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Macroeconomic Effects of a Low-Carbon Electricity Transition in Kenya and Ghana: An Exploratory Dynamic General Equilibrium Analysis

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Abbreviations and Acronyms

AGRODEP	African Growth & Development Modeling Consortium
aka	Also known as
BaU	Business as usual
bcf	Billion cubic feet
CES	Constant elasticity of substitution
CGE	Computable general equilibrium
CPI	Consumer price index
e.g.	Exempli gratia (for example)
EnCG	Energy Commission of Ghana
EPSRC	Engineering and Physical Sciences Research Council
GDP	Gross domestic product
GGDA	Green growth diagnostics for Africa
GHG	Greenhouse Gases
GLSS	Ghana Living Standards Survey
GSS	Ghana Statistical Service
GTAP	Global Trade Analysis Project
GWh	Gigawatt hours
GWS	Gesellschaft für Wirtschaftliche Strukturforschung
ibid	ibidem (in the same place)
i.e.	id est
IFPRI	International Food Policy Research Institute
IRENA	International Renewable Energy Agency
ISSER	Institute of Statistical, Social and Economic Research, University of Ghana
KIHBS	Kenya Integrated Household Budget Survey
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KLEM	Kapital Labour Energy Materials
KNBS	Kenya National Bureau of Statistics
KWh	Kilowatt hours

LAPSSET	Lamu-Port Southern Sudan-Ethiopia Transport Corridor
LCO	Light crude oil
LCOE	Levelised cost of electricity
LES	Linear expenditure system
LNG	Liquefied natural gas
MW	Megawatt
p.a.	per annum
PV	Photovoltaic
R^2	Coefficient of determination
RAS	Bi-proportional matrix balancing method
SAM	Social accounting matrix
SREP	Sustainable Renewable Energy Program
SUT	Supply and use tables
TD	Transmission and distribution
TFP	Total factor productivity
UN DESA	United Nations Department for Economic and Social Affairs
UNDP	United Nations Development Program
UNU-WIDER	United Nations University - World Institute for Development Economics Research
USc	United States cents
USD	United States Dollars
WIID	World Income Inequality Database

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 Ghana and Kenya. It is part of a wider research project that seeks to identify the binding constraints to economically viable investments in renewable energy and to analyse the political feasibility of a transition to a sustainable low carbon energy path in the two countries.

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 socio-economics 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 multi-sectoral general equilibrium approach that allows to capture the input-output linkages between 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, the present study develops purpose-built dynamic computable general equilibrium (CGE) models for Ghana and Kenya 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 these baselines with alternative lower carbon energy scenarios. 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

Computable general equilibrium (CGE) models – aka applied general equilibrium models – are widely used tools in energy and climate mitigation policy analysis. Applications range from short-run impact assessments of shocks to the energy system for particular countries to global long-run energy system scenario studies with a time horizon of multiple decades.[1]

The prime appeal of – and need for - 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). 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 characterized as modified dynamic extensions of standard comparative-static single-country CGE models for developing countries in the tradition of Dervis, de Melo and Robinson

[1] For a survey of energy-focused CGE studies up to the mid-1990s see Bhattacharyya (1996). For more recent overviews, see Sue Wing (2009) and Kemfert and Truong (2009). 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).

(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, labor force growth and technical progress,[2] the main difference to the standard model is a more sophisticated specification of the electricity sector as detailed below.

2.2.1. Domestic Production and Input Demand

Domestic producers in the model are price takers in output and input markets and maximize 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,[3] technology specifications belonging to the generic class of KLEM (Capital (**K**), **L**abour, **E**nergy, **M**aterials) production functions are employed to capture substitution possibilities among energy and-non-energy inputs and among different energy sources. In technical terms, the sectoral KLEM production functions take the form of nested multi-level functions with a (positive or zero) constant elasticity of substitution (CES) among inputs grouped together within the same nest. Figure 1 provides a schematic representation of the substitution hierarchy between different inputs in production in the model.

In each sector, the production of a given output quantity requires non-energy inputs and a composite value-added/energy composite in fixed proportions. The value added/energy composite requires energy and primary factors (i.e. skilled and unskilled labour, capital, land and natural resources) in variable proportions. Thus, when the composite price index of energy rises relative to primary factor prices, energy inputs are replaced to some extent by additional inputs of primary factors. In other words, the model generates a shift towards less energy-intensive modes of production in response to an increase in energy prices. Required energy inputs are composed of electricity purchases from the electricity sector in the model and direct use of fossil fuels. The model allows substitution of these primary fossil energy carriers for electricity in sectors where the input-output matrices of the GTAP database record intermediate

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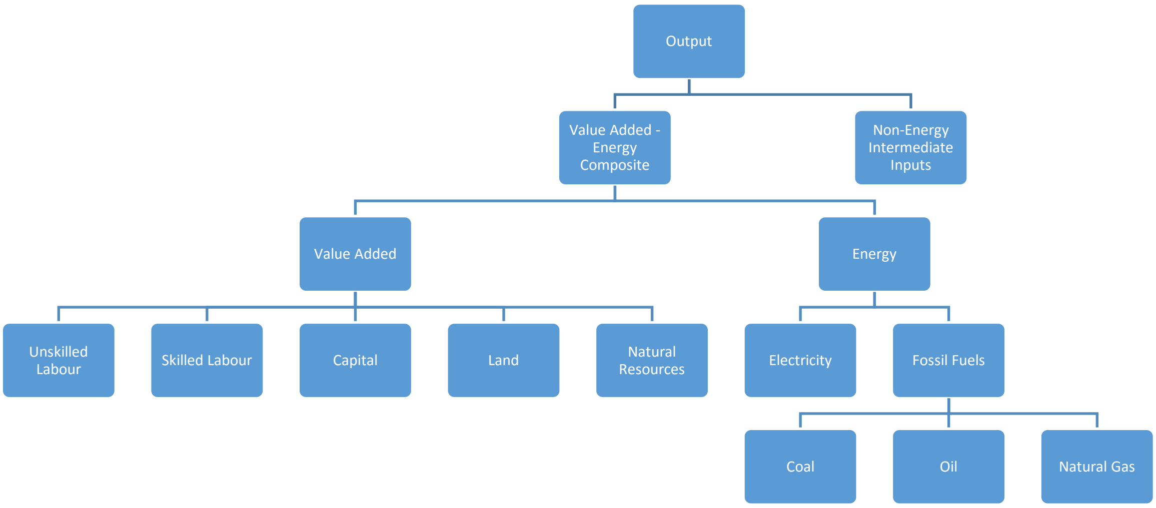
[2] See e.g. Arndt, Robinson and Willenbockel (2011) and Robinson, Willenbockel and Strzepek (2012) for earlier recursive-dynamic extensions of the standard model.

[3] See e.g. Böhringer and Löschel (2004), Böhringer, Löschel and Rutherford (2009), Willenbockel and Hoa (2011). For further reference to the literature on energy-focused top-down CGE models, see again Pueyo et al (2015: Chapter 6).

purchases of fossil fuels. At the bottom of the input substitution hierarchy, the sectoral production functions allow for imperfect substitutability between coal, refined oil and natural gas.

Figure 1: Production Function Nesting Structure



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 stylized 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 characterization of current and future technology options entails the danger that in the case of simulation scenarios involving large departures from the initial benchmark equilibrium 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; Bibas and Mejean, 2012). 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 and to simulate technology-specific policy measures in a fully persuasive manner (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.[4]

The present study adopts a similar hybrid top-down bottom-up approach by treating decomposing electricity generation according to power source and by treating electricity transmission / distribution 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. The system-wide supply price of electricity in the models is effectively determined as weighted average of the activity-specific supply prices across the power activities. The operational aspects of the power sector decomposition are outlined in section 3 below.

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 (forests, minerals, and in the case of Ghana crude oil and natural gas) is imperfectly elastic, i.e. the supply of these primary factors varies endogenously in response to changes in the corresponding factor price. The productive capital stock in each sector *a* evolves according to the dynamic accumulation equation

$$K(a,t+1) = I(a,t) + (1 - \delta(a))K(a,t),$$

where K denotes the installed real capital stock, I(a,t) is real gross investment flowing to sector a in period t and δ is the rate of physical capital depreciation. Sectoral gross investment is a positive function of a sector's rate of return to capital relative to the economy-wide average return to capital, i.e. the sectoral allocation of aggregate real investment is determined by return

[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), Bibas and Mejean (2012), Okagawa et al (2012) and Fortes et al (2013).

differentials. Once installed, capital is sector-specific (i.e. immobile across sectors) while new capital is intersectorally mobile.

2.2.4. Final Domestic Demand

Consumer behavior is derived from intra-temporal utility maximizing behavior subject to within-period budget constraints. Utility functions take the Stone-Geary form, yielding a Linear Expenditure System (LES) demand specification. 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 below.

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. Agents' optimizing behaviour entails that the expenditure-minimizing 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 technologies for conversion of output into exports are described by sectoral constant-elasticity-of- transformation (CET) functions. This entails that the profit-maximizing 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 endogenous 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, 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 database version 9 (Aguiar, Narayanan and McDougall, 2016). This data set provides a detailed and internally consistent representation the global economy-wide structure of production, demand and international trade at a regionally and sectorally disaggregated level. GTAP 9a – the latest available version of the database - combines detailed bilateral trade and protection data reflecting economic linkages among 140 world regions with individual regional input-output data, which account for intersectoral linkages among 57 production sectors for the benchmark year 2011.[5]

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 below.

3.2. Disaggregation of the Electricity Sector

The decomposition of the power activity for each country essentially involves (i) splitting the single electricity activity column vector of the original GTAP input-output matrix (which contains the annual input cost by input type for the benchmark year) into several new columns for the different electricity sub-sectors distinguished in the CGE model, and (ii) distributing

[5] 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 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 and Kiringai et al, 2007). In the case of Kenya, the GTAP input-output data have been triangulated with information from unpublished supply-and-use tables (SUT) for 2009 kindly 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.

the cost figures of the original aggregate electricity cost vectors horizontally across the new columns in line with available information about the cost composition in the electricity sub-sectors and in such a way that the original cost totals by input type are preserved. This is a non-trivial problem. The common procedure employed in the construction of databases for energy-focused hybrid top-down bottom-up CGE models is to start with an informed initial estimate for the entries in the new sub-industry column vectors and then apply a numerical matrix balancing method to enforce the target sub-matrix totals.[6]

Peters (2016) constructs a satellite database for GTAP9 which disaggregates the GTAP electricity activity for all regions in the database along these lines. However, the regional coverage of LCOE estimates used in the construction of the Peters database is incomplete, with country-specific estimates for Africa being notable by their virtual absence.[7] In cases, where the discrepancies between the row totals implied by the initial guesses in the absence of country-specific data and the target GTAP row totals is large, the application of the mechanical matrix balancing algorithm can generate seriously misleading results. The case of Kenya – flagged up explicitly by Peters (2016:231, n12) as a problematic case – illustrates the point: In the benchmark year 2011 Kenya generates electricity primarily from hydro, thermal (i.e. fossil fuel) and geothermal sources[8]. Geothermal is not identified as a separate technology in the Peters database, but would in principle be covered one-to-one by the residual "Other" category in that data base. Yet, attributing the reported cost figures in this category to geothermal would lead to seriously misleading results.[9]

Therefore, the decomposition of the electricity sectors for the present study uses additional country-specific data and information from other studies. For Kenya, the electricity activity is disaggregated into transmission and distribution (TD), hydro, geothermal, thermal and wind. First, the cost totals for the sub-activities are determined: The TD share is based on Peters (2016) while the total generation share is distributed across the four generation activities by combining the 2011 electricity generation data in GWh reported in Republic of Kenya (2014:

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[6] See Peters and Hertel (2016a,b) for a detailed discussion of comparison of existing matrix balancing algorithms used in this context and further references to the related technical literature.
[7] See Peters (2016: Appendix C). As Peters (2016:216) puts it, "(i)ncreasing the LCOE coverage is a major opportunity for subsequent versions".
[8] See Table 5 below.

[99] E.g. the reported share of fossil fuel inputs in total cost for this category is more than 70 percent.

Table 33)[10] with the LCOE cost differential estimates for Kenya (Table 1) reported in Pueyo et al (2016). Fossil fuel input are entirely allocated to the thermal electricity activity while initial estimates for the allocation of other inputs are informed by the cost shares for the different generation technologies in the Peters (2016) database and - for geothermal – on cost share data from Sue Wing (2008) and Lehr et al (2011).[11] Finally, to establish full consistency of the cost entries with the GTAP cost totals by input type and the target electricity sub-activity column sums, a standard bi-proportional RAS matrix balancing algorithm is employed.

The electricity sector decomposition for Ghana splits the sector into TD, hydro and thermal and follows the same procedural approach. The required physical data on power generation by technology for the benchmark year 2011 are drawn from EnCG (2016).

The resulting synthetic cost vectors capture the salient stylized facts with regard to input intensities of the different electricity generation technologies, namely that hydro, geothermal and wind are very capital-intensive and have moderate intermediate input requirements, geothermal is particularly skill-intensive and fossil fuel costs are the dominant cost factor in thermal generation (and more so in high-fossil-price periods such as in the benchmark year 2011).

Table 1 Levelised Cost of Electricity by Technology and Country

	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).

[10] See Table 5 below.

[11] These estimates have been further triangulated with the cost shares employed in related other hybrid top-down bottom-up CGE studies including Capros et al (2013) and Proenca and St Aubyn (2013).

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. The available data sources do not support a consistent rural-urban split. Information on the distribution of factor income is drawn from the Ghana Living Standards Survey (GLSS 6) (GSS, 2014: Section 10). To establish full consistency with the economy-wide functional household income distribution by factor type given by the GTAP database while preserving the GLSS factor income distribution by household quintile, a bi-proportional matrix balancing algorithm is used. In the benchmark year households in the top quintile receive 45.6 percent of total income while the share of the bottom quintile is 5.3 percent. For H1 to H4 the main income source is low-skilled employment (including imputed labour income from self-employment), whereas the dominant income source for H5 is skilled employment. Top quintile households also receive the largest shares of total capital and natural resource rent income. The decomposition of the aggregate household consumption vector by commodity group from the GTAP database uses household expenditure shares by quintile derived from GLSS.

For Kenya, no recent representative household income and expenditure survey is available. The last survey is the Kenya Integrated Household Budget Survey (KIHBS) 2005/06. As the published KIHBS results provides insufficient detail on the income distribution by income type, the household sector decomposition for Ghana draws upon the household disaggregation generated by Kiringai et al (2007) for the KIPPRA-IFPRI SAM, which is based on an earlier survey for 1997 and distinguishes urban and rural households by expenditure decile. Employing such a dated source is obviously unsatisfactory. However, Gakuro and Mathenge (2012:Table 2) show that there is remarkably little change between the 1997 and the 2005/06 expenditure distribution, except for a marked 5 percentage-point gain for the top urban decile primarily at the expense of the ninth and eighth decile and to a lesser extent at the expense of the bottom two deciles. Thus, across broader household aggregates the distribution is almost stable between 1997 and 2005/06, e.g. the share of the top 5 rural deciles remains constant at 75 percent, while the share of the top 5 urban deciles rises modestly from 77 to 79 percent.[12]

[12] An inspection of the corresponding KIHBS and 1997 data in World Bank (2008) and in the UNU-WIDER (2017) WIID database confirms this finding. It must be noted though that over this period the urban share of Kenya's total population has risen from 18.9 to 21.7 percent and further to 24.0 percent in our benchmark year 2011 according to World Bank data.

Correspondingly, the Kenya SAM and model uses a coarse household disaggregation with four household groups – labelled Rural Low, Rural High, Urban Low and Urban High – which represent respectively the bottom and top 50% rural and urban households in the benchmark year. In short, a more detailed household disaggregation is not supported by the available data at this point in time.

3.4. SAM Dimensions

The benchmark SAM for Kenya distinguishes 19 production activities (Table 1), 7 primary production factors including 3 sector-specific natural resource factors (forest, fish and mineral stocks) beside skilled and unskilled labour, capital, and agricultural land and 4 household categories. The Ghana SAM for the benchmark year contains 18 production activities (Table 2), 8 primary factors including oil / gas resource stocks in addition to the same factors as in the Kenya SAM, and 5 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, 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 behavioral parameter database (Hertel and van der Mensbrugghe, 2016). The region-specific income elasticity estimates reported in that source for a representative single aggregated household are further differentiated across the lower and higher income households in the model, e.g. for necessary goods such as food products with an observed higher budget share in low-income households, the initial elasticities are raised vis-à-vis the central GTAP values and vice versa for high-income households and 'luxury' goods.

Given the selection of these free parameters, the various share parameters of the models – including the effective initial direct and indirect model tax rates – are then entirely identified by the benchmark SAMs. Several of the model parameters, such as the factor productivity parameters governing the rate of autonomous technical progress are time-variant in the dynamic simulation analysis. The dynamic calibration of these time-variant parameters is discussed in the context of the description of the dynamic baseline construction process in sections 4 and 5 below.

Table 1: Kenya Model Production Sectors

Short Code	Description	Share in GTAP GDP 2011
Agriculture	Agriculture	0.224
Forestry	Forestry	0.013
Fishing	Fishing	0.006
Mining	Mining and Quarrying	0.006
ProcFood	Food Processing	0.168
BevTob	Beverages and Tobacco	0.093
TexCloth	Textiles, Clothing, Footwear and Leather	0.011
Petrol	Petrol Refining	0.001
Chemics	Chemicals, Rubber and Platic Products	0.009
OLightMnf	Other Light Manufacturing	0.036
OHeavyMnf	Other Heavy Manufacturing	0.018
ElTD	Electricity Transmission and Distribution	0.001
ElGeoTh	Geo-Thermal Electricity Generation	0.002
ElHydro	Hydro Electricity Generation	0.004
ElThermal	Fossil Fuel Based Electricity Generation	0.002
ElWind	Wind Powered Electricity Generation	0.000
Construction	Construction Services	0.035
TradeSv	Trade Services	0.048
TransSv	Transport Services	0.061
OServices	Other Services	0.269

Table 2: Ghana Model Production Sectors

Short Code	Description	Share in GTAP GDP 2011
Agriculture	Agriculture	0.236
Forestry	Forestry	0.007
Fishing	Fishing	0.018
CrudeOil	Crude Oil and Natural Gas	0.063
Mining	Mining and Quarrying	0.008
ProcFood	Food Processing	0.042
BevTob	Beverages and Tobacco	0.010
TexCloth	Textiles, Clothing, Footwear and Leather	0.012
Petrol	Petrol Refining	0.001
Chemics	Chemicals, Rubber and Platic Products	0.008
OLightMnf	Other Light Manufacturing	0.018
OHeavyMnf	Other Heavy Manufacturing	0.031
ElTD	Electricity Transmission and Distribution	0.001
ElHydro	Hydro Electricity Generation	0.008
ElThermal	Fossil Fuel Based Electricity Generation	0.000
Construction	Construction Services	0.138
TradeSv	Trade Services	0.054
TransSv	Transport Services	0.105
OServices	Other Services	0.240

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 3 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 price projections.

Table 3: Schematic Outline of Scenarios for Kenya

	Business as Usual Power Mix	**Lower Carbon Power Mix**
Low Fossil Fuel Prices	*Baseline Scenario* Power mix follows current 10-Year Plan: Rising share of Thermal Falling share of Hydro Constant share of Geothermal Rising but small share of Wind ____________________________ Oil import price 50% below 2011 level; Gas import price 55% below 2011 level	*Lower Carbon Scenario* Falling share of Thermal Falling share of Hydro Rising Share of Geothermal Rising but small share of Wind ____________________________ Oil import price 50% below 2011 level; Gas import price 55% below 2011 level
High Fossil Fuel Prices	*High Fossil Fuel Price Scenario* Power mix follows current 10-Year Plan: Rising share of Thermal Falling share of Hydro Constant share of Geothermal Rising but small share of Wind ____________________________ Oil import price 19% below 2011 level; Gas import price 17% below 2011 level	*Lower Carbon HFFP Scenario* Falling share of Thermal Falling share of Hydro Rising Share of Geothermal Rising but small share of Wind ____________________________ Oil import price 19% below 2011 level; Gas import price 17% below 2011 level

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 10 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 (Table 4). [13]

4.2.1. Population and Labour Force Growth

Population and labour force growth is based on the UN DESA (2015) medium-variant projections commonly used in contemporary long-run scenario studies. According to these projections, the total population of Kenya rises from 42.5 million in 2012 to 58.6 million in 2025. As shown, the scenario takes into account that over this period the annual growth rate of the working-age population – and thus the labour force growth rate in the model under the assumption of a constant participation rate - remains considerably higher than the population growth rate.

4.2.2. Total Factor Productivity and GDP Growth

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) (see Table 4) and by calibrating the TFP parameter of the model dynamically

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[13] The final specification of the baseline scenario benefited from insightful discussions with Helen Osiolo, Bernadette Wanjala, James Gachanja and Nahashon Mwongera (all KIPPRA) during a visit to Nairobi in November 2016.

to match this target growth path. Technically, to obtain the TFP growth path the model is first simulated in a dynamic calibration mode in which GDP is exogenized while the TFP parameter is treated as an endogenous variable. When the model is then simulated in normal mode, with GDP as an endogenous variable and exogenous imposition of the TFP growth path obtained in the dynamic calibration run, the model solution exactly replicates the target GDP growth path.

The GDP baseline scenario growth rates up to 2015 are the reported actual national accounts figure and the projections up to 2018 are taken from KIPPRA (2016). The assumed constant growth rate of 7.5 percent per annum beyond 2018 is an optimistic compromise between the annual growth rate target of 10 percent envisaged in Kenya's aspirational Vision 2030 development plan (Republic of Kenya, 2007) for the same period and the growth rates projected by the CGE model under the assumption that TFP grows at a moderate pace that is more in line with the country's actual observed growth performance over recent years: The average annual TFP growth rate for the period 2011-2015 that is required in the model to replicate Kenya's actual GDP growth reported in Table 4 is 0.8 percent[14] and the corresponding rate for the period 2016 to 2018 is 2.8 percent. To reach the assumed 7.5 percent GDP growth rate beyond 2018, the average annual TFP growth rate needs to rise further to reach 3.3 percent. Thus, the baseline scenario implies a strong acceleration in the growth rate of technical progress, yet the TFP growth rate figures are not entirely implausible, provided a significant portion of the measures to modernize the economy envisaged in the Kenya Vision 2030 are actually implemented over the time horizon considered here. However, GDP growth rates on the order of 10 percent per annum would require TFP growth rates well above 5 percent. Assuming a sustained productivity acceleration of such an order would seem to be unrealistic, given Kenya's actual growth performance under the Vision 2030 plan so far.[15]

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[14] This CGE-model-determined figure matches closely with the corresponding growth-accounting-based estimate of 0.8 percent TFP for Kenya in 2015 and average annual TFP growth of 0.6 percent over the period 2011 to 2015 presented in The Conference Board (2016).

[15] As shown in Republic of Kenya (2013: Table 2.1), in every single year of the first five-year implementation phase (2008/9 to 2012/13) Kenya missed the Vision 2030 GDP growth targets by a wide margin (i.e. by 4.0 to 4.6 percentage *points*). Despite a downward revision of the target rates for 2013 to 2015 (ibid: Table 2.2), Kenya's actual growth performance remained well below target subsequently, and the KIPPRA expert projections for 2016 to 2018 (Table 4 above) are likewise far below the annual 10 percent plan target.

Table 4: Key Features of Dynamic Baseline Scenario - Kenya

	Annual Growth Rates					World Market Prices	
Year	GDP	GDP per cap.	Labor Force	Population	Population	CrudeOil	Natural Gas
	%	%	%		1000	Price Index (2011 = 1)	
2012	4.6	1.9	2.87	2.71	42 543	1.01	1.02
2013	5.7	3.0	2.89	2.70	43 693	0.98	1.23
2014	5.3	2.6	2.93	2.68	44 864	0.89	1.16
2015	5.6	3.0	2.96	2.65	46 050	0.51	0.83
2016	5.7	3.1	2.96	2.61	47 251	0.50	0.44
2017	6.1	3.5	2.99	2.57	48 467	0.50	0.44
2018	6.1	3.6	3.02	2.53	49 695	0.50	0.44
2019	7.5	5.0	3.04	2.50	50 935	0.50	0.44
2020	7.5	5.0	3.05	2.46	52 187	0.50	0.44
2021	7.5	5.1	2.96	2.42	53 448	0.50	0.44
2022	7.5	5.1	2.98	2.38	54 719	0.50	0.44
2023	7.5	5.2	2.98	2.34	56 001	0.50	0.44
2024	7.5	5.2	2.96	2.32	57 298	0.50	0.44
2025	7.5	5.2	2.94	2.29	58 610	0.50	0.44

Sources: GDP growth: 2012, KNBS (2016); 2013-18 KIPPRA (2016); Population and labour force growth: UN DESA (2015), medium-variant projections.

4.2.3. Electricity Sector

The assumed evolution of the power mix in the baseline scenario draws upon Kenya's 10 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 10-Year Plan: This plan considers a high growth scenario with a 'fast-tracked' implementation of a range of energy-intensive Vision 2030 flagship investment projects[16] and a 'moderate load growth scenario' with a 'deferred' implementation of these flagship projects.

The high growth scenario assumes that GDP growth reaches 10.1 percent p.a. by 2018 and accelerates further to 12 percent p.a. by 2024. Effective electricity demand is projected to grow at average annual rate of 17.4 percent between 2015 and 2024 to reach 56,447 GWh by 2024

[16] These include inter alia major investments in iron ore smelting capacity, the eventual electrification of the new standard gauge rail link between Nairobi and Mombasa (initially served by diesel-fuelled locomotives), the development of a large-scale ICT park at Kenzo City south of Nairobi, the establishment of several special economic zones and the development of the Lamu-Port Southern Sudan-Ethiopia Transport (LAPSSET) Corridor project.

(Republic of Kenya, 2014: Table 28) Based on least cost power expansion simulations[17], this scenario proposes a strong expansion in hydro capacity (+74 percent relative to 2013) and massive expansions in geothermal (+1,200 percent), thermal (~ +2,400 percent) and wind (~ +18,600 percent from a tiny base) by 2024 to satisfy this demand growth (Republic of Kenya, 2014: Table 25). The projected domestic generation shares in 2024 under average hydrological conditions in this scenario are 47.2 percent for geothermal, 42.5 percent for thermal, 9.5 percent for hydro and 0.8 percent for wind. The scenario envisages that coal-fired power generation starts in 2016 and then rapidly expands to reach a share of 17.4 percent in total generation by 2024. With respect to the plausibility and economic viability of this scenario, the Plan itself states that

> "under the fast-tracked scenario, there would be a huge power surplus if demand does not grow fast enough which could lead to stranded investments and/or high power tariffs. Additionally, the report reveals that high cost technologies such as the thermal power plants particularly those planned for commissioning in 2014 may be poorly dispatched in the medium to long term while base plants such as coal and LNG may end up being run at below optimal levels of less than 70%" (Republic of Kenya, 2014:5).

According to the latest KNBS (2016b) figures actual electricity generation in 2015 was some 30 percent below the corresponding 2015 projection under this scenario and the plans for the construction of Kenya's first coal-fired power plant in Lamu as well as related plans for the exploitation of domestic coal resources detected in the Mui Basin are on hold.[18] Thus, the 10-Year Plan's high growth scenario provides no suitable basis for the development of a plausible baseline scenario for purposes of the present study.

The 'moderate load growth' scenario of the 10-Year plan assumes that annual GDP growth rises to 10 percent by 2020 and that the economy continues to grow at that rate up to 2024. The aforementioned flagship investments are implemented slightly later than in the high growth scenarios and the connection rate reaches 60 percent by 2024. Effective electricity demand is projected to grow at average annual rate of 15.5 percent between 2015 and 2024 and reaches 38,413 GWh by 2024 (Republic of Kenya, 2014: Table 33). Hydro capacity is projected to jump by 61 percent in 2019 relative to a constant 2014-2018 level with no further expansion up to 2024, geothermal capacity expands by 288 percent between 2014 and 2024, thermal by 322 percent, and wind generation capacity expands by a factor of 24.5 relative to the small 2014 level (Republic of Kenya, 2014: Table 32). The projected domestic generation shares in

[17] These simulations are an update of the earlier 2013 Least Cost Power Sector Development Plan (Republic of Kenya, 2013b).

[18] See Praxides (2016) and Kenya Engineer (2016).

2024 in this scenario are 48.2 percent for geothermal, 39.2 percent for thermal, 11.7 percent for hydro and 0.8 percent for wind. Coal-fired power plants start operating from 2019 and reach a share of 20.9 percent in total domestic electricity generation by 2024.

As discussed in section 4.2.2 above, our baseline scenario is an optimistic scenario but uses lower GDP growth projections than the 10-Year Plan's so-called 'moderate load growth scenario'. Correspondingly, the electricity demand growth projected by the CGE model - which equates to an annualized average growth rate of 12.8 percent over the period 2015 to 2025 - is significantly below the Plan's average annual growth rate of 15.5 percent. In absolute terms, this demand growth differential translates into a marked difference between the 2025 CGE-model-based baseline projection of 35,641 GWh (Table 5) for domestic supply and a one-year forward projection of the Plan's 2024 domestic supply, which amounts to nearly 44,000 GWh.[19] It is noteworthy, that this difference is larger than the entire projected coal-based generation for 2024 (7,965 GWh) according to the Plan. Thus, no coal-fired power-plants at all are required in our baseline scenario.

Table 5: Domestic Electricity Generation by Type – Baseline Scenario

Electricity Generation (*GWh*)					
Year	Total	Hydro	Geothermal	Thermal	Wind
2011	7250	3427	1453	2352	18
2015	10675	3427	5333	1868	47
2020	22735	4466	11343	6829	97
2025	35641	4466	18331	12529	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

Sources: All figures for 2011 and all GWh 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. Actual provisional 2015 figures in KNBS (2016b) released after the completion of the baseline construction: Total: 9456 GWh, Hydro: 3463 GWh (36.6%), Geothermal: 4521 GWh (47.8%), Thermal 1412 GWh (14.9%).

[19] Projected total supply (=effective demand) for 2024 is 38,413 GWh and projected 2024 imports are 356GWh (Republic of Kenya, 2014: Table 33). (38,413 – 356)(1+0.155) = 43,956.

As shown in Table 5, the baseline scenario assumes that hydro, geothermal and wind generation evolves in line with the moderate load growth scenario of the 10 Year Power Sector Expansion Plan[20] 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 to 2025 are broadly in line with the 10-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 to 2015, 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 one percent.

The main difference to the Plan scenario is that, due to the lower overall electricity demand growth, the baseline 2025 thermal share is slightly lower (35.2 versus 39.2 percent) and greener as it contains no coal-fired generation.

According to the moderate load growth scenario, the share of diesel within total non-coal thermal generation, which was 100 percent in the benchmark year 2011, drops markedly to 58 percent in 2015 and further to 14 percent in 2024 as diesel-fired generation is replaced by gas-fired generation. However, as the recent cancellation of the planned Dongu Kundu gas power station project indicates[21], such a shift appears unlikely to happen within the time horizon of the present study. Thus the baseline scenario assumes that thermal generation continues to remain entirely heavy-fuel-oil-fired. Nevertheless the cost disadvantage of thermal relative to geothermal drops significantly relative to the initial 2011 differential as a result of the assumed permanent oil price drop.

The baseline scenario captures the increase in household connectivity rates and the additional increase in commercial electricity demand assumed in the 10-Year Plan in a stylized form through gradual exogenous increases in the model parameters governing the shares of electricity consumption in total household consumption[22] and in intermediate consumption.

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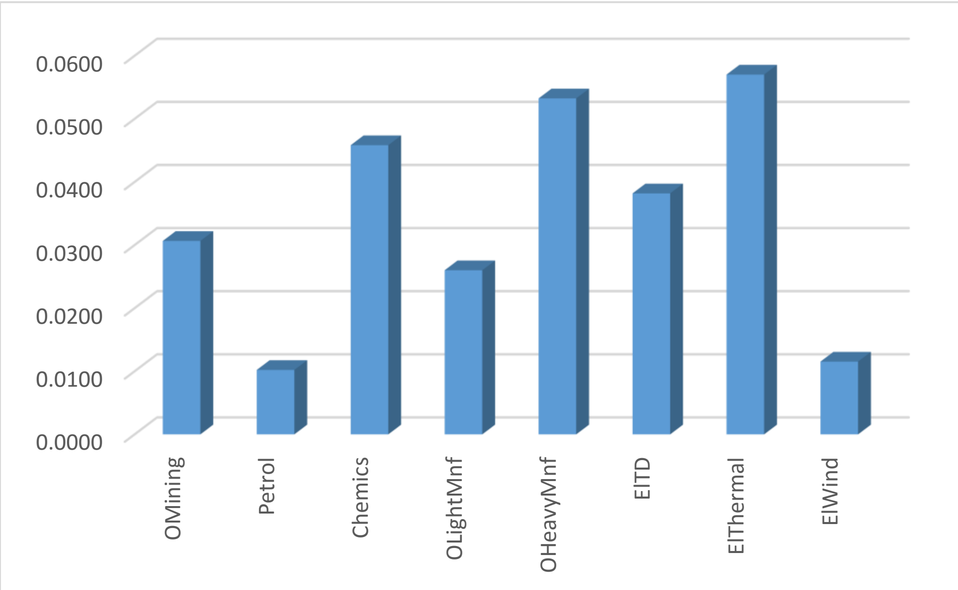
[20] With a slight lag over the 2021-2025 period, so that the Plan's generation figures for 2024 are realized in year 2025 of the baseline scenario.

[21] See Okuti (2016).

[22] As a technical aside for readers interested in the mechanics of the CGE model, this requires a recalibration of all other LES demand system parameters at each annual time step of the dynamic solution loop in order to maintain the theoretical consistency of the model. It is also worth noting in this context that the budget shares of electricity in total household spending in the model would increase even in the absence of exogenous shifts in the marginal

The additional increases in commercial electricity demand due to the promotion of the said Kenya Vision 2030 flagship projects and due to wider across-the-board shifts to more electrified modes of production as the Kenyan economy develops are captured in the CGE model via gradual increases in the electricity input-output coefficients for sectors where the 2011 GTAP electricity input-output coefficients are well below the average across lower middle income countries in the GTAP database. Shifts to more electrified modes of production reduce the need for physical labour and basic capital inputs to some extent, and so the technology parameters governing the demand for primary factors are gradually revised downwards accordingly in these sectors. Figure 2 displays the baseline 2025 shares of electricity in total production cost for all sectors in which this share exceeds one percent.

Figure 2: Share of Electricity Cost in Total Baseline Production Cost 2025 – Selected Sectors



budget share parameters, as the assumed income elasticities of household demand for electricity for Kenya (see section 3 above) are well above unity across all household categories.

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 GGDA project by Pueyo et al (2016) identifies geothermal electricity generation as the most promising technology option for Kenya. This assessment is in line with Kenyan government's own assessment in the 10 Year Power Sector Expansion Plan:

"In Kenya, more than 14 high temperature potential sites occur along Rift Valley with an estimated potential of more than 10,000 MW. 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 percent 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 percent in the 2025 baseline to 11.6 percent (Table 6 and Figure 3a). The hydro and wind shares remain unchanged. In absolute terms, this assumed expansion of geothermal electricity generation by 2025 is very close to the 10 Year Plan's least-cost high growth scenario, in which geothermal is projected to generate 26,000 GWh by 2024.

Table 6: 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
2016	52.7	17.6	52.7	17.6
2017	53.9	18.9	53.9	18.9
2018	51.9	24.2	58.7	17.4
2019	50.7	27.6	62.4	15.9
2020	49.9	30.0	65.4	14.6
2021	50.8	30.8	68.7	12.9
2022	51.4	31.7	71.3	11.8
2023	51.7	32.6	73.2	11.2
2024	51.7	33.8	74.4	11.1
2025	51.4	35.2	75.0	11.6

For a proper interpretation of this scenario it is important to emphasize that 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 (Figure 3b).

Figure 3a: Power Mix in Baseline and Lower Carbon Scenario

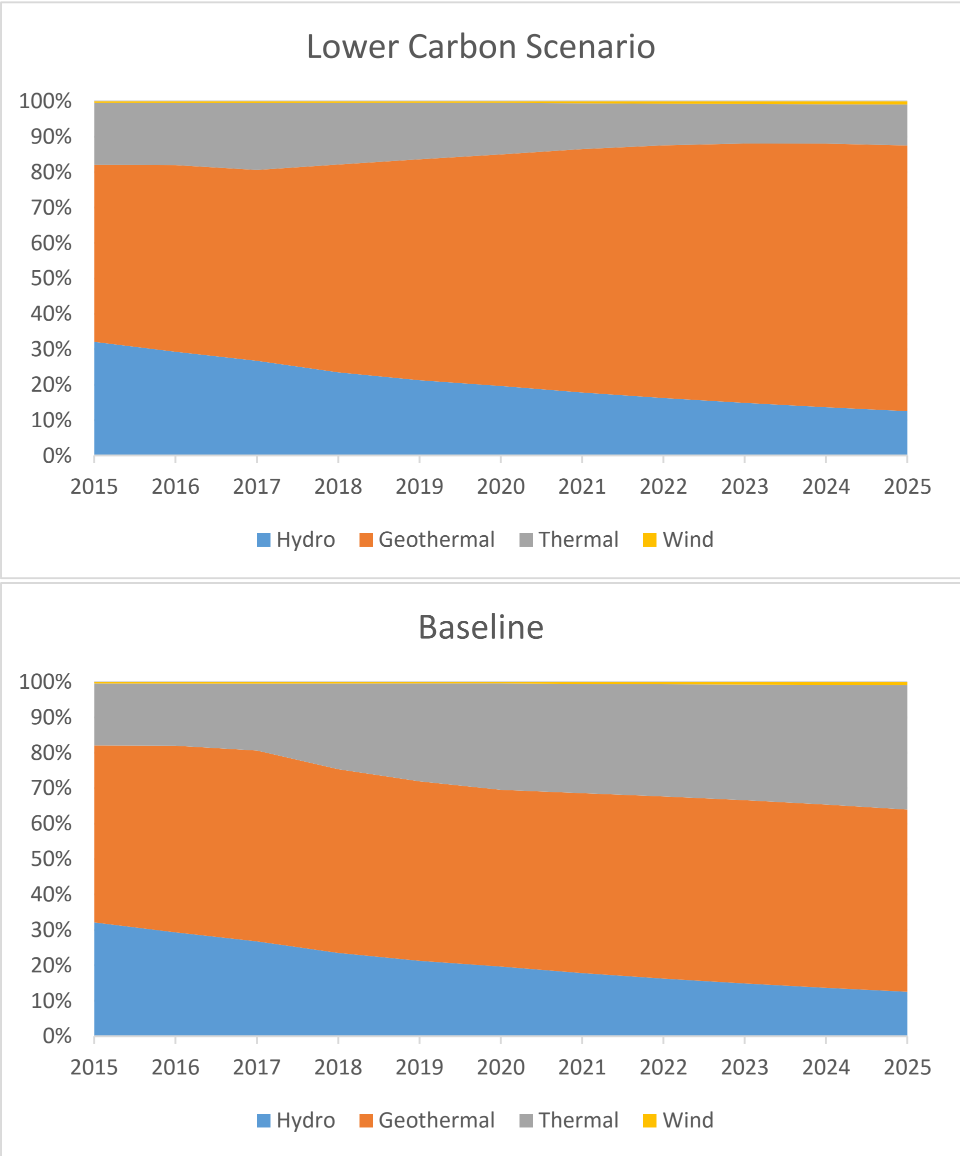
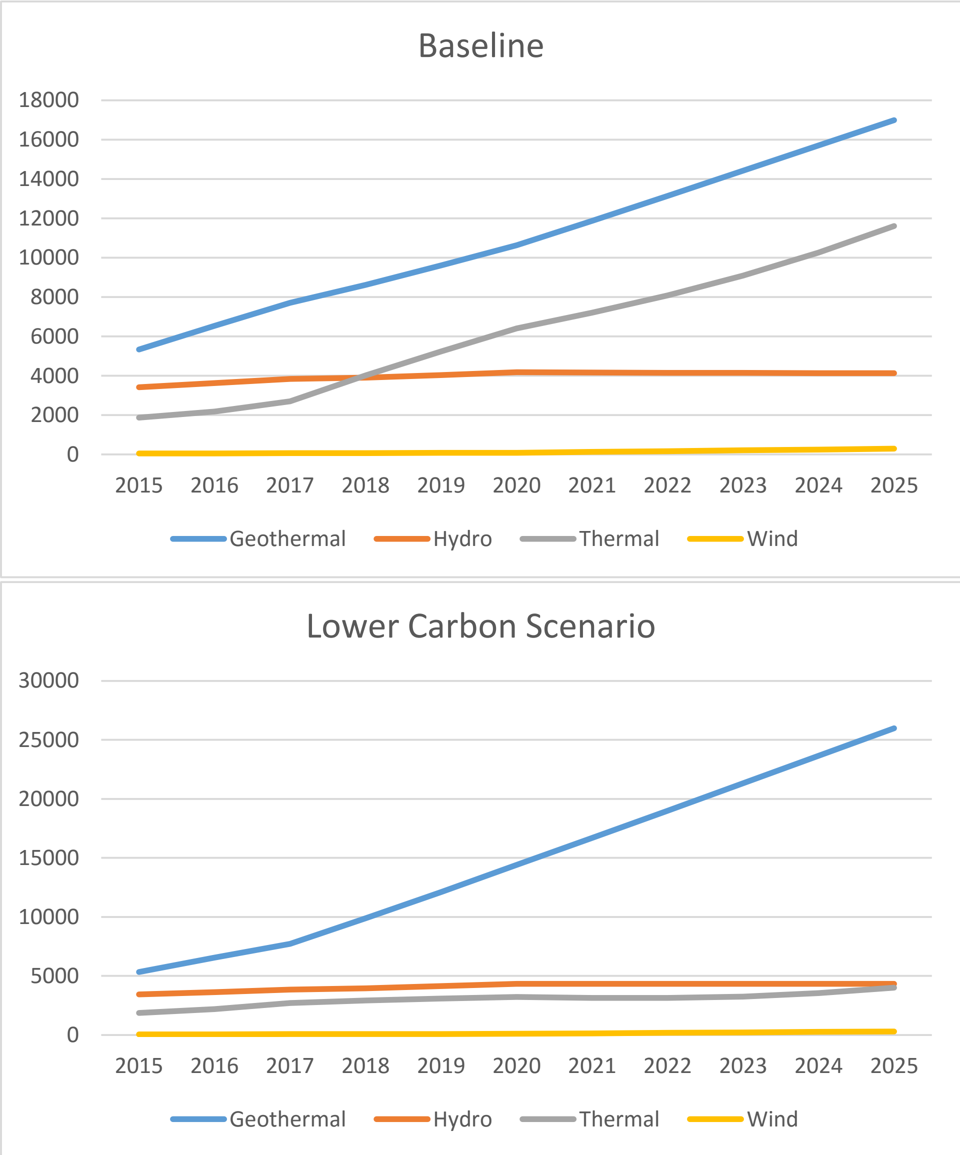


Figure 3b: Annual Electricity Generation in Baseline and Lower Carbon Scenario

(in GWh)

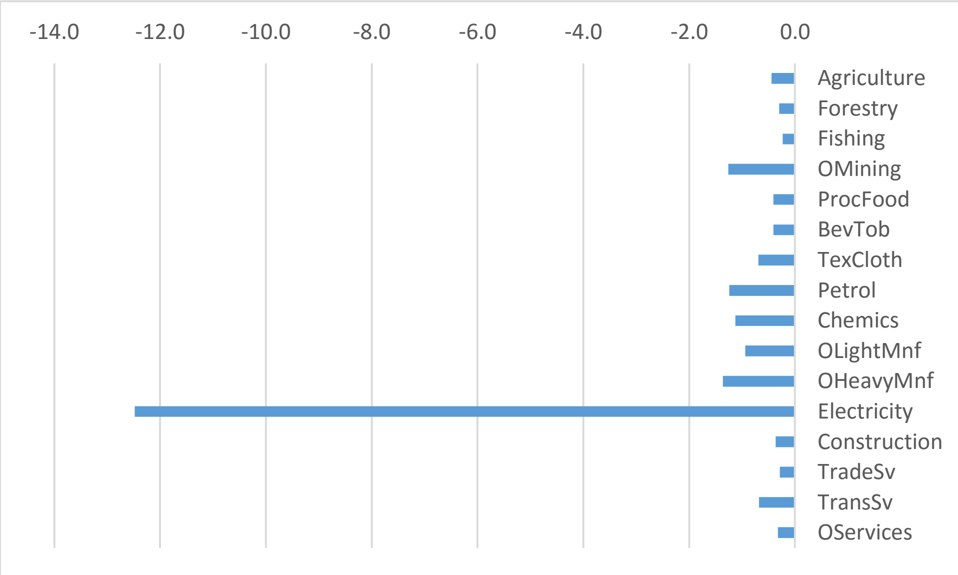


4.3.2. Results

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. As shown in Figure 4, in 2025 the domestic electricity price – here expressed relative to the equilibrium wage of unskilled workers – is over 12 percent 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 (Figure 4) such as mining, the chemical industry and heavy manufacturing than in sectors with a low power intensity.

Figure 4: Impact on Domestic Producer Prices – Lower Carbon Scenario 2025

(Percentage deviation of price relative to unskilled wage from 2025 baseline)



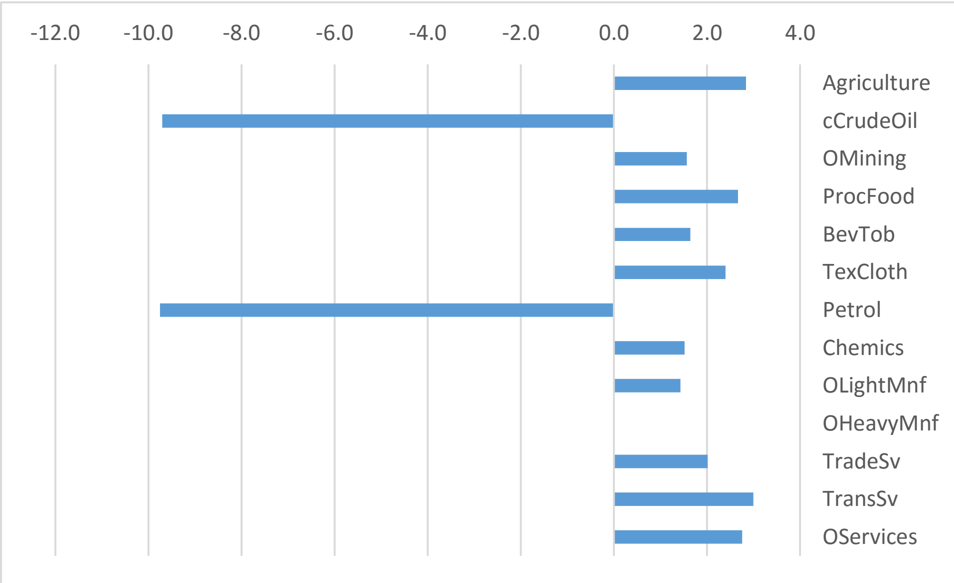
The assumed low carbon transition entails a strong reduction in fossil fuel imports. Both refined petrol and crude oil imports drop by nearly ten percent in volume terms relative to the baseline scenario towards 2025 (Figure 4). The indirect effect on crude oil imports arises due to the fact that in 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 Draft (Republic of Kenya, 2015) and as part of the aforementioned LAPSSET flagship development. 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 percent. The real appreciation lowers in tendency 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. This substitution effect affects both imports of final goods and intermediate inputs.

A further positive effect on imports across all final goods arises due the positive aggregate real income effects associated with the shift towards lower-cost electricity generation shown below. Thus, Figure 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 according to Figure 4.

Figure 5: Impact on Real Import Volumes by Commodity Group – Lower Carbon Scenario 2025

(Percentage deviation from 2025 baseline)



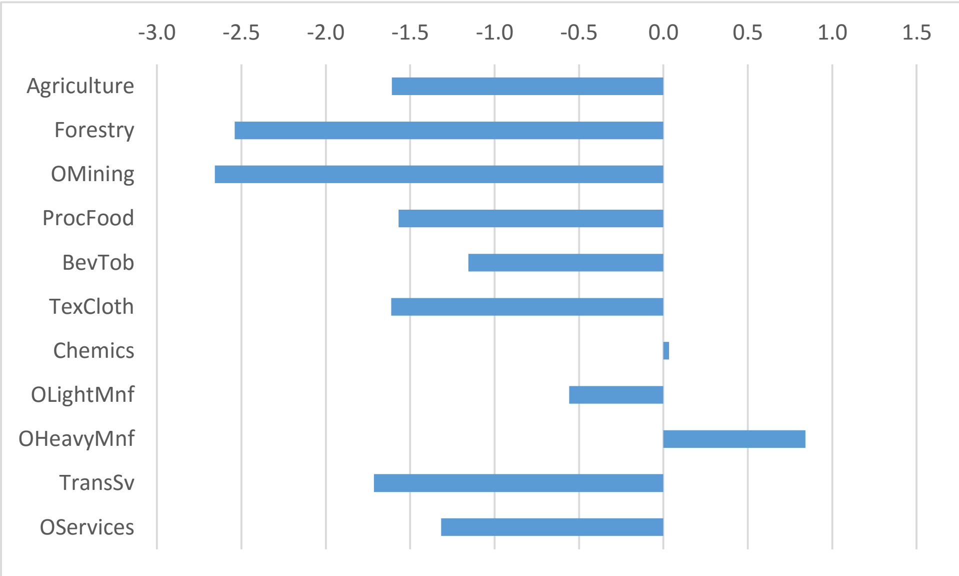
Note: This figure excludes commodity groups with negligible shares in Kenya's total imports.

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-maximizing output mix between export and home market production in favour of the latter. Correspondingly, Figure 6 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 shown in Figure 5 and 6 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.

Figure 6: Impact on Real Export Volumes by Commodity Group – Lower Carbon Scenario 2025

(Percentage deviation from 2025 baseline)



Note: The figure excludes commodity groups for which both the baseline share in total export revenue is small (<2.5 percent) and the export/output share is small (<10 percent).

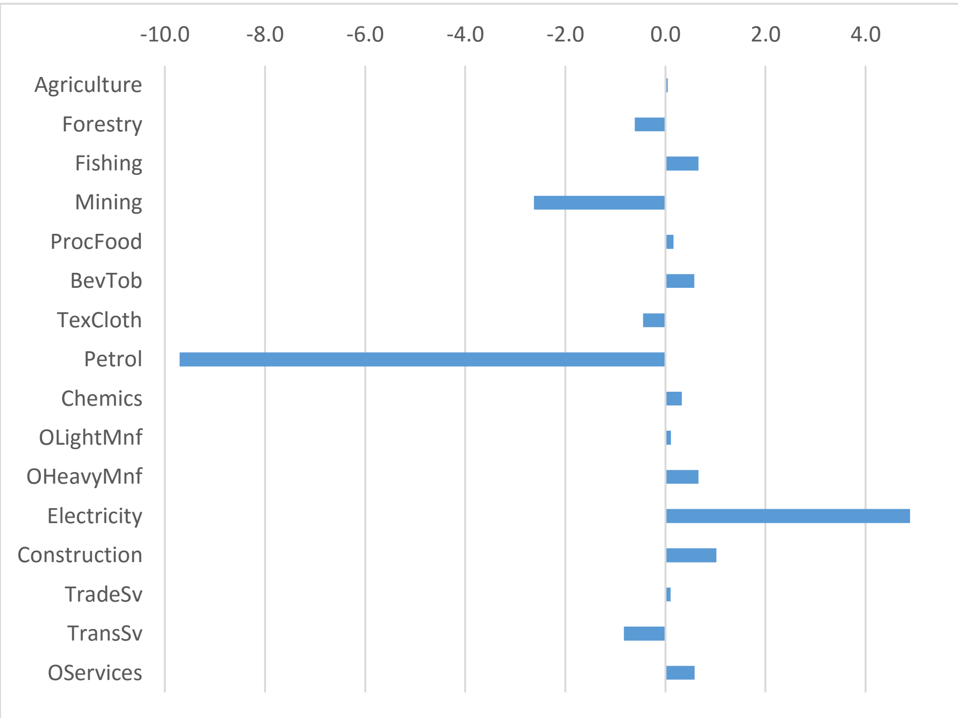
The equilibrium impact on real gross output by production sector for 2025 compared to the baseline scenario is shown in Figure 7. The sectoral employment effects have the same direction and broadly the same orders of magnitude, and are therefore not separately plotted. Not surprisingly, in percentage 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. However in relation to total employment the associated employment reallocation effects are tiny. The domestic power sector expands as the drop in electricity prices induces additional demand.

It is worth emphasizing that no sector contracts in absolute terms and thus no sector sheds existing workers along the dynamic scenario time path. A negative-signed output effect in Figure 7 merely indicates that the sector grows at a lower rate and that new workers are hired a slower pace than in the baseline scenario. E.g., while the domestic refining sector at the 2025 endpoint of the simulation horizon is projected to be nearly 10 percent smaller than in the baseline scenario for the same year, the sector is still 127 percent larger in 2025 than in 2027.

In line with economic theory, the real exchange appreciation shifts in tendency 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 percent and an import share of over 50 percent 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 are heavy manufacturing, which – as noted earlier – are among the most electricity-intensive sectors and thus benefit disproportionally from the reduction in energy input costs. However, the main message from Figure 7 is that the effects of the assumed low carbon transition on the sectoral composition of output and employment are very moderate.

Figure 7: Impact on Real Output by Sector – Lower Carbon Scenario 2025

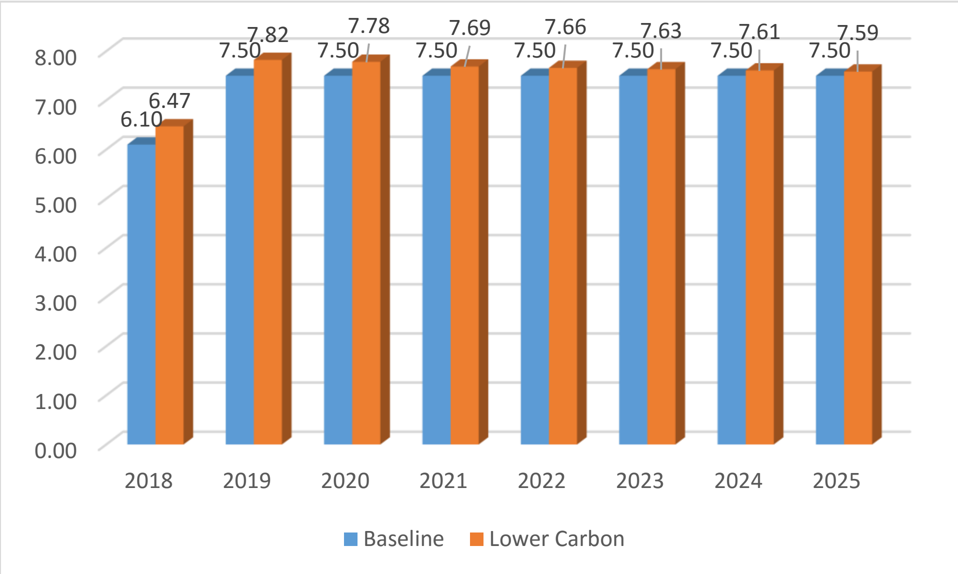
(Percentage deviation from 2025 baseline)



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 8. Like in a standard Solow growth model, the long-run growth rate in this multi-sectoral dynamic CGE model is exogenously determined by the sum of the aggregate growth rate of technical progress and the labour force growth rate. As these rates remain the same as in the baseline, the annual GDP growth rate in a hypothetical dynamic long-run equilibrium without further changes in exogenous parameter would eventually converge back to the baseline growth rates, yet the positive effect on the level of GDP is of course permanent along such a steady state path. The cumulative effect of the small annual growth rate increments reported in Figure 8 over the period 2018 to 2025 entails that the level of real GDP by 2025 is 1.1 percent higher than in the baseline scenario.

Figure 8: Annual Growth Rate of Real GDP – Baseline and Low Carbon Scenario

(in Percent)



Turning to the effects on the functional income distribution – that is the distribution of primary income by type of factor – Figure 9 displays the impacts on real factor prices (i.e. nominal factor prices deflated by the consumer price index) in 2020 and 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 arise from factor intensity differentials between sectors that grow quicker and sectors that grow slower than in the baseline (recall Figure 7): 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.

The natural resource rent drop is due to the growth slow-down of the domestic mining sector which is the sole user of the mineral endowment factor in the model. The reason for the reversal of the effect on agricultural land rents is related to the fact that electricity use in agriculture is initially very low but grows over time with technical progress and the rise in rural access rates. Thus, agriculture initially benefits very little from the drop in electricity prices while being hit by the exchange rate appreciation effect on agricultural exports and imports (Figure 5 and 6). As a result, agricultural output drops marginally (by 0.1 percent) below baseline levels over the initial period up to 2020 but then recovers subsequently (and ends up 0.1 percent above base level by 2025) as the direct and indirect[23] input cost reduction effects become more pronounced over time.

For households with a single source of factor income, Figure 9 directly indicates the direction of the effects on total factor income. Figure 10 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 disproportionally.

In other words, as far as this rather coarse-grained distributional analysis based on outdated underlying raw data goes, the low-carbon transition has a pro-poor effect in an absolute or "weak" sense (namely that 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 disproportionally).[24]

[23] E.g. the drop in chemical fertilizer prices.

[24] See Willenbockel (2015) for critical reflections on the recent literature concerned with pro-poor low-carbon development in this context.

Figure 9: Impact on Factor Returns – Low Carbon Scenario

(Percentage deviation of factor prices relative to CPI baseline level 2020 and 2025)

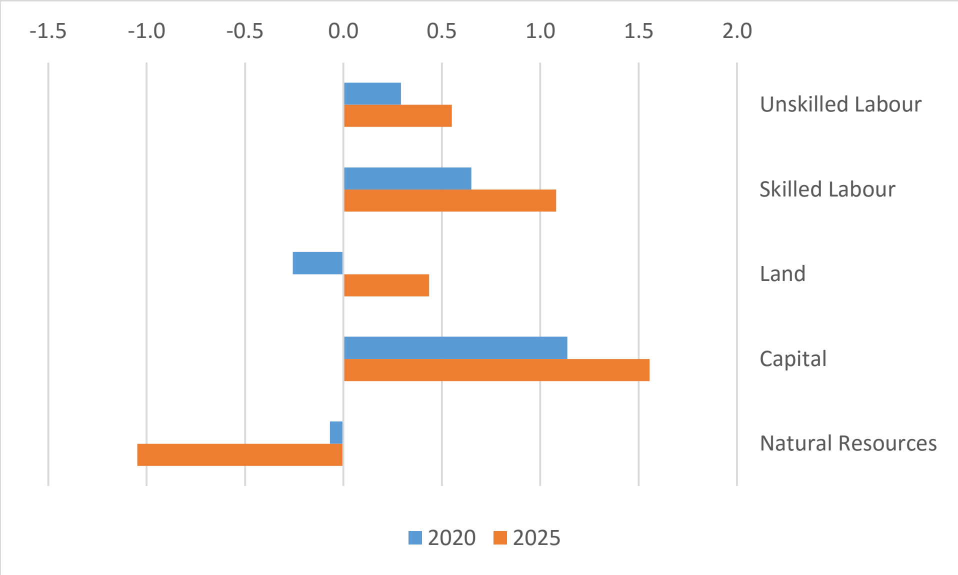
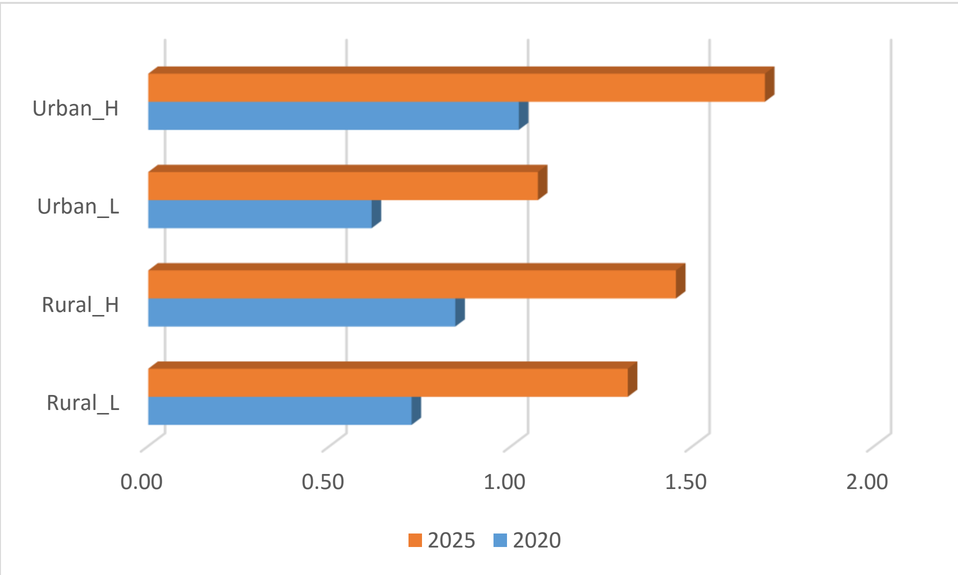


Figure 10: Impact on Real Household Income – Low Carbon Scenario

(Percentage deviation from Baseline level 2020 and 2025)



4.4. High Fossil Fuel Price Scenario

As the cost differentials between thermal and renewable technologies are necessarily contingent on the assumptions about future fossil fuel 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, section 4.5 assesses 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 percent higher than the 2018 baseline price (but still 19 percent lower than the 2011 benchmark price) and then stay put at that level beyond 2018.[25]

The high fossil fuel price scenario under *baseline* assumptions about the power mix provides the relevant reference scenario for comparison with the high-fossil-fuel-price (HFFP) lower carbon scenario presented in the following section. In other words, this reference scenario serves to enable an analytical separation of impacts due to exogenous changes in the power mix from the HFFP impacts. 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.

Figure 11 displays the effects on domestic supply prices in 2025 relative to the baseline. Not surprisingly, the size orders of the sectoral price effects are highly correlated with the sectoral baseline energy cost (i.e. direct fossil fuel cost plus electricity cost) shares in total production costs: As shown in Figure 12, the cross-sectoral variation in baseline energy cost shares explains nearly 98 percent of the cross-sectoral variation in the price impacts.

These price increases entail a marked growth slow-down in the most affected sectors (in particular mining, petrol, electricity and transport services). 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

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[25] International gas prices also return to a higher level (Table 3), but in the case of Kenya assumptions about the gas import price matter very little as gas imports remain tiny under the maintained assumption that thermal generation continues to be oil-fired over the simulation horizon.

welfare-reducing terms-of trade shock requires a real exchange depreciation on the order of 7.6 percent by 2025 relative to the baseline. The depreciation effect discourages imports and stimulates exports. The sectors that expand in relation to the baseline are sectors with both low energy cost shares and relatively high initial export-output ratios, in particular agriculture, food processing, and textiles and clothing. In those sectors, the stimulating export growth effect due to the exchange rate depreciation dominates the output-depressing rise in energy costs.

The effects on GDP growth are displayed in Figures 13 and 14. 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 percent below base (Figure 14).

The real income loss is reflected in a slower growth of real wages, capital returns and natural resource rents. Because of the marked growth slow-down in the mining sector, the drop in resource rents is particularly pronounced. Only the real returns to land rise relative to the baseline as a result of the afore-mentioned increase in agricultural output and exports. This effect is reinforced by the expansion of food processing exports, which raises the demand for agricultural output further via backward linkage effects.

Figure 11: Impact on Domestic Producer Prices - High Oil Price Scenario 2025

(Percentage deviation of price relative to unskilled wage from 2025 baseline)

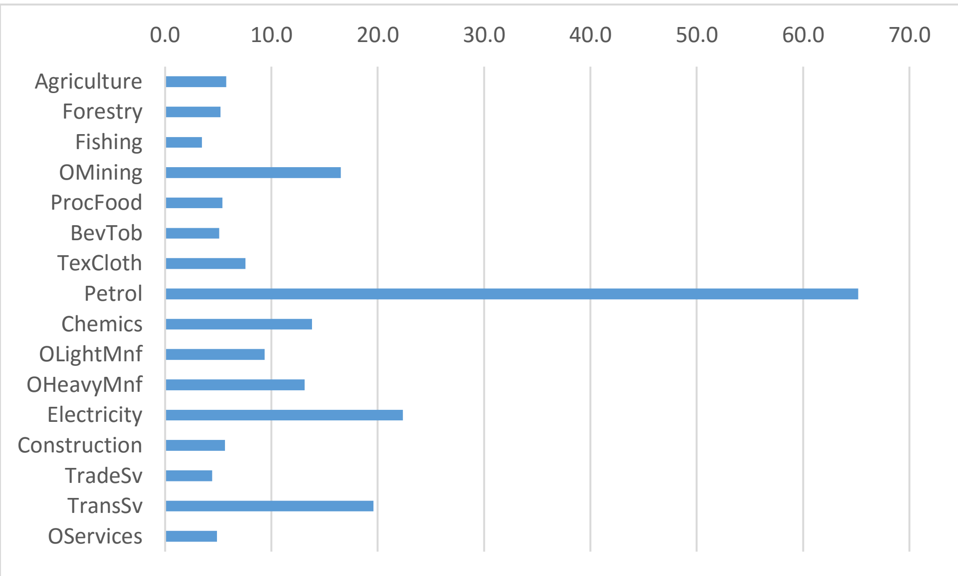


Figure 12: Correlation between Domestic Supply Price Changes and Baseline Energy Cost Shares 2025 – HFFP Scenario

(dPX: Deviation of 2025 domestic supply prices from baseline in percent)

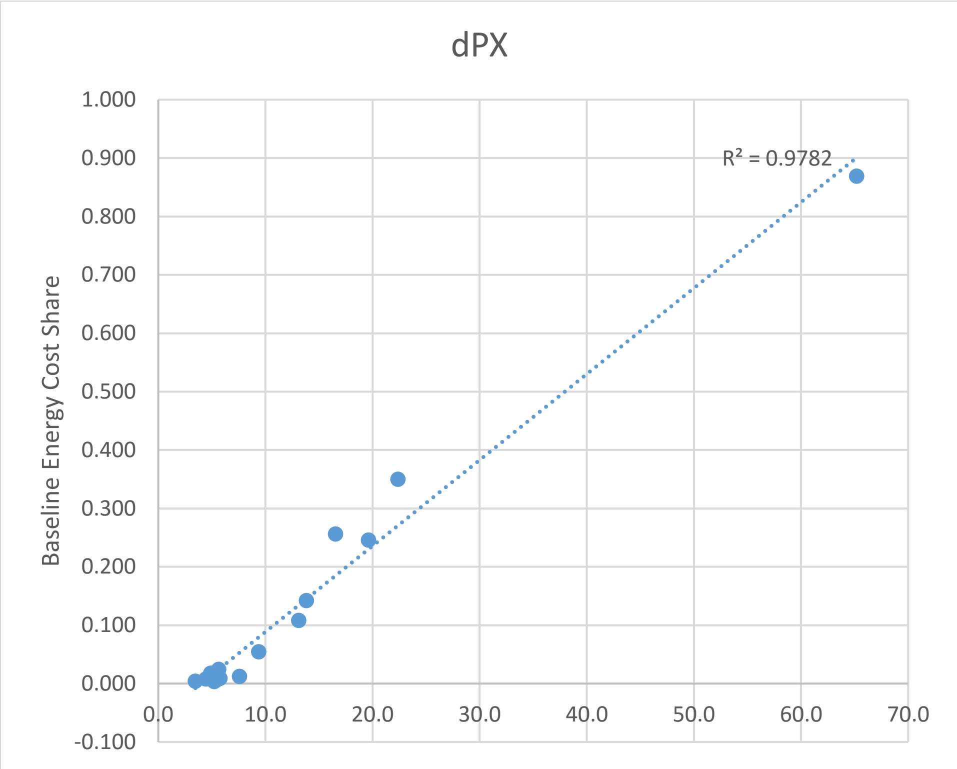


Figure 13: Annual Growth Rate of Real GDP – Baseline and High Oil Price Scenario

(in Percent)

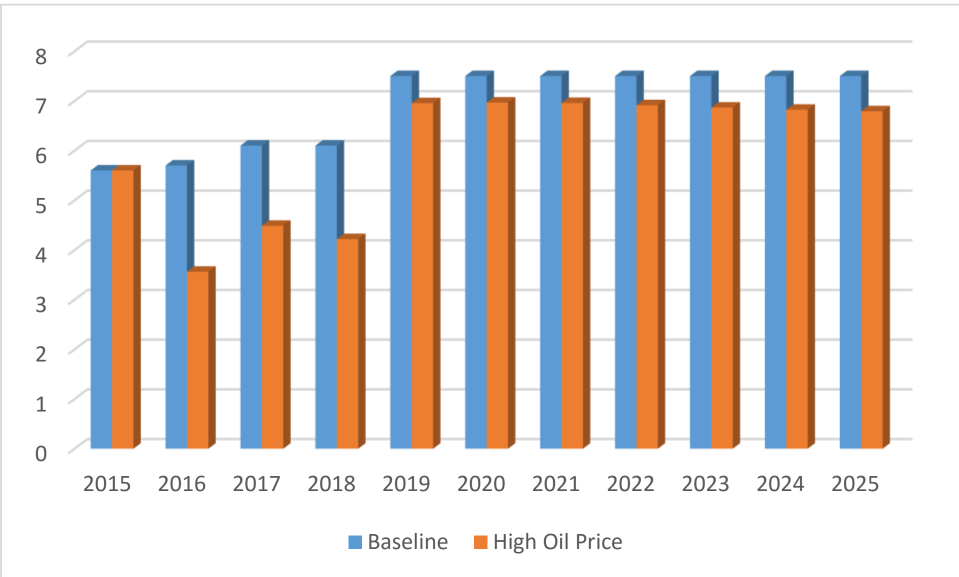
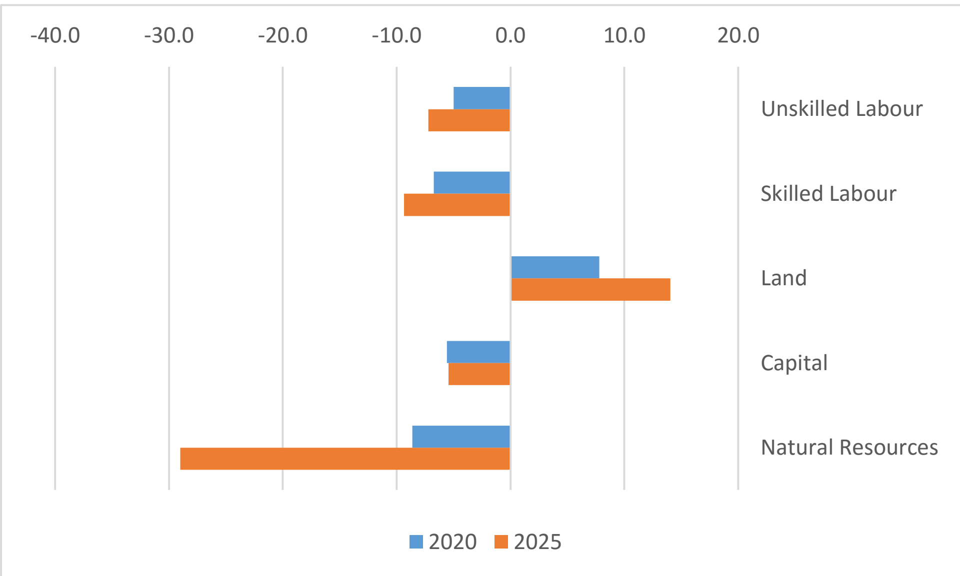


Figure 14: Level of Real GDP 2015 to 2025 - Baseline and High Oil Price Scenario

(Index, 2015 = 1.0)

Figure 15: Impact on Factor Returns - High Fossil Fuel Price Scenario

(Percentage deviation from Baseline level 2020 and 2025)



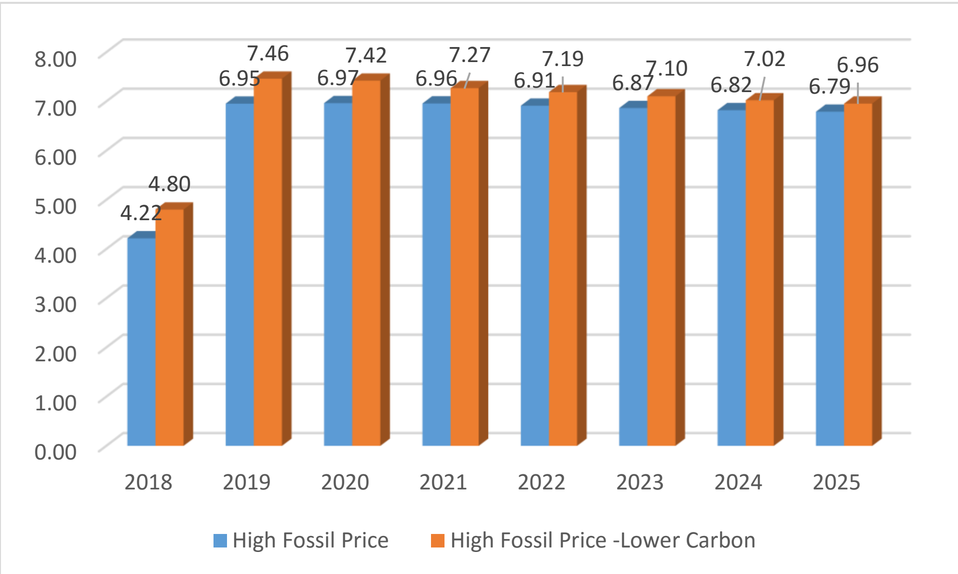
4.5. HFFP Lower Carbon Scenario

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 (Figure 16 and Figure 8). The cumulative effect of the increases in annual GDP growth means that by 2025 GDP is 2.6 percent 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 percent.

The real exchange rate appreciation associated with the lower dependency on fossil fuel imports is on the order of 1.2 percent by 2025 and thus likewise slightly more pronounced than the corresponding real appreciation of 0.7 percent reported in section 4.3. As illustrated by Figure 17 for domestic producer prices, 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.

Figure 16: Annual Growth Rate of Real GDP – High Fossil Fuel Price Lower Carbon Scenario

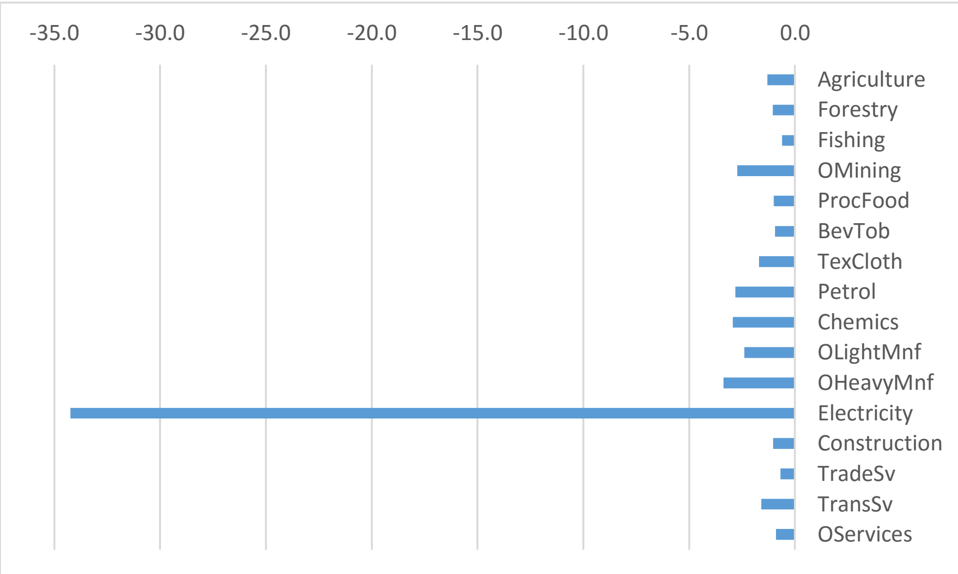
(in Percent)



The same conclusion applies to the impacts on the functional income distribution (Figure 18), except for the impact of the low-carbon transition on the real returns to agricultural land. As discussed in section 4.4, 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, whereas Figure 9 reports a reversal of the impacts on real land rents between 2020 and 2025 as discussed in section 4.3.

Figure 17: Impact on Domestic Producer Prices – High Fossil Fuel Price Lower Carbon Scenario 2025

(Percentage deviation of price relative to unskilled wage from 2025 baseline)

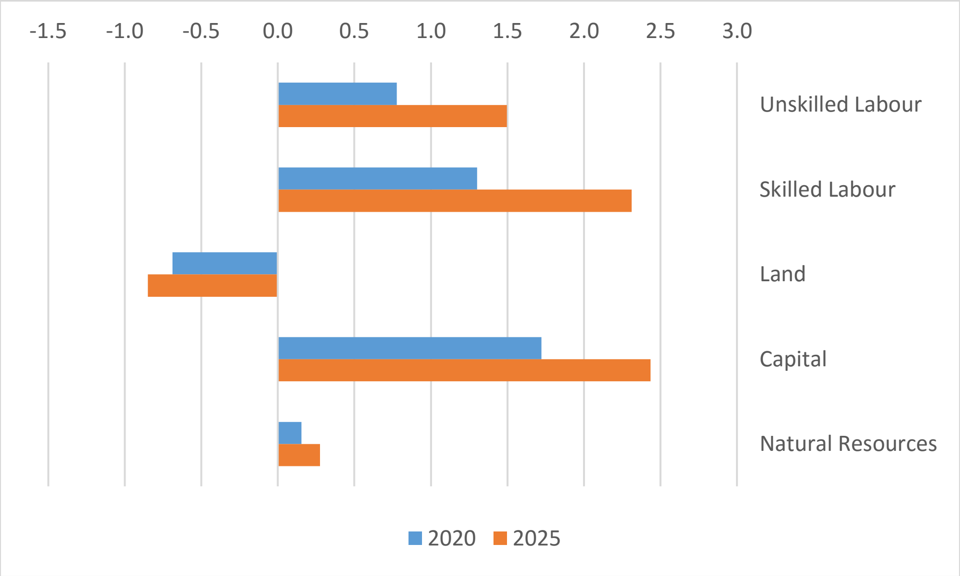


To sum up, the results of the sensitivity analysis presented here confirm the findings of section 4.3. A higher of share of low-cost geothermal in the power mix reduces electricity prices and mildly stimulates economic growth. The associated reduction in the fossil fuel import bill triggers a moderate 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. All household groups gain, but urban and rural higher-income households gain relatively more than urban and rural low-income households, as skilled real wages and real returns to capital rise slightly more than unskilled wages and returns to land. Impacts on the sectoral composition of real output and employment are generally small. In tendency, sectors with a higher baseline share of electricity costs in total production cost and lower trade shares expand relative to sectors with a low electricity cost share and with less exposure to international trade.

Moreover, the results in this section demonstrate that the size of the beneficial aggregate effects depends on the evolution of fossil fuel prices over the simulation horizon: Under the Lower Carbon scenario, real GDP in 2025 is about 1.1 percent higher than in the Baseline scenario. Under the Lower Carbon High Fossil Fuel Price scenario, real GDP in 2025 is more than 2 percent higher than in the High Fossil Fuel Price scenario.

Figure 18: Impact on Factor Returns – High Fossil Fuel Price Lower Carbon Scenario

(Percentage deviation from High Fossil Fuel Price Scenario 2020 and 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. We consider again 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 7 outlines the alternative scenario assumptions along these two dimensions. The specification of the lower carbon scenarios is again motivated by the results of the comparative LCOE analysis by Pueyo et al (2016, 2017)

Table 7: Schematic Outline of Scenarios for Kenya

	Baseline Power Mix	**Lower Carbon Power Mix**
Low Fossil Fuel Prices	*Baseline Scenario* Rising share of Thermal Falling share of Hydro ——————————— Oil import price 50% below 2011 level; Gas import price 55% below 2011 level	*Lower Carbon Scenario* 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
High Fossil Fuel Prices	*High Fossil Fuel Price Scenario* Rising share of Thermal Falling share of Hydro ——————————— Oil import price 19% below 2011 level; Gas import price 17% below 2011 level	*Lower Carbon HFFP Scenario* 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

5.2. Baseline Scenario

The construction of the baseline scenario starts from the 2011 benchmark SAM for Ghana outlined in section 3. For the period up to 2015, the forward projection takes account of recent available data observations, while the projections from 2016 to 2025 draw upon expert forecasts for the for the determination of the main model-exogenous drivers of economic growth (Table 8).[26]

4.2.1. Population and Labour Force Growth

Population and labour force growth is based on the UN DESA (2015) medium-variant projections commonly used in contemporary long-run scenario studies. According to these projections, the total population of Ghana rises from 25.5 million in 2012 to 33.7 million in 2025. As shown, the scenario takes into account that over this period the annual growth rate of the working-age population – and thus the labour force growth rate in the model under the assumption of a constant participation rate - remains considerably higher than the population growth rate.

5.2.2. Total Factor Productivity and GDP Growth

The time path for the annual TFP growth rate is determined indirectly by imposing a target growth path for Ghana's real GDP (Table 8) and by calibrating the TFP parameter of the model dynamically to match this target growth path as further explained in section 4.2.2 above.

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, which is consistent with a plausible slightly decelerating TFP growth trend. The growth rates imply that aggregate GDP in 2025 is 2.68 times higher than in 2011 and per-capita GDP doubles over this period.

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[26] The final specification of the baseline scenario benefited from clarifying discussions with S. Bawakyillenuo and ISSER colleagues (who also provided access to additional GLSS data) during a visit to Accra in December 2016.

5.2.3. Electricity Sector and Domestic Natural Gas Extraction

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, 2010), the Ministry of Petroleum's Gas Master Plan (Republic of Ghana, 2015a), the Ghana SREP (Republic of Ghana, 2015b), and is also informed by a range of other sources including World Bank (2013), EnRC (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 19); (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 percent 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. According to the model-generated power demand projection, around 35,000 GWh of thermal generation would be required in 2025 under the baseline assumption of a constant hydro capacity. About 350 billion cubic feet (bcf) of natural gas would be required to generate this amount of electricity. The Gas Master Plan's most optimistic 'balanced high case' scenario projects 216 bcf for Ghana's domestic natural gas production in 2025, and a 'balanced base case' scenario forecasts 111 bcf for the same year (Republic of Ghana, 2015a: Tables 43 and 41). At the midpoint between these two supply projections about 45 percent of the electricity sector's natural gas demand could be satisfied from domestic sources by 2025.

Technically these changes over the simulation horizon are implemented in the CGE model by shifts in the parameters governing the gas import share and the share of natural gas output (which is virtually zero in the initial 2011 benchmark equilibrium) in the total output of Ghana's oil-gas extraction sector from 2018 onwards together with corresponding shifts in the sector's natural resource factor supply, and by shifts in the thermal electricity sector's input-output parameters for crude oil[27], natural gas and refined petrol.

As in the Kenya study, the baseline scenario captures increase in household connectivity rates in a stylized form through gradual exogenous increases in the model parameters governing the shares of electricity consumption in total household consumption. Shifts to more electrified modes of production as the Kenyan economy develops are captured in the CGE model via gradual increases in the electricity input-output coefficients for sectors where the 2011 GTAP electricity input-output coefficients are well below the average across lower middle income countries in the GTAP database. Again, shifts to more electrified modes of production reduce the need for physical labour and basic capital inputs to some extent, and so the technology parameters governing the demand for primary factors are gradually revised downwards accordingly in these sectors.

Table 8: Key Features of Dynamic Baseline Scenario – Ghana

	Annual Growth Rates					**World Market Prices**	
Year	**GDP**	**GDP per cap.**	**Labor Force**	**Population**	**Population**	**CrudeOil**	**Natural Gas**
	%	*%*	*%*		*1000*	*Price Index (2011 = 1)*	
2012	9.3	6.8	2.58	2.47	25 545	1.01	1.02
2013	7.3	4.9	2.49	2.43	26 164	0.98	1.23
2014	4.0	1.6	2.50	2.38	26 787	0.89	1.16
2015	3.4	1.1	2.56	2.33	27 410	0.51	0.83
2016	5.9	3.6	2.32	2.27	28 033	0.50	0.64
2017	8.2	6.0	2.46	2.22	28 657	0.50	0.44
2018	8.2	6.0	2.53	2.18	29 280	0.50	0.44
2019	8.1	6.0	2.51	2.13	29 905	0.50	0.44
2020	8.0	5.9	2.45	2.09	30 530	0.50	0.44
2021	8.0	5.9	2.43	2.05	31 158	0.50	0.44
2022	8.0	6.0	2.35	2.02	31 786	0.50	0.44
2023	8.0	6.0	2.33	1.98	32 416	0.50	0.44
2024	8.0	6.1	2.38	1.95	33 046	0.50	0.44
2025	8.0	6.1	2.47	1.91	33 678	0.50	0.44

Sources: GDP Growth 2012-14, GSS (2015), 2015-18, World Bank (2016); Population and labour force growth: UN DESA (2015), medium-variant projections.

[27] Presently, Ghana's oil-fired thermal generation uses predominantly light crude oil (LCO).

5.3. Lower Carbon Scenario

5.3.1. Scenario Specification

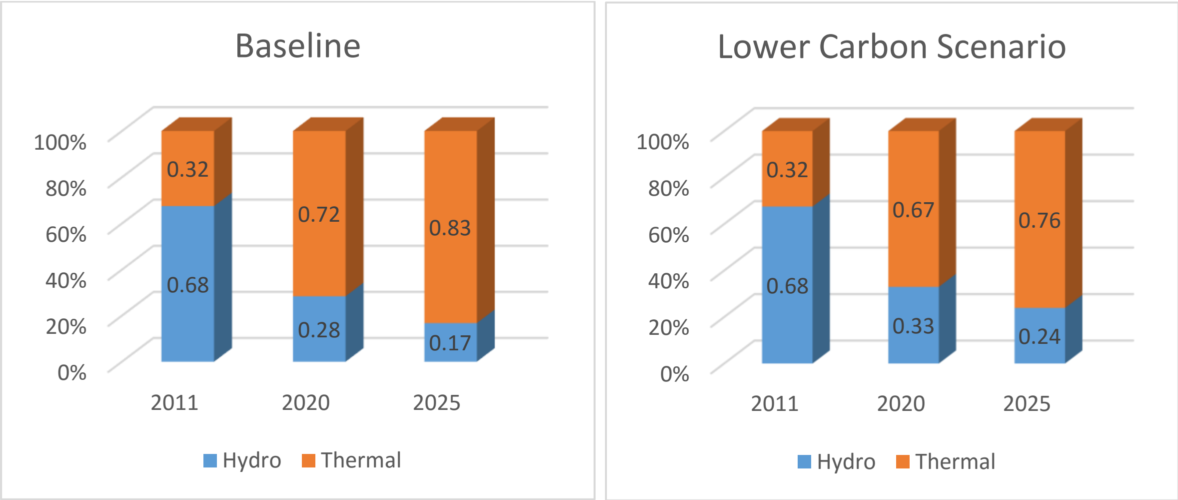
As noted in Pueyo et al (2016:16), in comparison to Kenya Ghana's "renewable energy potential is considerably smaller except for large hydropower, (…). Hydropower potential has been harnessed to a large extent but substantial potential is still untapped and several areas have been marked as potential sites for medium and mini hydropower plants". In line with Table 1 above, Pueyo et al (2017:29) report that "(o)ur estimates of LCOE for renewable power plants show hydropower is the least cost technology in Ghana, at 7.9 USc per KWh. The LCOE of generic wind power is 14.3 USc per KWh and that of solar PV 18.7 USc per KWh", and thus wind and solar are not yet cost-competitive in relation to gas-fired power plants with an estimated LCOE of 13 USc per KWh (Table 1).

IRENA (2015: Table 8) identifies small- and medium-scale hydro power sites with an estimated total capacity of 837 MW and a generation potential of around 3,500 GWh. IRENA estimates suggest that the LCOE "for new small hydropower projects is between USD 0.03 and USD 0.115/kWh in developing countries",[28] 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.

In line with these estimates, the stylized lower carbon scenario for Ghana considered here assumes a gradual linear expansion in hydro generation over the period 2018 to 2025 such that hydro generation is about 3,500 GWh higher than in the baseline by 2025. Thermal generation drops accordingly in relation to the baseline thermal expansion growth path. This means that the hydro share in total generation in 2025 is 7 percentage-points higher than in the baseline scenario and the 2025 thermal share drops from 83 to 76 percent (Figure 19)

[28] http://costing.irena.org/technology-costs/power-generation/hydropower.aspx (accessed December 2016).

Figure 19: Electricity Generation Shares in Baseline and Lower Carbon Scenario

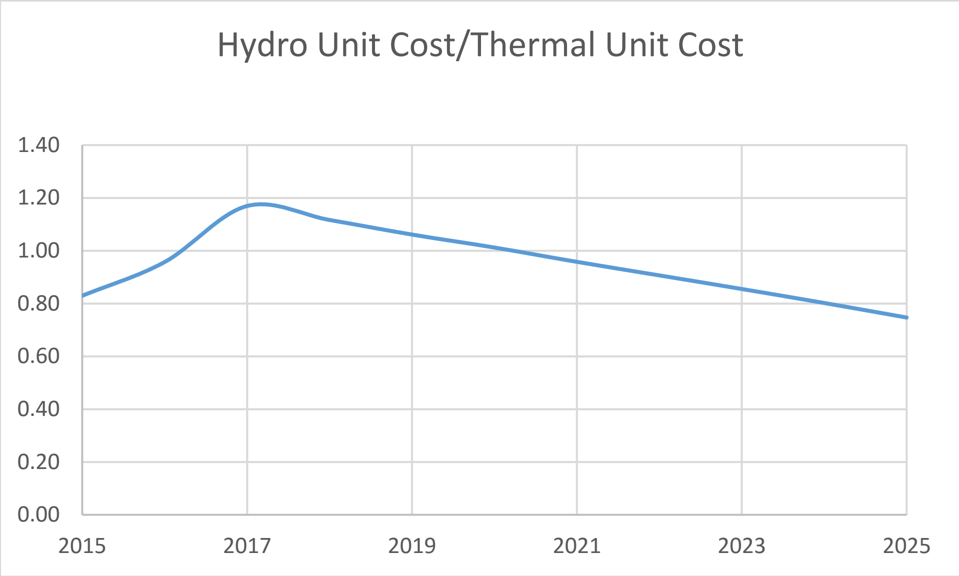


5.3.2. Results

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 to 2025, and these cost reductions are by assumption fully passed on to electricity users. By 2025, the electricity supply price in this scenario is 1.1 percent lower than in the baseline (Figure 22). This electricity price effect is far less pronounced than the corresponding price effect in the low carbon scenario for Kenya (Figure 4), because the size order of the assumed shift from thermal to low-carbon power is far less extreme – which reflects the fact that Ghana's potential for an economically viable expansion of small- and medium-scale hydro is far more limited than Kenya's potential for an expansion of low-cost geothermal according to the cited studies.

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 21: Over the period 2015 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 begin to rise relative to the hydro unit costs and beyond 2021 hydro restores its status as the least-cost electricity technology.

Figure 20: Ratio of Average Hydro to Average Thermal Generation Cost 2015 - 2025

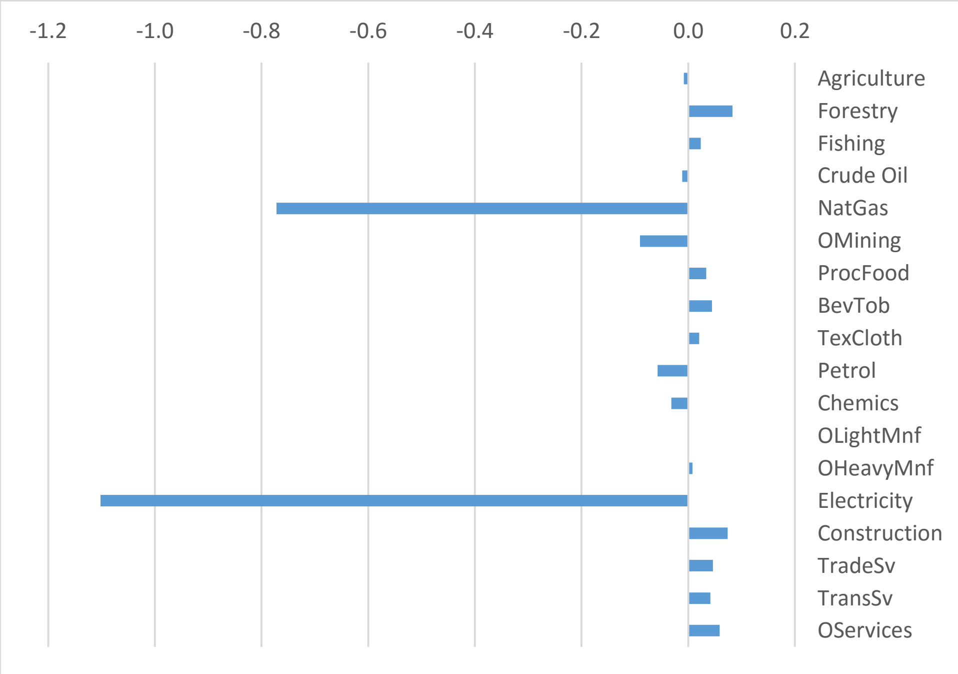


Primarily three features of the baseline scenario drive this peculiar time path of the hydro / thermal cost differential. First, fossil fuel import prices and particularly gas prices drop strongly over the period 2015 to 2017 (Table 8), and entail a sharp drop in the thermal generation cost over this 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. 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.[29] 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.

[29] Over the period 2015 to 2025, the baseline real exchange rate – here measured as aggregate import price relative to the domestic producer price index – rises by 5.4 percent.

Figure 20: Impact on Domestic Producer Prices – Lower Carbon Scenario 2025

(Percentage deviation of price relative to unskilled wage from 2025 baseline)

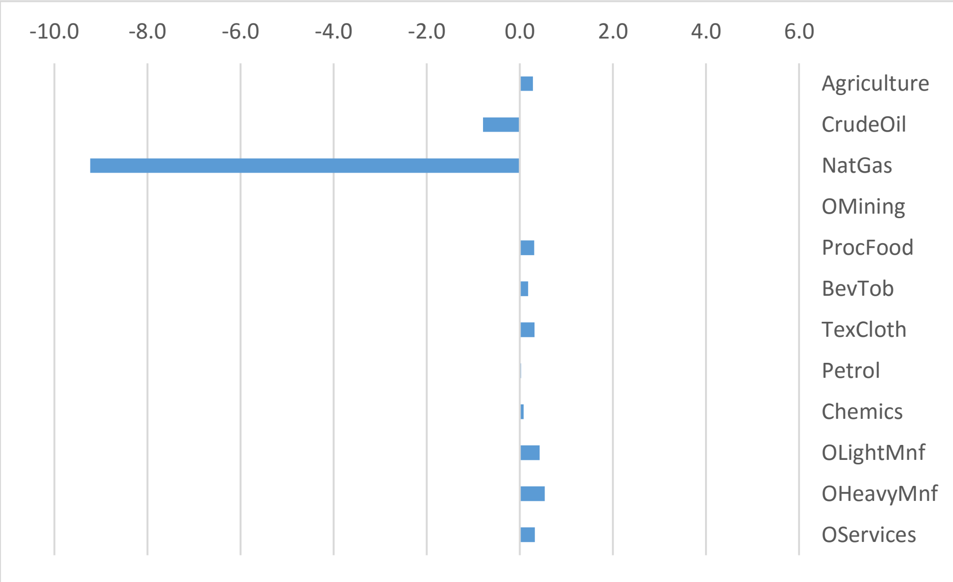


It is not surprising, that the small direct electricity cost reduction effect towards 2025 triggers only weak intersectoral spill-over effects via input-output linkages and other general equilibrium repercussions. As shown in Figure 21, the equilibrium effects on the supply prices of other sectors are generally tiny. The only noteworthy indirect price effect is the 0.8 percent 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 (Figure 22). 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 (Figures 22 and 23).

Figure 21: Impact on Real Import Volumes by Commodity Group – Lower Carbon Scenario 2025

(Percentage deviation from 2025 baseline)



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 increments reported in Figure 23 over the period 2021 to 2025 entails that the level of real GDP by 2025 is a negligible 0.025 percent higher than in the baseline scenario. Given, the high baseline annual growth rate of 8 percent, this difference is equivalent to about 1 day's value of economic activity – i.e. the baseline growth path would reach the lower carbon scenario end-of-2025 GDP level about 1 day later.

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 percent) due to the hump-shaped time profile of the hydro / thermal cost differential (Figure 20) discussed above. 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 percent, while the baseline contribution of this factor to GDP is about 2 percent – so the effect on real GDP is well below 0.05 percent.

Figure 22: Impact on Real Export Volumes by Commodity Group – Lower Carbon Scenario 2025

(Percentage deviation from 2025 baseline)

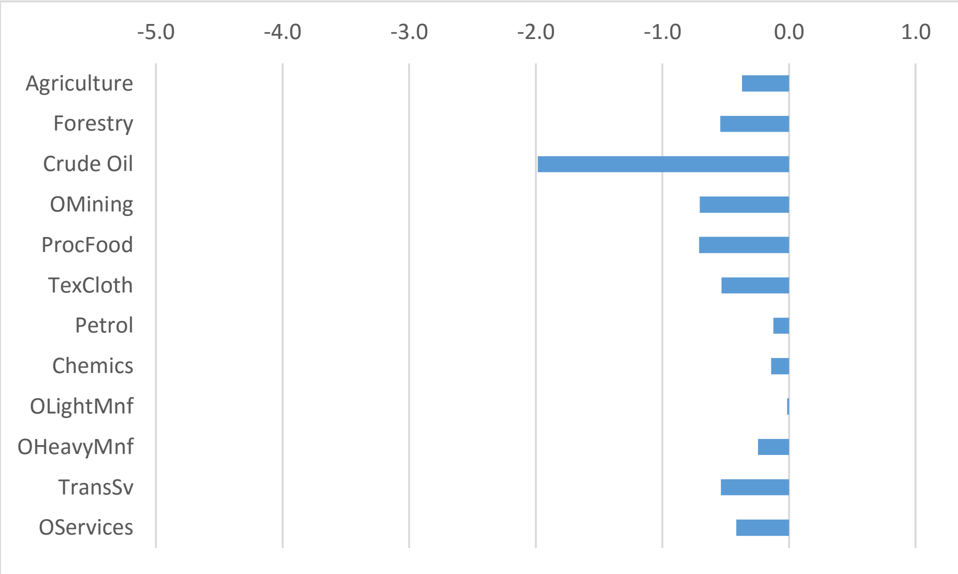
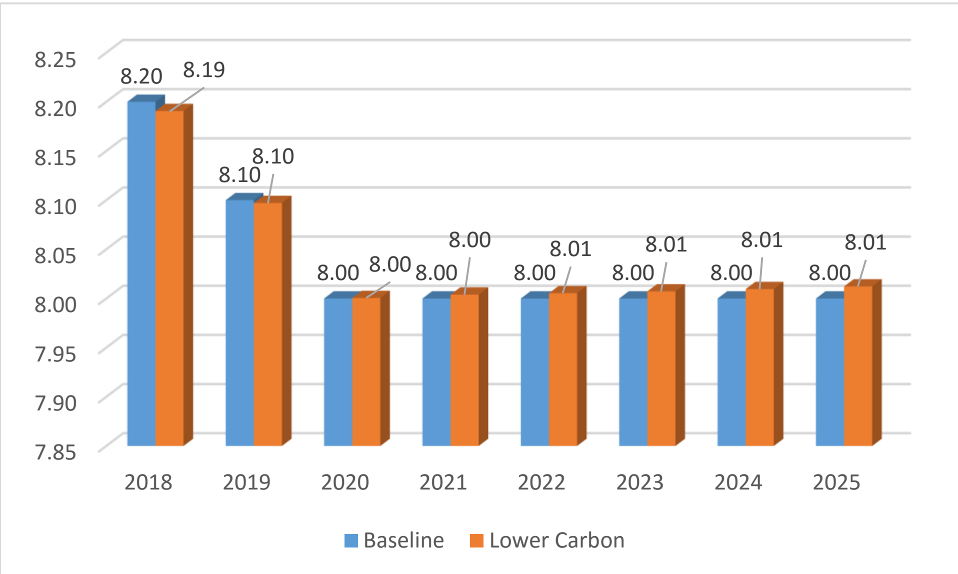


Figure 23: Annual Growth Rate of Real GDP – Baseline and Low Carbon Scenario

(in Percent)



Finally, Figures 24 and 25 report the effects on the functional distribution of income and real factor income by household type for 2020 and 2025. Unsurprisingly, the impacts are again tiny. Like 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. As explained earlier in section 4.3., this indicates that on average the sectors with higher growth than in the baseline tend to be more capital- and /or skill-intensive than sectors subject to a growth decline. The drop in agricultural land returns relative to the baseline scenario is due to the slight growth slowdown of the agricultural sector as agricultural imports rise and agricultural export growth declines marginally in response to the real appreciation.

Figure 24: Impact on Factor Returns – Low Carbon Scenario

(Percentage deviation of factor prices relative to CPI from baseline level 2020 and 2025)

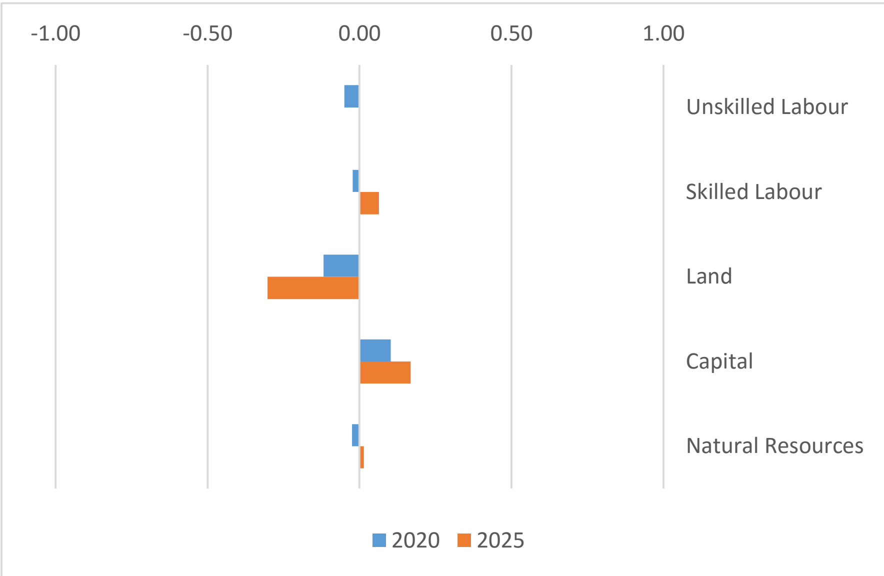
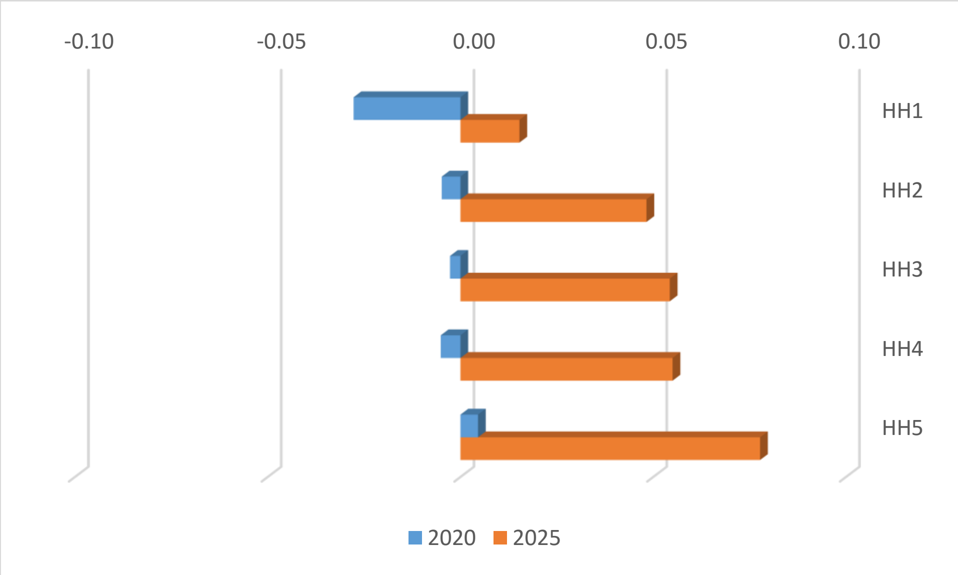


Figure 25: Impact on Real Household Income – Low Carbon Scenario

(Percentage deviation from Baseline level 2020 and 2025)



5.4. High Fossil Fuel Price Scenario

The high fossil fuel price scenario under *baseline* assumptions about the power mix considered here provides the relevant reference scenario for comparison with the high-fossil-fuel-price (HFFP) lower carbon scenario presented in the following section. In contrast to the baseline scenario, crude oil and refined petrol world prices are assumed to return to higher levels beyond 2016. As in the HFFP scenario for Kenya (section 4.3), between 2016 and 2018 oil prices rise linearly to a level that is 62 percent higher than the 2018 baseline price (Table 8) and then remain at that higher level beyond 2018, i.e. the oil price index with base 2011 rises to 0.81 by 2018 compared to 0.50 in the baseline scenario. The natural gas import price index is assumed to stay permanently at the 2016 baseline scenario level of 0.83, and is thus 89 percent higher than the corresponding baseline level (0.44) over the period 2017 to 2025. Given that the purpose of this study is not to provide an exhaustive analysis of the sensitivity of Ghana's economy to oil price shocks, the exposition of this reference scenario is brief and focuses on key differences to the baseline scenario.

Figure 26: Impact on Domestic Producer Prices – High Fossil Fuel Price Scenario 2025

(Percentage deviation of price relative to unskilled wage from 2025 baseline)

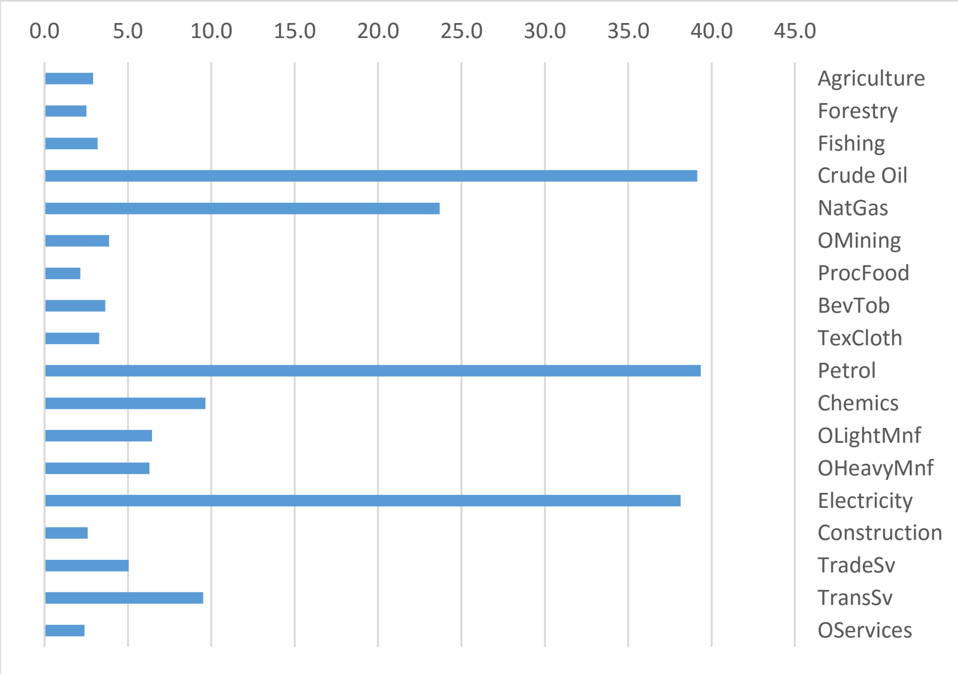


Figure 26 displays the effects on domestic supply prices in 2025 relative to the baseline. The world market crude oil price increase incentivizes a marked rise in Ghana' crude oil export supply and the domestic fossil fuel extraction sector expands vis-a-à-vis the baseline. Due to the large thermal share in total electricity generation by 2025, the cost-push effect on the price of electricity is strong, and as a result the annual average growth rate of the electricity sector over the period 2015 to 2025 drops from 12.4 to 8.6 percent. 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.

Figures 27 and 28 show the effects on GDP growth. As in the case of Kenya, GDP growth rates are hit strongly by the initially by the 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, as shown in Figure 28, this effect is not strong enough to push the level of GDP above the baseline path: By 2021 real GDP is 4.0 percent below base and by 2025 still 3.2 percent below base.

Finally, for the interpretation of the results of the HFFP Lower Carbon scenario considered in the following section it is important to note that the hump-shaped time profile of the hydro-thermal cost-differential (Figure 20) does of course *not* occur in the HFFP scenarios: Since fossil fuel prices remain high over the entire 2015-2025 period, the hydro/thermal unit cost ratio remains below unity throughout.

Figure 27: Annual Growth Rate of Real GDP – Baseline and High Oil Price Scenario

(in Percent)

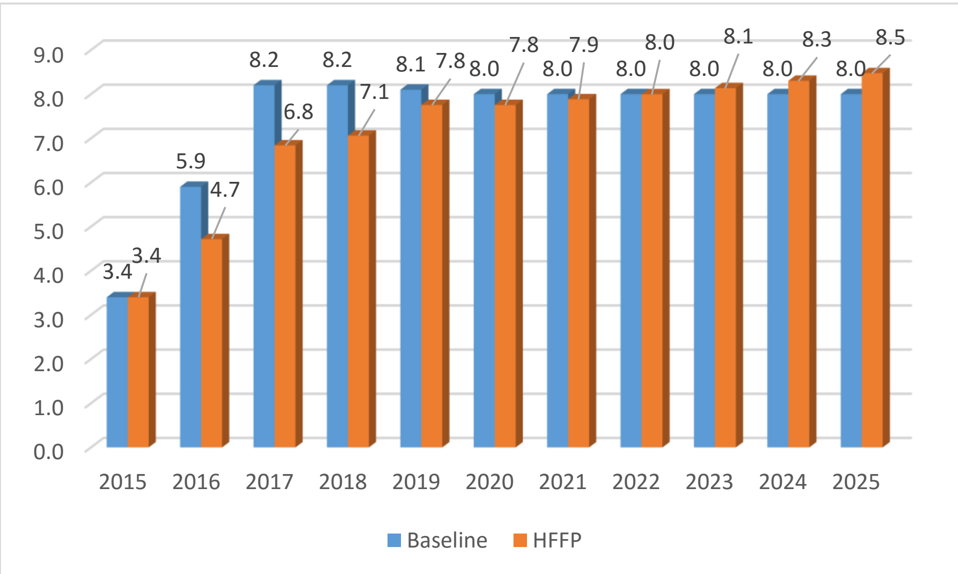
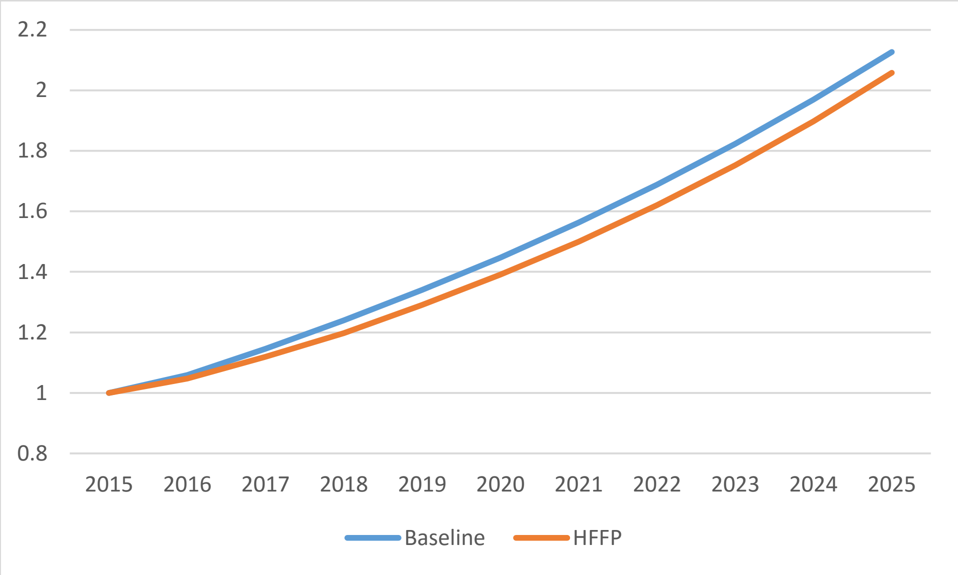


Figure 28: Level of Real GDP 2015 to 2025 - Baseline and High Oil Price Scenario

(Index, 2015 = 1.0)



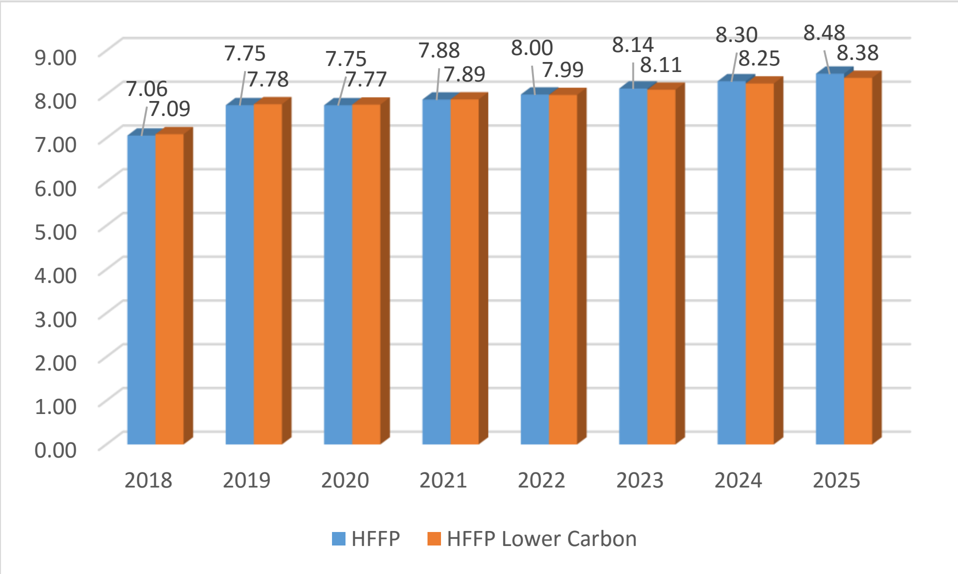
5.5. HFFP Lower Carbon Scenario

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 percent 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 percent.

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 (Figure 20). Correspondingly, the initial impact on the growth rate of real GDP turns from marginally negative (-0.01 percentage points in 2018, Figure 23) in the low carbon scenario to marginally positive (+0.03 percentage points in 2018, Figure 29).

Figure 29: Annual Growth Rate of Real GDP – High Fossil Fuel Price Lower Carbon Scenario

(in Percent)

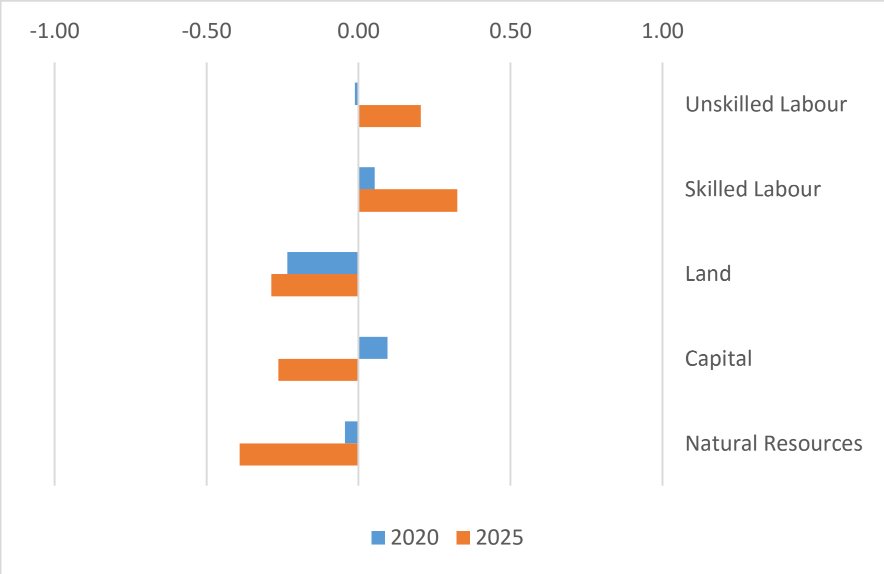


However, the reduction in demand for domestic natural gas by the thermal sector and the real appreciation effect due to the reduced net fossil fuel import bill discussed in section 5.3 again lead to a small reduction in the primary resource extraction activity of the domestic fossil fuel sector. As explained earlier, 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 (Figure 29). The cumulative impact of these miniscule effects on annual GDP growth rates remains small: By 2020, the level of real GDP in the HFFP low carbon scenario is 0.06 percent higher and by 2020 0.11 percent 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. As elaborated above, 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.

Figure 30: Impact on Factor Returns – Low Carbon Scenario

(Percentage deviation of factor prices relative to CPI from baseline level 2020 and 2025)



As shown in Figure 30, impacts on the functional distribution of income remain small. As in the lower carbon scenario of section 3, the drop in returns to land relative to the reference scenario is due to a slight decline of the growth rate of the agricultural sector as a result of the real exchange rate appreciation effect: The 2025 gross output this sector is 0.37 percent lower than in the reference scenario, which is equivalent to a drop in the average annual growth rate over the period 2015-2025 on the order of -0.04 percentage point. The slight drop in average real returns to capital by 2025 relative to the reference scenario is primarily driven by the slower growth of the relatively capital-intensive fossil fuel extraction section. In the HFFP reference scenario this sector is larger than in the baseline scenario and thus its growth slow-down has a stronger adverse effect on capital returns and natural resource rents in the HFFP low carbon scenario than in the low carbon scenario of section 5.3.

6. Conclusions

The present study applies purpose-built dynamic computable general equilibrium 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 to reach 75 percent in 2025, so that the 2025 geothermal share is about 24 percentage points higher than in the baseline scenario.

The higher of 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 percent 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 percent higher than in the corresponding high-fossil-fuel-price 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 7 percentage-points higher than in the baseline scenario and the 2025 thermal share drops from 83 to 76 percent.

This moderate electricity sector transition shock generates only marginal impacts on macroeconomic growth: The effect on real GDP in 2025 ranges from +0.2 percent under low world market fossil fuel prices to -0.1 percent under high international fossil fuel prices. 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 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.

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