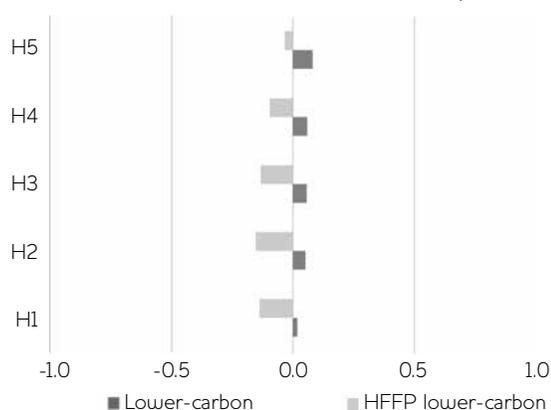
increments reported in Figure 7 over the period 2021–25 entails that the level of real GDP by 2025 is a negligible 0.025 per cent higher than in the baseline scenario. Part of the reason for the small GDP effect is that between 2018 and 2020 the low-carbon transition initially raises the average price of electricity (by about 1 per cent) due to the hump-shaped time profile of the hydro-thermal cost differential discussed previously. A further reason is that the reduction in demand for domestic natural gas by the thermal sector leads to a small reduction in the primary resource extraction activity of the domestic fossil fuel sector. In economic terms, this means a reduction in the supply of a primary production factor which entails *per se* a negative effect on real GDP. However, this effect is likewise tiny: the 2025 supply of domestic fossil fuel primary resources drops by 1.8 per cent, while the baseline contribution of this factor to GDP is about 2 per cent – so the effect on real GDP is well below 0.05 per cent.

Figure 8 Impact on factor returns in Ghana by scenario (percentage deviation of factor prices relative to CPI from baseline level 2025)



Source Authors' simulation results.

**Figure 9 Impact on real household income in Ghana by scenario (percentage deviation from baseline level or HFFP level 2025)**



Source Authors' simulation results.

Figures 8 and 9 report the effects on the functional distribution of income and real factor income by household type for 2025. Unsurprisingly, the impacts are again tiny. As in the case of Kenya, the distribution impact is slightly regressive in tendency as by 2025 capital and skilled labour gain slightly in relation to other factors.

## 5.4 Sensitivity of results to future fossil fuel prices

### 5.4.1 HFFP scenario

The world market crude oil price increase under the HFFP scenario incentivises a marked rise in Ghana's crude oil export supply and the domestic fossil fuel extraction sector expands *vis-à-vis* the baseline. Due to the large thermal share in total electricity generation by 2025, the cost-push effect on the price of electricity is strong (+38 per cent). The supply prices of non-energy sectors with relatively high energy cost (direct fuel plus electricity) shares in total production costs including the chemical industry, heavy and light manufacturing, other mining, and transport services are likewise pushed up significantly, and the growth of these sectors slows down accordingly.

In the baseline scenario, Ghana remains a marginal net fossil fuel importer despite its crude oil exports, and thus the rise in international fossil fuel prices is an adverse terms-of-trade shock for the country. However, due to the additional crude oil export revenue growth in the HFFP scenario, the absolute size of the annual net fossil fuel import bill relative to the baseline scenario becomes smaller over time, and thus towards 2025 Ghana needs to earn less non-fuel export revenue than in the baseline to pay for the net fossil fuel import bill. This is a noteworthy difference to the HFFP scenario for Kenya discussed in Section 4.4.

Figure 7 shows the effects on GDP growth. As in the case of Kenya, GDP growth rates are hit strongly by the initially higher energy costs and then start to recover as international oil prices settle at the new higher level and the economy adapts to the shock. In contrast to Kenya, however, from

2023 onwards GDP growth rates start to overshoot the baseline rates. The reason for this effect is that the expansion of the domestic fossil fuel sector is associated with a higher rate of domestic natural resource extraction than in the baseline. By 2023, the impact of this increase in the supply of a primary production factor on total economy-wide value-added is sufficiently strong to dominate the growth-depressing effects of higher energy prices on the annual growth rate. However, this effect is not strong enough to push the level of GDP above the baseline path: by 2025, real GDP is still 3.2 per cent below baseline level.

It is important to note that the hump-shaped time profile of the hydro-thermal cost differential (Figure 6) does *not* occur in the HFFP scenarios: since fossil fuel prices remain high over the entire 2015–25 period, the hydro-thermal unit cost ratio remains below unity throughout.

#### 5.4.2 HFFP lower-carbon scenario

Higher fossil fuel prices increase the cost advantage of hydro *vis-à-vis* thermal power generation, and so the impact of the transition towards a higher hydro share entails a stronger reduction of the electricity than in the low-carbon scenario of Section 5.3: by 2025, the electricity price is 6.2 per cent lower than in the HFFP reference scenario, whereas in the low-carbon scenario with low fossil fuel prices, the electricity price impact is only -1.1 per cent.

Moreover, since in contrast to the previous low-carbon scenario the hydro cost advantage now prevails over the entire 2018–25 period, the gradual downward shift in electricity prices begins right at the start of the transition process in 2018, whereas in the low-carbon scenario with low fossil fuel prices the same transition entails an initial electricity price increase due to the hump-shaped time profile of the hydro-thermal cost differential.

However, the reduction in demand for domestic natural gas by the thermal sector and the real appreciation effect due to the reduced net fossil fuel import bill again leads to a small reduction in the primary resource extraction activity of the domestic fossil fuel sector. This effect entails *per se* a negative impact on real GDP. By 2022, this effect begins to slightly dominate the growth-enhancing effect of lower electricity prices. The cumulative impact of these minuscule effects on annual GDP growth rates remains small: by 2020, the level of real GDP in the HFFP low-carbon scenario is 0.1 per cent higher and by 2025, 0.11 per cent lower than in the HFFP reference scenario.

Thus, in contrast to the corresponding analysis for Kenya, the *quantitative* impact of the lower-carbon transition in the electricity sector on macroeconomic growth in Ghana is not particularly sensitive to variations in the assumptions about international fossil fuel prices: both in the low-carbon scenario and the HFFP low-carbon scenario the impacts on real GDP remain negligibly small despite the *qualitative* differences across the two scenarios. Also in contrast to the findings for Kenya, higher fossil fuel prices do not enlarge but rather reduce the

beneficial impacts of a transition from thermal to lower-cost renewable electricity generation in the case of Ghana. The main reason for these differences is related to the endogenous changes in domestic fossil fuel resource extraction that occur in the case of Ghana but not in the case of Kenya. Impacts on the functional distribution of income and the distribution by household quintile remain small (Figures 8 and 9).

## 6 Conclusions

The present study applies purpose-built dynamic CGE models for Ghana and Kenya with a disaggregated country-specific representation of the power sector, to simulate the prospective medium-run growth and distributional implications associated with a shift towards a higher share of renewables in the power mix, up to 2025.

In both countries, the share of fossil fuel-based thermal electricity generation in the power mix will increase sharply over the next decade and beyond according to current national energy sector development plans.

Kenya has a considerable potential for a further expansion of geothermal electricity generation and existing estimates suggest a significant cost advantage of geothermal over thermal power generation. In line with this assessment, the simulation analysis for Kenya considers a stylised low-carbon transition scenario in which the geothermal share in total domestic on-grid electricity generation increases along a steep linear schedule, so that the 2025 geothermal share is 24 percentage points higher than in the baseline scenario.

The higher share of low-cost geothermal in the power mix reduces electricity prices and mildly stimulates economic growth. The associated reduction in the fossil fuel import bill triggers a moderate real exchange rate appreciation, which reduces the prices of imports faced by domestic producers and households and entails a further economy-wide real income gain. The size of these beneficial aggregate effects depends on the evolution of international fossil fuel prices over the simulation horizon: under a low-carbon transition scenario with low world market fossil fuel prices, real GDP in 2025 is about 1.1 per cent higher than in the baseline scenario. In a low-carbon scenario with high fossil fuel import price scenario, real GDP in 2025 is more than 2 per cent higher than in the corresponding HFFP baseline scenario. All household groups gain, but urban and rural higher-income households gain relatively more than urban and rural low-income households, because skilled real wages and real returns to capital rise slightly more than unskilled wages and returns to land. Impacts on the sectoral structure of production are generally small. In tendency, sectors with a higher baseline share of electricity costs in total production cost expand relative to sectors with a low electricity cost share.

In comparison to Kenya, Ghana's potential for an economically viable expansion of renewable on-grid power generation is considerably smaller. Moreover, in contrast to Kenya, Ghana has an already active

domestic fossil fuel extraction sector and is planning to satisfy a significant share of the fuel demand of its expanding gas-fired thermal generation using domestic natural gas resources. The available levelised cost estimates suggest that in the case of Ghana presently, hydro is the only renewable energy option with a clear cost advantage over gas-fired thermal generation, yet the potential for a further expansion of hydro capacity is limited. In line with this assessment, the simulation analysis for Ghana considers a moderate lower-carbon transition scenario in which the hydro share in total generation by 2025 is seven percentage points higher than in the baseline scenario and the 2025 thermal share drops from 83 per cent to 76 per cent.

This moderate electricity sector transition shock generates only marginal impacts on macroeconomic growth. The presence of a domestic fossil fuel extraction sector in Ghana changes the qualitative nature of the dynamic adjustment to the transition shock in relation to the case of Kenya. As in the analysis for Kenya, the partial shift to lower-cost renewable power generation reduces the cost of electricity and this *per se* stimulates economic growth. However, the associated drop in demand for domestic natural gas by the electricity sector slightly dampens the growth of domestic natural resource extraction, and this reduction in primary factor supply growth *per se* reduces real GDP growth. Thus, in the case of Ghana, these two effects drag GDP in opposite directions and the net effect is miniscule. Similar to Kenya, the impacts on the sectoral structure of domestic production are small and thus the effects on relative factor prices that determine the functional income distribution remain unremarkable.

The overarching general message suggested by the simulation results presented here is that in both countries it appears feasible to reduce the carbon content of electricity generation significantly without adverse consequences for economic growth and without noteworthy distributional effects.

### Notes

- 1 Sue Wing (2009) and Kemfert and Truong (2009) survey this literature. For a concise recent survey of the small number of CGE studies concerned with a low-carbon energy transition in developing countries, see Pueyo *et al.* (2015: 52–59).
- 2 See e.g. Robinson, Willenbockel and Strzepek (2012) for an earlier recursive-dynamic extension of the standard model.
- 3 See e.g. Böhringer and Löschel (2004), Böhringer, Löschel and Rutherford (2009), and Willenbockel and Hoa (2011). For further reference to the literature on energy-focused top-down CGE models, see Pueyo *et al.* (2015: Chapter 6).
- 4 Examples for the development and application of such hybrid top-down bottom-up models include *inter alia* McFarland, Reilly and Herzog (2004), Böhringer and Löschel (2006), Sue Wing (2008), Böhringer and Rutherford (2008, 2013), Sassi *et al.* (2010), Boeters and Koornneef (2011), Lanz and Rausch (2011), Okagawa *et al.* (2012), Proenca and St. Aubin (2013), and Fortes *et al.* (2013).

- 5 In the recent low-carbon development literature, the deployment of decentralised renewable energy systems is widely seen as a promising and economically viable approach to reducing energy poverty in remote rural areas (see Willenbockel 2015: 171–72 for further reference), and thus the incorporation of such scenarios in future research appears desirable. However, assessing the scope for a cost-effective expansion of stand-alone renewable energy generation as an alternative to centralised grid supply is a complex task and requires spatially explicit modelling, as exemplified by Deichmann *et al.* (2011) for Ethiopia, Ghana, and Kenya. For a study of the evolution of the solar home system market in Kenya see Byrne *et al.* (2014).
- 6 The raw data for the Ghana country bloc of the GTAP database include a SAM for 2005 constructed by Breisinger, Thurlow and Duncan (2007) and the raw data for Kenya in GTAP include a 2001 SAM developed at the Kenya Institute for Public Policy Research and Analysis (KIPPRA) in collaboration with the International Food Policy Research Institute (IFPRI), a predecessor of the latest available KIPPRA–IFPRI SAM for 2003 (Kiringai, Thurlow and Wanjala 2006). In the case of Kenya, the GTAP input–output data have been triangulated with information from more recent unpublished supply-and-use tables (SUTs) provided by Dr Bernadette Wanjala (KIPPRA). Following minor revisions in the course of this triangulation process, the SAM has been rebalanced using a variant of the cross-entropy approach proposed by Robinson, Cattaneo and El-Said (2001). For Ghana, no recent SUT data are available.
- 7 See Willenbockel, Osiolo and Bawakyillenuo (2017) for further elaboration. See Peters and Hertel (2016a, 2016b) for a detailed discussion and comparison of existing matrix-balancing algorithms commonly used in this context and further references to the related technical literature.
- 8 See Willenbockel (2015) for critical reflections on the recent literature concerned with pro-poor low-carbon development in this context.
- 9 <http://costing.irena.org/technology-costs/power-generation/hydropower.aspx> (accessed December 2016).

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